Foreword

Located on a map, Tucson is seen as a geographic area with specific boundaries. Those of us who actually live in Tucson know the setting more intimately, beyond the one-dimensional view on the map. We know its mountain ranges, rivers and vegetation, and we experience its distinct sense of distance and space. And there is more. We know Tucson as a human setting or, in other words, a home to 750,000 people. The way we live our lives, our beliefs, activities and interests help explain the values that also make Tucson unique.

The human way of life and the physical setting, whether human-made or natural, are not independent of each other; instead they interact. Nowhere is this more evident than in the need for water to sustain a rich and complex urban life. Water is the beginning of such a life, but water also can be the end of it. If a sustainable source of water is not available, a community obviously is in dire straits.

Tucson now relies predominantly on groundwater, considered "old water" because of its storage underground for hundreds and even thousands of years. Most people realize the city cannot continue to pump this mostly nonrenewable source of water and that other sources of water must be utilized. This raises the important question: What must Tucson do to ensure a sustainable water supply?

Answering this complex question requires a consideration of the physical or environmental conditions of this desert city. Also to be considered are the social, cultural and economic values that prevail in the area. Science and technology are tools to be used. Not to be overlooked are the different sets of values and beliefs that also guide and motivate human actions. The perspective must consider the past, present and future. Obviously there are no simple solutions.

The following study charts a course among the many issues to be considered when attempting to plan a sustainable water future for Tucson. A guiding premise of the study is that identifying such a course is the responsibility of everyone in the community, not just politicians and those with a professional interest in water. With so much at stake, identifying sustainable water supplies might be thought of as a quest, of concern to literally everyone who uses water.

To do justice to the topic, the study provides a broad focus, examining many and varied issues that relate in some way to ensuring future Tucson water supplies, including historic, hydrologic, political, economic and technological concerns. No direct solutions are recommended, but by offering a wealth of information the study intends to demonstrate the complexity of the situation. By promoting an understanding of the various issues, the study will help Tucsonans make informed decisions about their future water supplies.

No other issue better demonstrates the complexity involved in deciding water policy than the Central Arizona Project. To use its water or not to use it and under what conditions and circumstances are considerations that have divided the community and have launched CAP as today's premier Tucson water issue. The first question is whether CAP, which promises a renewable supply of Colorado River water, should be part of Tucson's sustainable water supplies. In the absence of other viable alternatives, use of CAP water becomes a necessity for Tucson's survival. Other questions about CAP water remain. How should it be treated and how should it be distributed? Is it feasible to continue relying exclusively on groundwater for drinking water, with CAP water used only to recharge the aquifer? Is some combination of CAP water, groundwater and effluent viable for Tucson?

What are the implications of Tucson's water supply to the culture and character of the city, now and in the distant future?

This study addresses all of these questions, but it does not propose definitive answers. Ultimately the people must decide social policy. Our goal is to give everyone an opportunity to make well-informed decisions.

Peter Likins, President
The University of Arizona

Acknowledgments

The Water Resources Research Center thanks the Office of the President of the University of Arizona for its generous financial support of this study. This publication is one part of the University of Arizona's Water Sustainability Project.

Many thanks to the following UA faculty and staff who reviewed all or portions of this report and whose expertise was invaluable: Cornelius Steelink, Chemistry Department; Robert Glennon, College of Law; Marv Waterstone, Department of Geography and Regional Development; Gerald Matlock, International Agriculture; Victor Baker, Nathan Buras, Jim Washburne, Gray Wilson, Hydrology and Water Resources Department; Janick Artiola, Jim Riley, Arthur Warrick, Peter Wierenga, Soil Water and Environmental Science Department; Sol Resnick, Val Little, Water Resources Research Center.

A project of this sort builds an awareness of the incredibly varied talents, interests and abilities of members of the Tucson water community, whether employed by government or the private sector, or whose interest in water is not directly related to job or profession. Gratitude is due to many in the water community who provided advice, encouragement and information.

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Preface

How, ultimately, do we make a rich, a full, a complete water policy? The beginning of the answer is that a great many factors must go into any natural resources policy in the American West, for these are complex times. Water means too many things to too many people for it to be pat, one-dimensional, bound up in a single ideology... Another, related part of the answer is that we must move away from jargon, from bland words and thinking that dehumanize what ultimately are intensely human, even spiritual matters.
–Charles Wilkinson, The Eagle Bird, *1992*

Tucsonans face important decisions in the coming months and years that will affect the future of their community. At issue is Tucson's water supply, the true lifeblood of the area. A topic of vital importance and one that affects every citizen, Tucson's water supply has long been the focus of controversy. Debates about water issues have caused divisiveness and strife within the community. A major and ongoing source of controversy has been the city's effort to introduce Central Arizona Project (CAP) water into the city system. This did not go smoothly, and the many problems that resulted from this effort frustrated and angered many citizens. This situation helped create a climate that discouraged constructive community debate and consideration of important water information.

Tucsonans now must grapple with the question of how best to ensure a long-term water supply for the community. This involves examining various options, with special attention devoted to finding ways to more effectively use present supplies. Further, if CAP water is to be part of the solution to Tucson's water supply problem, the community must find the ways and means to use this renewable source that are both affordable and acceptable to Tucson citizens.

The many thousands of people who have moved into the Tucson metropolitan area in the past 50 years are using millions of gallons of water daily. Most of that water is "old" water, stored underground for hundreds or thousands of years. Because more "old water" is used each year than is replaced by precipitation, either by rain or snowmelt from surrounding mountains, water tables decline and wells must reach deeper and deeper to tap remaining water. If we do not reduce the amount of water we use and/or unless we utilize a new dependable supply, we will suffer the consequences of our excessive reliance on groundwater. These include the increased cost of pumping from greater depths, decreased water quality and the occurrence of subsidence which can threaten structures, homes, streets and utilities.

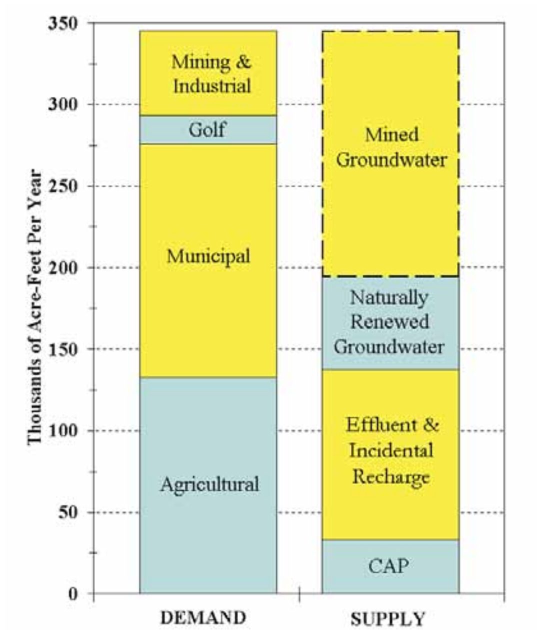
Figure 2 shows major water demand categories and sources of water supply for the Tucson area. What is readily apparent is that municipal

Figure1 View from "A" Mountain at the end of the twentieth century. Photo: UA Biomedical Communications.

uses represent the greatest demand and mined groundwater is our primary water source.

Our largest new water source is the CAP which brings water from the Colorado River.

Figure 2 Water demand and supply in the Tucson AMA (1997 conditions)



Because first efforts to introduce CAP water in Tucson met with serious problems, a majority of voters subsequently rejected its use in their homes unless certain conditions were met. Tucson Water, Tucson's largest water utility, is making efforts to meet those conditions. When contemplating CAP water use the public needs to understand how its use will affect their homes and lives and the costs involved to minimize any adverse impacts. Tucsonans could then better evaluate CAP options compared to other kinds of water management actions.

Other community water issues also need attention. For example: Who should help pay to prolong the usefulness of the aquifer? Should this be the obligation of all water users or just those users who actually use alternative supplies such as CAP and effluent? Should the mines and farms be required to use CAP water or at least help pay for it? Other management issues that need addressing include: Should all Tucson Water customers have a say in Tucson Water policy? Should there be more comprehensive basin-wide management of water supplies? Should there be further limits on total water use? The report notes areas where information for making necessary decisions is lacking. The authors do not recommend any solution, but instead have presented facts and information to assist citizens and decision-makers.

As is evident from its title, this publication is about the sustainability of our water resources. Sustainability is a popular word nowadays, often heard when natural resources is the topic of discussion. Used in varied contexts, in government reports, academic journals and the popular press, sustainability is not easily summarized in a one-size-fits-all definition. One point of shared understanding, however, is that sustainability is a desirable goal.

At one level, sustainability, when referring to water resources, means we are not consuming more water than can be renewed. Sustainability implies a balance between supply and demand. For example, groundwater is not an unlimited resource. If we use groundwater supplies at a greater rate than the aquifer is recharged, we are violating the principles of sustainability. Groundwater use at that level is not sustainable. This definition generally corresponds to the definition of safe yield, which is the management goal of the Tucson Active Management Area (TAMA).

Sustainability also has a broader definition, one that takes into account social, economic and environmental values. In this context, a sustained water supply involves more than matching water demand with supply. Sustainability also means that our water resources are managed in a way to preserve the environment, to maintain the economy, and to ensure that all water users share equitably in

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Figure 3 View from "A" Mountain at the end of the nineteenth century. Photo: Arizona Historical Society/Tucson.

reaching and maintaining a balance between water supply and demand.

Both definitions, but especially the latter, involve a shift in mind set. What is involved is less emphasis on developing new water supplies, which has been the traditional approach, with more attention devoted to learning to use water in a way that allows current and future users to live in balance with nature and one another.

One final point: The geographical area covered by the report needs defining. Tucson as the "study area" of this report covers more territory than what is bounded by city limits. This presents some difficulties. Defining a "study area" is complex and often contextual. The most common term used in this report is the "Tucson area." This term is meant to encompass the most heavily populated portions of eastern Pima County, from Avra Valley on the west, to the Rincons to the east, and from Green Valley on the south, to Pinal County on the north. These boundaries are approximate and are intended to roughly delineate an area in which there are extensive political and hydrologic connections.

The maps in this document show most of the Tucson area, with the exception of Green Valley. (See Figure 4.) The choice of map extent represents a compromise between showing sufficient detail in the most heavily populated areas and showing the larger geographic extent. The map boundaries are not intended to be absolute.

In many instances this report refers to more specific boundaries, usually in the context of the source of available data. For instance, many of the data in this report come from the Arizona Department of Water Resources' Tucson Active Management Area. TAMA is based, in part, on groundwater basin boundaries.

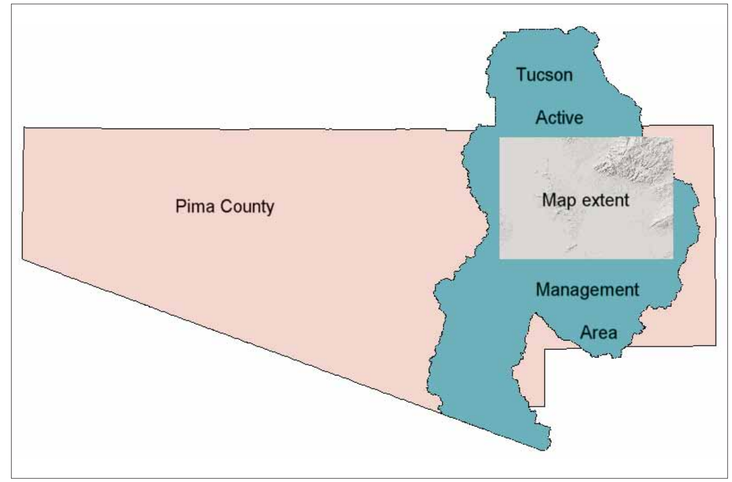
An effort has been made to be both precise and consistent in the use of terms and geographic extent. The reader should be aware, however, that there is some inherent "fuzziness" in these definitions, due to overlapping political and hydrologic boundaries.

Each of the following chapters begins with a brief summary of its content. Background information then is provided on topics crucial to understanding Tucson's water dilemma. The final chapter offers readers an opportunity to make their own choices from a range of options, based on the information in the previous chapters.

If this report can be said to have a single, underlying message, it is that there is no one simple, inexpensive solution to our water problems. Each proposed solution has both positive and negative impacts.

All of us – Tucson Water customers, private utility customers, farmers, miners, industrial water users and those with their own wells – have straws in the same glass. What we do affects everyone else. The challenge for the community is to pick an effective and desirable solution at a price it is willing to pay.

Figure 4 Study area.



This report was funded entirely by the University of Arizona and was produced by the UA Water Resources Research Center as a service to the community. Its intent is to provide useful, accurate information for Tucson citizens to use in making water decisions. The authors believe both scientific information and community values have important roles to play in deciding water issues. With this in mind, the authors have collected information from a wide variety of sources including federal, state and local agencies' reports, university research, information from private water utilities and studies by nonprofit groups. Although staff members of local agencies were consulted at various times during the preparation the report, the Water Resources Research Center researchers defined the issues and summarized the information with the assistance of other university experts.

Chapter 1
The Setting

This first chapter sets the scene by describing the climate and terrain of the Tucson area. Ultimately, climate and terrain determine water availability, from the occurrence and extent of precipitation to the storage of groundwater. Water availability – or, stated differently, water scarcity – in turn determines the course of human life in the area, from population densities to economic activities.

Southern Arizona is located within a physiographic region called the basin and range province. The region, which stretches from Nevada southeast to northern Mexico, is characterized by mountain ranges running in a roughly north-south orientation, interspersed with broad flat valleys or deep basins. (See Figure 1-1.)

Tucson is located within a broad valley, with mountains on each side – Santa Catalinas to the north, the Rincons to the east, the Tucson Mountains to the west and the Santa Ritas to the south. Most of the population of the greater Tucson area lives in the Santa Cruz Valley.

About 10,000 years ago, before the climate began to get warmer and drier, much more moisture reached the basin than does today. Water isotope studies show that much of the water now stored underground fell as rain during these ancient times. The alluvial soil that holds the subsurface water is called the aquifer. Alluvial soil or alluvium, which consists of clay, sand and rock, washed from the surrounding mountains and accumulated over many thousands of years. Groundwater is stored in the open spaces between the particles of sand and rock within the alluvium.

As is shown in Figure 1-2 various water courses transect the area. When flows occur, the Santa Cruz River runs north-northwest through the area, and the Rillito Creek runs from southeast to west, connecting with the Santa Cruz River near Orange Grove Road. The Pantano Wash flows northwest and enters the Rillito Creek before the Rillito connects with the Santa Cruz River. In years of heavy precipitation, some water will flow north to reach the Gila River west of Phoenix, then continue to the Colorado River and the Gulf of California. But in most years, flows do not get that far.

The basin's low annual precipitation results in very few streams or rivers with perennial (year-round) flow today. The most notable exception, Sabino Creek, begins at relatively high elevations and is supplied by snowmelt as well as rainfall. Most of the rivers, streams and washes in the Tucson Basin are ephemeral (i.e., they flow only immediately after rains). Overall scarcity and variability of flow has made surface water an unreliable and largely impractical water supply for a large population.

Historically, the groundwater table in the Tucson area was much higher, and surface water and groundwater were connected along much of the Santa Cruz River. At that time the water table was high enough to feed the river.

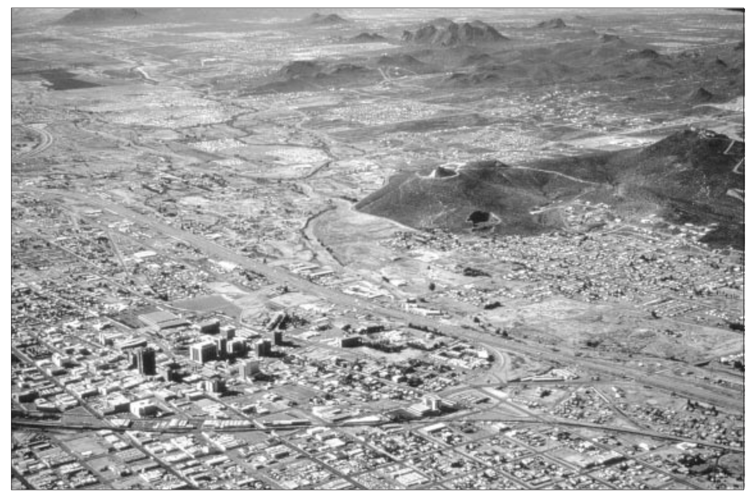
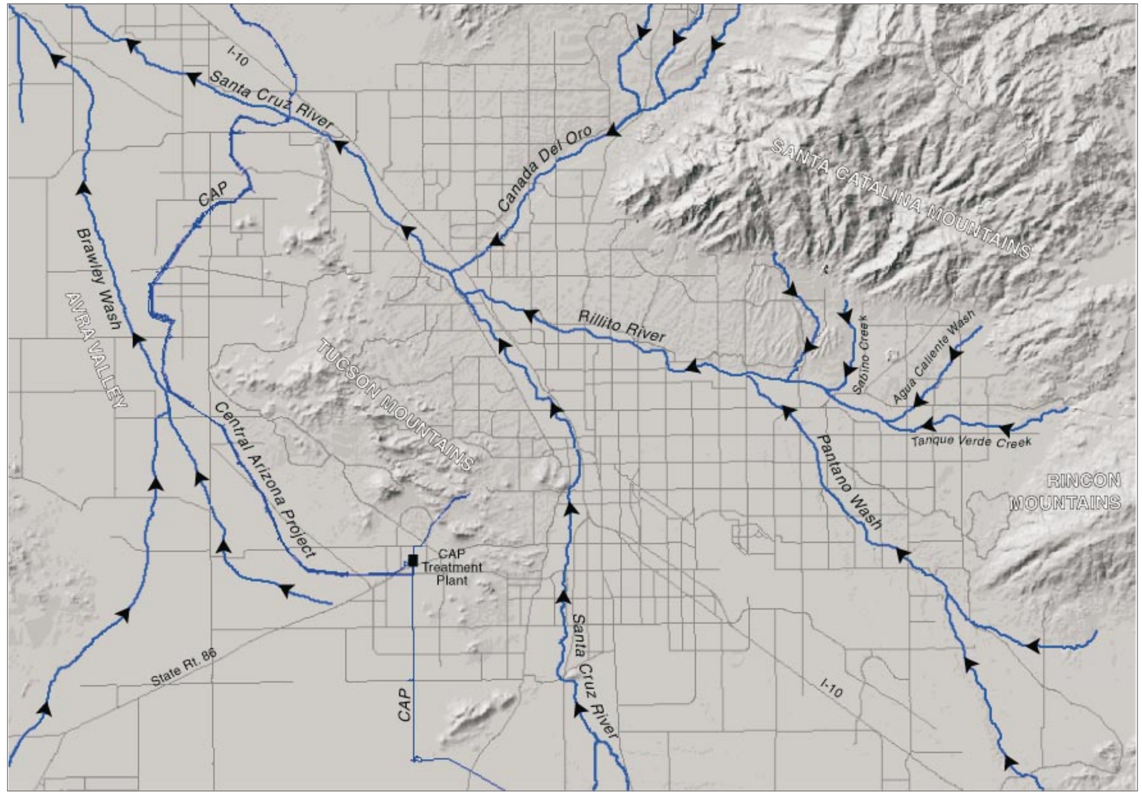


Figure 1-1 Tucson is located within a basin and range province with alternating mountains and valleys. Photo: Arizona Geological Survey.

This no longer occurs because the water table levels have dropped far below the surface due to groundwater pumping.

Figure 1-2 Tucson area mountains and rivers.



Sources: United States Geological Survey, Pima County, Water Resources Research Center.

CLIMATIC INFLUENCES

Global Circulation

At 32.2° north latitude, Tucson lies along an arid and semi-arid zone that stretches from North Africa (Marrakech 31.2, Tripoli 32.7), the Middle East (Jerusalem 31.8, Baghdad 33.3), across Southwest and South Asia (Iran, Afghanistan, Pakistan), and into Central Asia (Tibet). (See Figure 1-5.) Air over the equator heats, rises, loses moisture and then sinks at about 30 degrees north latitude, creating large cells of stable high pressure. With low moisture content, and little to disturb the airflow, precipitation is sparse and infrequent along this global desert zone.

Tucson Precipitation

An annual average of 12 inches of rain falls within the Tucson Basin. Rainfall varies greatly according to the season and the location within the area. The mountains ringing the basin, particularly the Santa Catalinas, cause some local uplifting of air masses (orographic effect) resulting in annual precipitation as high as 28 inches on Mt. Lemmon. The east side of the mountain range gets less rain than the rest of the range.

The precipitation arrives in two distinct seasons. Fifty-two percent falls during a summer "monsoon" (July–September) and 28 percent from December through March. In the summer, as land temperatures rise, dense, moist air from the Gulf of California and Gulf of Mexico is drawn inland. In the afternoon, as temperatures reach their peak, the moist air is pushed upwards, forming large thunderheads. Summer "monsoon" rains are characterized by brief but intense thunderstorms with highly localized precipitation. (See Figure 1-3.)

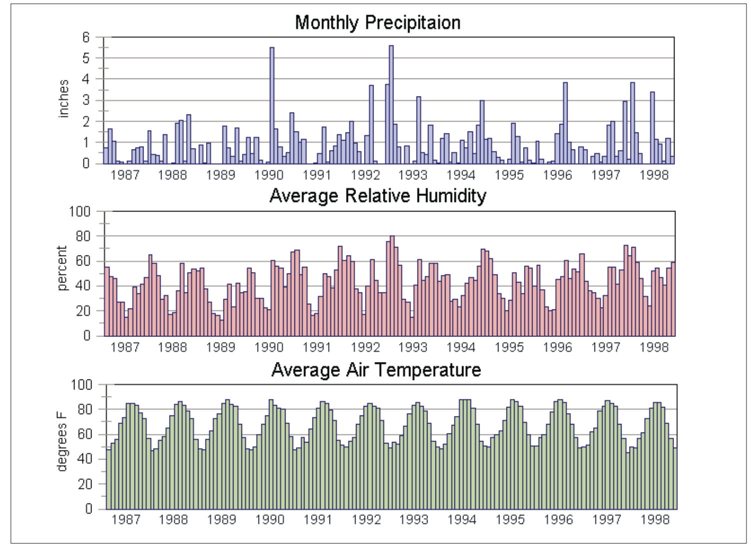
In the winter, large fronts develop over the Pacific Ocean. The global circulation patterns, and specifically the jet stream, carry these storms eastward. The persistent high pressure normally diverts the jet stream and storms away from the Southwest. In the late fall, however, the high pressure cell is weakened and can be displaced, allowing large, slow-moving fronts to pass over the Tucson Basin. Winter rains are characterized by heavy cloud cover and precipitation that persists for many hours or even several days and covers most of the area.

Precipitation in October and November (about 14 percent of annual rainfall) is quite variable from year to year and is often a result of severe storms or Pacific hurricanes that "graze" the region. These storms can produce flooding, often over large areas. These rainfall patterns are distinctive of the Sonoran Desert and explain the extraordinary vegetation of the area. The Mohave Desert to the west of Tucson does not receive as much summer rain, and the Chihuahuan Desert to the east gets less winter rain than the Sonoran Desert.

The year-to-year variation of precipitation in the Tucson Basin is quite substantial. (See Figure 1- 4.) Global phenomena such as El Niño and La Niña affect the distribution and magnitude of precipitation. Winter precipitation in 1992/93 and 1997/98 was as much as 55 percent higher than the winter average in the Tucson Basin.

Figure 1-3 Summer storms in the area often are confined to isolated locations. Photo: David Bright, U.S. National Weather Service.

Figure 1-4 Climatological factors 1987-1998.



Source: U.S. National Weather Service.

Evapotranspiration

Clear skies and a relatively low latitude make Tucson one of the warmest areas in the United States. Average summer highs are in the upper 90s with peaks above 110° F. These high temperatures, along with low relative humidity, contribute to very high water loss through evapotranspiration. (Evapotranspiration is the combined effect of surface evaporation and transpiration by plants.) The potential evapotranspiration rate averages about 77 inches per year which is about 6.5 times greater than the approximate total annual precipitation in the area. Most of the precipitation that falls in summer storms evaporates without being used by plants or people or being recharged into the aquifer.

Figure 1-5 Location of cities along 30° "arid zone"

Chapter 2
LOOKING TO THE PAST TO UNDERSTAND THE PRESENT

Chapter Two summarizes Tucson's water history from the days of carrying water in olla or buckets from rivers and springs to our ability today to turn on the tap and get as much water as we desire. This change demonstrates how for over 100 years we have looked to more distant sources for a dependable water supply, starting with a pipeline from the Santa Cruz River and continuing into the present with the CAP canal carrying water from the Colorado River. The chapter also shows that the influence of politics on water affairs began early in Tucson's history.

THE SEARCH FOR WATER

The history of water use in the Tucson area is primarily one of reaching out farther and farther to provide enough good water for a growing community. From the first water suppliers who brought water from springs or the Santa Cruz River to today's Central Arizona Project (CAP), which lifts water 2,900 feet through 14 pumping plants, delivering it 335 miles from the Colorado River, people have looked for new and reliable sources of good quality water. Attempts to persuade people to conserve water also have been part of the picture for more than 100 years, as have been projects to utilize new technologies to increase supplies. People have proposed various projects over the years including dams to capture flood waters so this resource could be used rather than "wasted." Tucson also has experienced occasional water quality problems for more than 100 years. And finally, politics has played a major role in many significant water decisions over the century.

Santa Cruz River

The first people who lived in the Tucson area got their water from the Santa Cruz River or from springs that bubbled to the surface at the base of Sentinel Peak (now called "A" Mountain), Black Mountain near San Xavier Mission and several other spots. Enough water was available to satisfy the needs of a few thousand people, including irrigating crops. In fact, Santa Cruz River water has been used to irrigate farms for at least 2,000 years. The Santa

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Figure 2-1 Rincon Mountain Water truck from the early twentieth century. Photo: Arizona Historical Society/Tucson.

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Figure 2-2 A well at Fort Lowell in the 1880s. Photo: Arizona Historical Society/Tucson.

Cruz River was not a big river like the Colorado or Gila rivers, but the river did flow most of the time in the Tucson area. The Hohokam caught edible fish in the Santa Cruz, and early pioneers hunted water-loving muskrats. When Father Kino came to the area in the late seventeenth century, he stated that he believed there was plenty of water — enough to support a large town of 5,000 people.

Fort Lowell's Waterworks

When the U.S. Army established Fort Lowell near the Rillito Creek in 1873, the water supply in the area was plentiful. Acequias (canals) brought water from the river; windmills pumped groundwater from about 35 feet down; and storage tanks held water at points of high elevation to provide running water to all the buildings. But problems arose. The windmills often were inactive for days at a time, and even when water filled the storage tanks, the water was hot and unappealing. Diseases were blamed on the bad water which was polluted by livestock, people and unsanitary water storage facilities. "Squatters" diverting surface water for their farms provoked conflict. Debate raged about whether to purchase a steam- powered pump to get water from greater depths or import water from Sabino Canyon. The military built larger storage tanks, installed the steam pump and abandoned the Sabino Canyon project. By the time the fort was closed in 1891, the water problem had been solved by installing additional wells.

19TH CENTURY SUPPLIES

Before the American Civil War, Tucson women washed their clothes in the Santa Cruz River, with a guard nearby as protection against Apaches. Drinking water was available from a well inside the walled city or from the well on Bishop's Farm. El Aegypti Spring (near the Wishing Shrine, south of the present Tucson Community Center) was a reliable water source for many years, but few people dared to venture alone so far outside of town, even for water.

After the end of the Civil War and the defeat of the Apaches in the late 1860s, more and more people moved to Tucson, which became Arizona's most important city. The services of a water carrier were needed to supply the growing population. The water carrier got his water from El Aegypti to deliver to homes in bags on his burro. Later Adam Saunders and Joe Phy modernized the system, using a two-wheeled cart for delivery at five cents a bucket. At this high price, fresh water was seldom used for watering plants. Instead people used waste water from their washing for this purpose. Adam Sanders built a bath house at El Ojito, where rich and poor alike (but only males) could get their occasional bath for twenty five cents. A daily bath was considered a downright "waste of water." W.C. Davis installed Tucson's first personal bathtub in a home on Congress Street sometime in the 1880s. The uses of water were increasing.

"A tenacious eastern dream to convert the desert into a garden characterized Tucson Basin water control history since the Gadsden Purchase in 1854. The reactions of American settlers to a series of water supply crises demonstrated the persistence of this theme. When faced with each crisis, Americans responded by applying an increasingly sophisticated technology to the problem of water scarcity." Kupel, page 162.

Entrepreneurs built dams in the Santa Cruz River near the base of Sentinel Peak, backing up water into lakes which were used for boating and fishing as well as to power flour mills. These lakes were destroyed by floods during the 1890s and not rebuilt.

Obtaining a reliable supply of potable water was a problem even in the early days. In 1870, John Bourke complained of the many holes in the town which he said were abandoned wells. "... wells, which were good and sweet in the first months of their career, but generally became so impregnated with 'alkali' that they had to be abandoned; and as lumber was worth twenty five cents a foot, and therefore too costly to be used in covering them, they were left to dry up of their own accord, and remain a menace to the lives and limbs of belated pedestrians." He describes an incident in which an inebriated citizen fell down an empty 25-foot well.

The area near Sentinel Peak was dominated by farms with a network of irrigation ditches that directed water from rivers and springs. These uses left little water in the river north of the Congress Street Bridge. During the 1870s, the city made three attempts to increase the water supply. The city contracted to have artesian wells drilled, but that effort failed. The city awarded another contract to a well driller who was to receive one block of city land for every successful well drilled, but that effort also came to naught. Some entrepreneurs south of town started building a canal to bring water to Tucson from Canoa (near present-day Green Valley), but that, too, proved unsuccessful. By the 1880s, many people had their own windmills, but the windmills often were still during the dry months when little wind was blowing. The demand for water had become so great that springs were no longer dependable.

The then-recently formed Tucson Water Company gets credit for first successfully tapping a new water source. With a franchise from the city, the company built a distribution system to bring water from Valencia Road to downtown Tucson via a redwood flume laid in the river and a 4.5-mile-long water pipe made of sheet metal coated with tar. Following this success, the Tucson Water Company in 1889 installed its first steam-driven pumping plant and dug a 40-foot deep well, capable of pumping 1,250 gallons per minute. Water came to town along the alignment of what is now Osborne Street, which is why a diagonal street is there today instead of the north-south, east-west grid common in other older sections of town.

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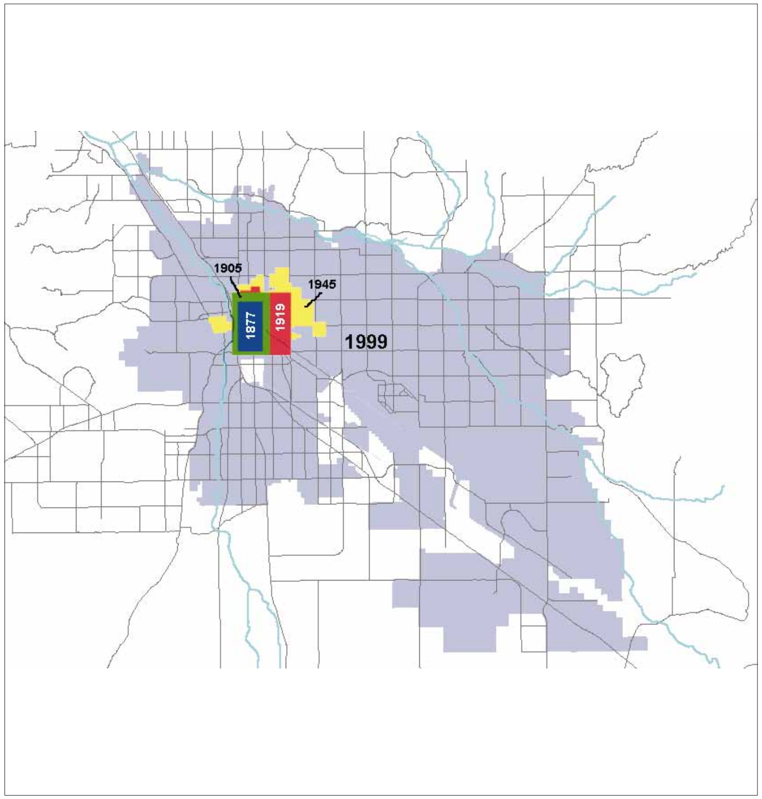
Figure 2-3 The Parker and Watts Water Company office in the late nineteenth century. Photo: Arizona Historical Society/Tucson.

This new water source would have solved the supply problem if Tucson's population had not continued to grow and if droughts did not periodically occur. In 1892, the City Council debated limiting irrigation to nighttime hours because of water shortages, but did not pass the ordinance. The mayor, however, ordered the water supply to city parks be cut off. It was not until 1903 that the City Council (which now owned the water company) passed an ordinance limiting irrigation to between 5 a.m. and 8 a.m. and between 5 p.m. and 8 p.m., with a maximum fine of $50 for violations.

EARLY 20TH CENTURY EXPANSION

In 1900, the City of Tucson bought the Tucson Water Company and its southside wells for $110,000 and formed the Water and Sewerage Department. Hetty Green, a wealthy New York financier, bought the bonds to finance the purchase. Things did not go smoothly at first. In 1908, Mayor Heeney decided to remove the water superintendent without consulting

Figure 2-4 The growth of the City of Tucson.

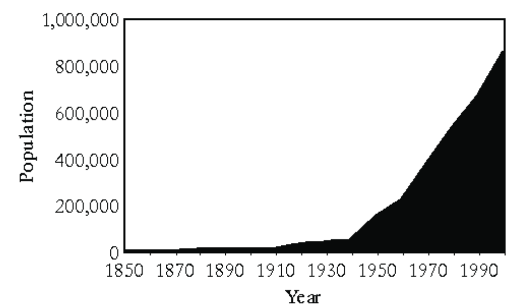


the City Council. As Councilman Moses Drachman explained, "The row which this precipitated lasted to December of that year and finally resulted in the council removing Mayor Heeney from office for misconduct." (Many other differences of opinion and accusations of scandal also contributed to the mayor's dismissal.) Also in 1908, the city faced its first water crisis when a new residential district was established, way out in the country between the University of Arizona and the railroad tracks. The windmills installed on home sites couldn't produce enough water so residents demanded that the city extend the water system to service the district. The city authorized the water superintendent to spend $260,000 to expand the system northward. In 1911, when citizens started complaining of their water bills, which were based on a flat rate per month, the city installed meters, at first only for the complainers and later for everyone. From then on people paid according to use.

In 1914, another bond issue financed six new wells and a reservoir, at the far east side of town at Second and Campbell. A new pumping technology was installed that could produce one millions gallons of water per day from one well. Windmills could extract water from shallow wells, but the new gas or electric pumps were much more efficient and could lift water from greater depths.

By 1920, water shortages again were a problem, and the City Council again banned watering except between 5 a.m. and 8 a.m. and 5 p.m. and 8 p.m. with a maximum fine of $50 for violations. The City Council also hired a staff person to provide water conservation information to the public. Meanwhile more wells were dug north of town to improve the water supply and increase water pressure for fighting fires. Over the years, more wells were added either by buying private water companies or by digging wells, until a peak of 61 wells was reached on the north side, eight of which are still active today. By that time the system had expanded and parts of the city were as much as 80 feet higher than downtown. To accommodate the situation, the city was divided into two separate pressure zones. Water circulated separately in each zone, because it could not easily be lifted to the higher areas. In later years, the zones were connected with booster stations.

Figure 2-5 Population of Pima County, 1850 to date.



Source: Arizona Department of Economic Security.

Wells were generally around 50 feet deep at this time, but water levels were dropping, and people with shallower wells had problems. Groundwater pumping near the Santa Cruz River began to affect river flow, but not until the 1940s did this pumping finally caused the water table in the area to drop so low that the river flowed only during floods. During the 1930s and 1940s, population growth slowed. In response, the water system expanded less rapidly, although the city drilled ten new wells and purchased several water companies during this period.

Growth and Controversy

After World War II the pace of population growth quickened, and by the 1950s, the southside and northside wells could no longer produce enough water. *The Arizona Daily Star* headline read "More Water is Urgently Needed." (July 23, 1952) "Living in desert country, where a rainbucket on the roof wouldn't provide more than a good shampoo, it is natural to wonder if the city can furnish sufficient water to meet this modern expansion. The answer is a big YES, according to Water Superintendent Phil J. Martin, Jr., if the proposed $5,500,000 water revenue bond issue is given the nod by voters Aug. 12."

The big bond issue passed, and a series of wells was drilled between 1954 and 1968 along Old Nogales Highway, south of Valencia Road on the edge of the San Xavier District. Some private wells in the area also were purchased, for a total of 34 wells, 15 of which are still active today. The area is called the Santa Cruz Wellfield. This additional pumping contributed to further lowering of the area's water table,, causing the extensive mesquite bosque south of San Xavier Mission to die in the 1950s. Water problems at San Xavier intensified.

By the 1960s, population had increased to the extent that even these three established wellfields did not provide enough water. The city began to purchase farms in the Avra Valley to the west to gain access to their wells. The plan was to bring the water to the city through a large pipeline. During its period of peak operation, 27 wells were operating in the Avra Valley area, 20 of which are still active. The city also purchased land along the San Pedro River north of Benson to obtain water rights. The plan called for construction of a pipeline over the mountain pass to bring San Pedro River water to Tucson. This pipeline was never built, and the city ultimately sold the land.

This photo has been removed due to copyright restrictions on the web

Figure 2-6 One of Tucson's first fire brigades. An adequate water supply to fight fires has long been an important civic planning goal. Pressure and volume must be sufficient to fight fires during times of peak summer demand. Photo: Arizona Historical Society/Tucson.

During this time, the city also was buying water companies and their wells throughout the city limits. When a new area was annexed, the city would offer to buy the water company. Having all the water service under city control had the advantage of providing uniform water service and assuring adequate pressure for fire fighting (See Figure 2-6). Some areas such as Flowing Wells and Winterhaven never came under city control. The collection of almost 300 city-owned wells in the central city area is referred to as the Central Wellfield, although it is not a coherent system, but rather a collection of former private systems and some city-drilled wells. In 1998, 185 wells were active in this area

Starting in the 1960s the city adopted a policy of buying water companies outside city limits. The city also extended its water service outside city limits in areas not served by other companies. The purpose of this strategy was to enable the city to engage in basinwide management of water supplies. This would promote more equitable water service and allow sharing of costs to augment the supply. This patchwork of water systems often caused problems. Water mains had to be connected to the central system in most cases, and the quality and size of the wells and pipelines varied greatly. Serving water outside city limits also meant that many customers would have no vote on water matters and no representation on the City Council that decided water issues.

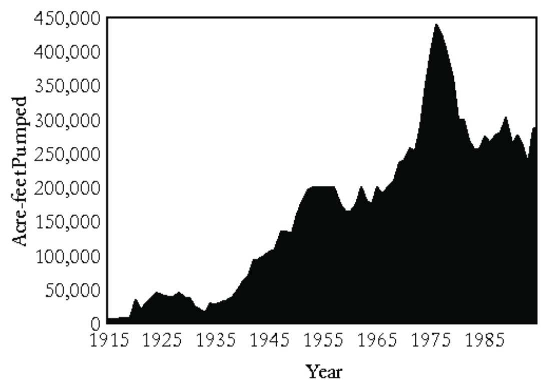
CONTROVERSY OF 1975-76

The 1970s were a period of turmoil for the community. Advocates of "controlled growth" gained a majority on the City Council and also were a significant presence on the Pima County Board of Supervisors and in the Pima County delegation to the Legislature. Congress had approved the CAP, and Tucson had to decide whether to contract for CAP water. The controlled growth advocates were skeptical about CAP, questioning its cost, need, long-term reliability and the quality of the water. They also argued that controlling sprawl was an appropriate strategy to discourage a rapid increase in the cost of water. They supported much stronger water conservation efforts and less agricultural use of water.

Controlled growth advocates on the Tucson City Council soon found an opportunity to press for change by dealing with the pressures facing the Tucson Water Department. The distribution system was expanded rapidly in the early 1970s to keep up with growth. Revenues from relatively low water rates were not enough to keep up with increasing costs and there was not enough system capacity to meet peak demand during hot summers, such as the summer of 1974. To address the problem, a consultant's report recommended a six-year program of improvements to the distribution system, to be financed by bond sales, higher water rates and system development charges. Water rates would be designed to recover the actual costs of providing service, including a "lift charge" for providing water to customers at higher elevations, such as those in the foothills. System development charges would be applied to new customers to help pay for expansion of the system.

In 1976, the City Council voted for a water rate increase designed both to keep up with inflation and to recover actual costs of delivery. The new rates included the lift charge and retained the progressive rate structure (i.e., people who use water above certain amounts were charged higher rates for water consumed above that amount) which was first used in Tucson Water's rate structure in 1974. The new rates were adopted in June, and water bills of some customers in the high lift zones quadrupled from June to July, while bills of many others doubled.

Figure 2-7 Groundwater pumping in the Upper Santa Cruz River Basin from headwaters to Pinal County.



Source: Arizona Department of Water Resources.

The pro-CAP and pro-growth forces encouraged an angry public to revolt, and the City Council majority was recalled even though they rescinded the lift charge in August. After discovering that rates had been raised not to control growth, as had been assumed, but to build distribution systems and gain new water supplies to meet expected growth, their successors retained the rest of the new rate structure and even raised the rates again. The impact of the recall continues to this day, with City Council members and water staff reluctant to make major changes to water rates in fear of angering water customers. "Remember the recall" remains a formidable slogan.

At the next regular election in 1978 controlled growth advocates were defeated in the Board of Supervisors and the Legislature, and the City Council approved Tucson's CAP sub-contract. The sub-contract was for the entire metropolitan area, based on the assumption that the city system would continue to expand. The Council also approved water conservation programs, and Pete the Beak, cartoon star of the Beat the Peak program, was hatched. The program was originally designed to encourage landscape watering at non-peak hours, thereby delaying the need for expanding the system of water mains and reservoirs. The program, however, also had the effect of encouraging water conservation more generally.

During the 1980s, the city increased its water conservation efforts, partly in response to the requirements of Arizona's new Groundwater Management Act. Tucson had some of the lowest rates of per capita water consumption in Arizona because of these programs and the perceived high cost of water. The metropolitan area expanded rapidly beyond the central area into higher elevations. Since the main water supplies were at the lower elevations, this meant water had to be pumped uphill and stored in reservoirs, to flow by gravity to customers. The fact that all customers pay the same rate no matter where they live is an advantage to those living in more distant and higher areas.

CENTRAL ARIZONA PROJECT

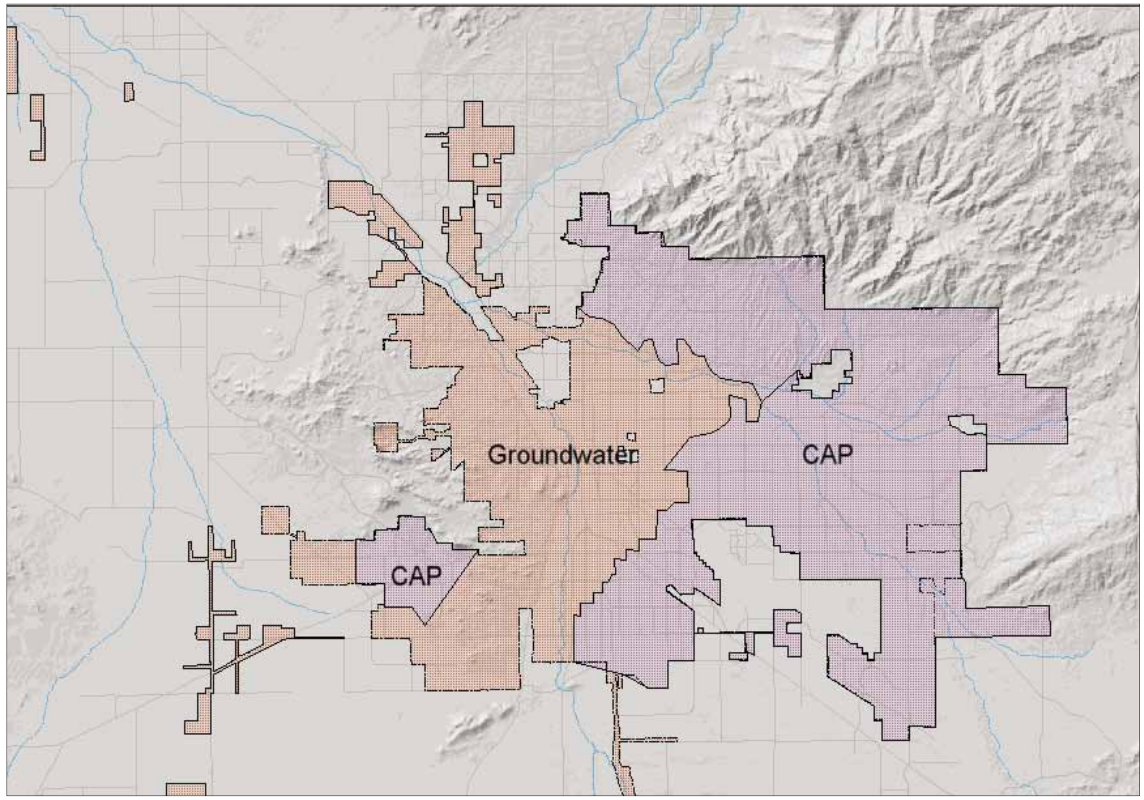
The CAP is a system of canals, pumping stations and storage facilities that brings water 336 miles from the Colorado River at Lake Havasu east to the Phoenix area and then south to the Tucson area. Fourteen pumping plants lift water 2,400 feet in elevation to the terminus.

The CAP idea preceded Arizona statehood. In the early years of the twentieth century some visionaries talked about bringing Colorado River water to central and southern Arizona. At the time this seemed infeasible. Meanwhile events were transpiring to make the vision a reality.

In the 1920s, six of the seven Colorado River states agreed to divide the river water. Arizona was the sole dissenter and did not go along with the agreement for more than twelve years. Meanwhile Hoover Dam was built in the 1930s, along with other Colorado River projects. When a large aqueduct was built to supply southern California with Colorado River water in the 1940s, Arizonans took notice and began lobbying for their own project. By 1960, all major Arizona politicians and political interests were behind the project. Congress approved CAP in 1968.

The original project included dams on the upper Gila River in New Mexico, the middle Gila River in Arizona, the San Pedro River, and the Verde River at Fort McDowell. Ultimately none of these dams was built. Instead changes were made to some existing dams, and a new dam was added along the Agua Fria River. Construction began.

Figure 2-8 Original extent of CAP delivery areas.



Sources:Tucson Water; Pima County Technical Services; Water Resources Research Center.

President Carter expressed doubts about the project-building approach to solving western water problems, and demanded changes in Arizona water laws to promote conservation. The Arizona Legislature responded to the threatened loss of CAP funding by passing the Groundwater Management Act of 1980. A three-county water district was formed to manage the project after completion and to develop water subcontracts with cities, farms, mines and other prospective users.

Completed to Tucson by 1990, the project faced problems. Few farms or mines signed CAP contracts, not even those that once enthusiastically supported the concept. Farmers found the cost too high and the supply too unreliable. The mines were concerned that the quality of the water would affect their mining processes. The cost of extending pipelines to individual farms and mines also was a significant factor. The City of Tucson was virtually the only commercial customer for CAP in Pima County, although water was allocated to the Tohono O'odham through a legal settlement.

Figure 2-9 Aerial view of the Central Arizona Project canal. Photo: Central Arizona Water Conservation District.

Since Tucson Water has by far the largest municipal CAP contract, its customers, by supporting CAP, pay the majority of the costs to augment the water supply. Farms, mines and water companies meanwhile can continue to pump groundwater at a relatively low cost. Many people believed that other water users in the basin should be required to use CAP water and/or to share the costs of those switching to renewable supplies. Arizona law, however, has no provisions to enforce such a requirement.

To many people, however, CAP water represented a long-awaited water source to benefit the Tucson area. With CAP on-line, less groundwater would be pumped. CAP's Colorado River water, however, differed from the groundwater to which most people in the area were accustomed. CAP water is harder and contains more total dissolved solids than local groundwater. Despite this situation officials believed that citizens would find the new water source to be acceptable.

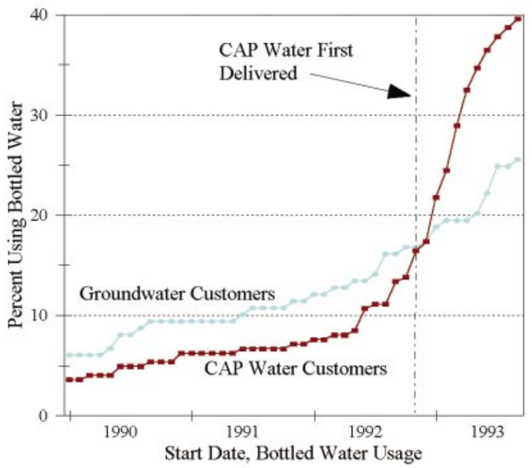
As the CAP canal neared completion in 1989, the Tucson City Council adopted the Tucson Water Resources Plan for the 110-year period, 1990-2100. It called for an aggressive phase-in of direct use of CAP water, combined with recharge and recovery of excess CAP water in early years, recovery of recharge credits, reuse of effluent and some continued use of groundwater. There was a heavy media campaign surrounding the introduction of CAP water, including a well publicized taste-test, TV and radio ads, and direct-mail fliers. The only substantive warnings about water quality were directed at kidney dialysis patients, those on restricted salt diets, and aquarium owners. In general, the introduction of CAP water was expected to go smoothly.

Starting in November 1992, CAP water was delivered to approximately 84,000 customers, or about 58 percent of the connections in the Tucson Water service area. Problems were soon reported by some customers. Many people complained of red, brown or yellow-colored water coming from their taps. Some reported broken pipes, damage to water-using appliances such as water heaters or evaporative coolers, skin rashes, and even dead fish in aquariums and damage to pools.

Many customers receiving CAP water sought to avoid some of these unpleasant effects by buying bottled water or in-home treatment systems, such as filters installed under the sink. Figure 2-10 shows the increase in bottled water usage by Tucson Water customers in response to the introduction of CAP water in November 1992. Purchases of both bottled water and in-home treatment systems have been rising on a national basis for a number of years, and aggressive marketing of bottled water by a growing number of bottled water outlets led to an increase in bottled water usage for all Tucson Water customers over this time period. However, customers switched from groundwater to CAP water increased their bottled water usage more than ten fold, compared to a tripling in the rate of bottled water usage for those kept on groundwater.

Research by the Water Resources Research Center revealed a similar pattern for purchases of in-home water treatment systems, as customers with in-home treatment systems increasing four-fold to nearly 20 percent. The study also documented dramatically higher rates of plumbing and water-using appliances failing in households switched to CAP water. While an accurate estimate of all costs could not be made, the study suggested that Tucson Water customers receiving CAP water were incurring many millions of dollars of expenses per year

Figure 2-10 Percent bottled water users over time, CAP vs. groundwater customers.



Source: Water Resources Research Center.

to avoid and compensate for the decreased water quality.

The City Council debated the possibility of ending direct delivery of CAP water, but in August 1993 twice voted by narrow margins to keep delivering CAP water. In October 1993, deliveries were halted to the east side of the CAP delivery area, which generally had a high number of older galvanized steel water mains and was most heavily affected.

As more complaints were reported, Tucson Water responded by adding a corrosion inhibitor to the water as it left the treatment plant. However, maintaining effective corrosion inhibitor levels throughout the distribution system proved difficult. The utility also began frequently adjusting the chemistry of the water in an effort to control the problems. Several different levels of pH adjustment were tried for varying lengths of time. These frequent changes in pH level were later identified as probably contributing to the problem rather than correcting it.

The City of Tucson also set up a program to handle damage claims. While not admitting fault or responsibility for damages, the City offered to pay up to specified amounts to reimburse for specific types of damage. As of 1995, the City had paid over $1 million dollars in damage claims, and has since added to this amount.

Public exasperation with the delivery problems grew as damage to homes mounted and the extent of the problem became apparent. In May 1994, voters surprised some observers by approving $31 million in bonds for improvement of the water delivery system, mostly to replace old galvanized steel or iron water mains.

All CAP water deliveries had to be halted in November 1994 to allow for repairs to siphons in the CAP system, and City Council voted not to resume deliveries. By this time, the head of Tucson Water and the CAP plant manager had resigned, and the utility's reputation had been seriously damaged in the eyes of many citizens.

Petitions were circulated for a ballot issue to limit future direct delivery and in November 1995, voters approved the Water Consumer Protection Act (WCPA), which outlawed direct use of CAP water unless it was treated to the quality of Avra Valley groundwater and was free of disinfection by-products (See chapter 7). The WCPA had the effect of shifting the focus for how to use CAP water in Tucson to artificial recharge. In 1997, voters reaffirmed their opposition to direct use of CAP water in favor of its recharge and use by farms and industry, by defeating a ballot initiative which would have repealed or substantially changed many of the provisions of the WCPA. Some citizens also joined a class-action lawsuit against the City. Resolution of this litigation is pending.

TODAY'S WATER PROVIDERS

Tucson Water now has four major wellfields — Southside, Santa Cruz, Central and Avra Valley — along with a large number of wells scattered throughout the city, and a few small isolated systems in remote areas. In addition, more than 30 water companies operate well systems in the Tucson area. The largest of these are Metropolitan Domestic Water Improvement District, Oro Valley Water Department and Flowing Wells Irrigation District. Other significant water pumpers include the University of Arizona, Davis-Monthan Air Force Base, Cortaro Marana Irrigation District, Farmers' Investment Company (FICO), Farmers' Water Company and the ASARCO Mining Co. Finally, approximately 22,000 individuals and businesses have their own wells. No one agency coordinates or regulates the activities, of all these users; instead, the Arizona Department of Water Resources (ADWR), the Arizona Corporation Commission (ACC), the Arizona Department of Environmental Quality (ADEQ), the Central Arizona Water Conservation District (CAWCD), the U.S. Environmental Protection Agency (EPA) and the courts all have roles in managing water supply, water quality and water rates. (See Chapter 7 for additional information on regulatory agencies.)

AGRICULTURAL WATER USE

People have been irrigating fields in the Tucson area for at least 2,000 years. Before the Spaniards arrived, most crops were grown in the summer, taking advantage of monsoon rains. The Spaniards introduced winter crops that needed irrigation. They also introduced cattle and horses, animals that affected water supplies as well as vegetation near the streams. The first Anglo farmers continued in the Spanish pattern, with cooperative irrigation systems run by an irrigation master responsible for fairly distributing water. In 1886, the Arizona Mining Index described Tucson farming: "Eight streams of water run through the Santa Cruz Valley opposite Tucson. Five of these ditches are 7-feet wide that now contain a foot and a half of running water. The other three are narrower and contain less." John Davidson started to build a canal to irrigate 3,500 acres, but the floods of 1887 washed it out before it was finished.

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Figure 2-11 San Xavier Mission. The water table was high enough to obtain water with a windmill. Photo: Arizona Historical Society/Tucson.

An important technological advance in the 1890s enabled wells to be drilled in various locations, powered with wood-burning steam engines and, later, gas or electricity. In 1891, a University of Arizona professor reported that water could be pumped from underground to irrigate the campus. About that time, the first farm in the area began to use pumped groundwater. From then on, groundwater pumping increased steadily. With the new technology, wells could be drilled to much greater depths. On the Canoa Ranch south of Tucson a well was drilled to 500 feet, hitting water at 300 feet. The new steam pump could produce a flow of 2,000 gallons per hour.

In 1892, Frank and Warren Allison built a new ditch for irrigation that was later extended to lands beyond St. Mary's Hospital and constructed a reservoir near the old Warner Dam site. By 1895, they had built more ditches and acquired another source of water known as "Flowing Wells" near Sentinel Peak as well as the Tucson Farms Company south of town. This later developed into the Flowing Wells Irrigation District which stretched from far south of town all the way to Marana. That district continues to exist (although greatly reduced), supplying water for urban use on the northwest side of town through its wells.

In the 1890s, new legal systems of apportioning surface water were developed, with the first people to file water claims having the first rights to surface water. Water use increased to the extent that by 1910, all of the water flowing in the Santa Cruz River in the downtown area (other than during floods) was being diverted for agricultural or municipal purposes. With the growth of agriculture around Sentinel Peak new irrigation canals were soon insufficient, and water disputes arose.

ONGOING SEARCH FOR WATER QUALITY

Sewers and Wastewater Treatment

Before the 1890s, Tucsonans used outhouses for their sewage. In the 1890s, when water was first piped to houses, people drained their sewage into cesspools. In 1900, the city opened its new Water and Sewerage Department and laid the first public sewers along Main Avenue between 17thth Street and St. Mary's Road. The untreated sewage was delivered by open ditch to a small farm where it was used for irrigation. In 1914, people were complaining of the odor.

When the farm had a sufficient supply of sewage, a new farm was opened along the Santa Cruz River at Roger Road, four and a half miles northwest of downtown, and a new pipeline was constructed to deliver sewage water to the farm. The city considered the farm a profitable business, but the arrangement met with increased complaints. In 1928, the first treatment plant was built which reduced the solids content of the sewage. After treatment the sewage was delivered to the farm. The facility was expanded and improved in the 1940s, with the sewage still used for irrigation.

As population increased, Tucson could no longer be responsible for the sewage needs all residents, so citizens formed a sanitary district to serve residents outside city limits. It was not until 1961 that the district built a new sewage lagoon near Ina Road and the Santa Cruz River. The Roger Road treatment plant was expanded in 1960 and again in 1968. The Sanitary District was dissolved in 1968, and Pima County took over wastewater management for the area outside Tucson. In 1975, Tucson opened a Wastewater Reclamation Facility at Randolph (Reid) Park which provided wastewater for the golf course, but the facility was closed in 1995. Pima County built a new advanced treatment plant at Ina Road in 1977.

By the 1970s, both city and county officials felt a need to combine their efforts, and they formed the Metropolitan Utilities Management (MUM) Agency for better basinwide management of wastewater facilities in the metropolitan area. Tucson and Pima County, however, continued to operate separate facilities. For the first time, however, they adopted basin-wide sewer connection fees and sewer user fees, charging the approximate cost of providing services. In 1976, elected officials dissolved MUM. Tucson and Pima County then signed an intergovernmental agreement in 1979, stipulating that Pima County would own and operate all the wastewater systems for both city and county, but that Tucson would retain rights to 90 percent of the wastewater coming from metropolitan area treatments plants. The city deeded to the county its Roger Road Treatment Plant and its other wastewater facilities. Between 1980 and 1984, the Roger Road Plant was expanded and upgraded in stages. The federal government paid a large share of construction costs, sparing county taxpayers much of the expense of the expansions.

In 1985, Pima County began a project to export sludge from the wastewater process for agricultural use in the Marana area, thus lessening the burden on the nearby landfill. In 1987, a system for transferring sludge from Roger Road to Ina Road was completed. As a result, neither plant sends sludge to landfills.

In the late 1980s and early 1990s, both the Roger Road and Ina Road plants were expanded and modified and various smaller facilities were built, including the Catalina out-fall sewer and a facility in Avra Valley. Work to further expand the Roger Road facility was recently completed, and work is about to begin to expand the Ina Road plant. Pima County funded a University of Arizona wetlands research project to determine how effectively water hyacinths (and later other plants) could treat wastewater.

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Figure 2-12 Woman washing clothes in the Santa Cruz River, with the ruins of the Convento in the background. Photo: Arizona Historical Society/Tucson.

Recharging Reclaimed Water

In 1983, the City of Tucson constructed a tertiary treatment plant to further treat wastewater from Pima County's Roger Road plant for use on golf courses and other turf. Over the years mains were installed to deliver water to various facilities on the far east side of town and in the central area. Today effluent is delivered to over 200 water consumers, including 13 golf facilities, 25 parks and 30 schools.

Starting in the 1980s the city began recharge experiments, with pilot projects along the Santa Cruz River opposite the Roger Road Wastewater Treatment Plant. Recharge involves adding water to the aquifer. Monitoring determined the rate recharge was occurring and detected changes in water quality. The city subsequently developed other recharge projects. The project with the largest anticipated full-scale capacity is the Central Avra Valley Storage and Recovery Project.

In the 1960s, the city experimented with a series of ponds for wastewater treatment using effluent from Roger Road. Then Tucson Water Director Frank Brooks used to boast of the high quality of the water by eating fish caught in those ponds. The last of the ponds was eliminated in the 1980s in response to fears that water leaching out of the ponds to groundwater was being contaminated by old landfill material. In 1998, the city opened its first constructed wetland to the public — the Sweetwater Wetland near the Roger Road Treatment Plant.

OTHER WATER QUALITY PROBLEMS

Treatment of sewage has been the major water quality challenge for many years, but by no means the only one. During World War II Tucson became a center of airplane construction and maintenance. Several plants located near the Tucson Airport regularly used solvents to degrease aircraft parts. Solvents were not known then to be a health hazard, and the waste products were often evaporated in unlined ponds or allowed to run into washes. A few employees expressed concern at the time, but it was not until the 1970s that people on the south side of town noticed the occurrence of an unusually high incidence of certain illnesses. The Arizona Department of Health and the EPA began studies to determine the cause. As a result of these studies and legal action, officials came to believe that trichloroethylene (TCE) had reached the groundwater and was probably creating health problems such as lupus and birth deformities. A citizen group, Tucsonans for a Clean Environment (TCE), formed on the southside to ensure that the problem was taken resolved to the benefit of the residents.

Since most of the manufacturing companies had long since left town, Hughes Aircraft (now Raytheon), the Tucson Airport Authority, the U.S. Air Force and the City of Tucson shared the burden of cleaning up the contaminated water. The city shut down three production wells and brought water from other wells to area customers. Hughes and the city installed a clean-up facility, under EPA oversight. What to do with the water after the TCE was removed became a major concern. The issue was later addressed as part of the anti-CAP initiative or Proposition 200. This passed and became the Water Consumer Protection Act. Tucson voters stated that water from polluted sources could not be used in the city system, even if federal Safe Drinking Water standards were met.

ADEQ has identified a number of other water quality problems in the Tucson area, including 17 groundwater contamination sites. The sources of contamination include historic landfills, manufacturing plants, mining and agricultural activities, aircraft waste disposal, and gas station and dry cleaning operations. In some cases the contamination exceeds federal Safe Drinking Water standards, and groundwater from the affected areas cannot be used for drinking unless treated to meet those standards. (See Chapter 6).

Chapter 3
IN SEARCH OF ADEQUATE WATER SUPPLIES

Most water issues have to do with either water supply or water quality. In more personal terms these issues have to do with our need for an adequate supply of good quality water. This chapter looks at Tucson's water supplies and our need for sufficient water resources to support our growing community. Present resources are described; methods to make present supplies go further are discussed; and possible strategies for bringing new water supplies into the basin are described. Chapter 5 discusses how we use water, and Chapter 6 discusses water quality.

TUCSON'S WATER SUPPLIES

For many centuries, people who lived in the Tucson area used less water than was available from snow in the mountains or rain. Precipitation or runoff and a high water table could be counted on to maintain the flow of the river. Those days are long gone. Today, virtually all the water we use originates as stored groundwater. This groundwater also is naturally replenished, partly by rainwater and snowmelt from the mountains and partly from return flow after various human uses, such as irrigation and wastewater effluent discharges. The surface water that replenishes the aquifer, however, is not sufficient to ensure a sustainable supply of groundwater in the face of current levels of demand. The stored groundwater supplies have not been substantially renewed for many years. In fact, our excessive pumping of groundwater is the reason little or no surface flow remains in Tucson rivers. New sources of water, such as CAP water and effluent, offer the possibility that we can stop or reduce the mining of our stored groundwater.

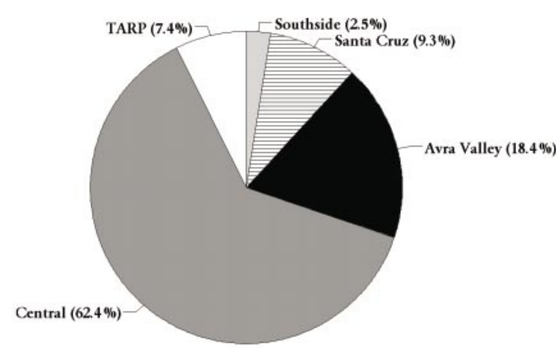
NON-RENEWABLE SUPPLIES

Stored Groundwater

Two main aquifers supply water to the Tucson area, one located in the Tucson Basin and the other in the Avra Valley Basin. In 1940, when Tucson began to increase its groundwater pumping, these aquifers held approximately 70 million acre-feet of groundwater at depths less than 1,200 feet below the surface. Since 1940, approximately 6 to 8 million acre-feet, or 9 to 11 percent of the total has been withdrawn.

A wellfield is a group of wells used by a water provider in an area where the subsurface geology is suitable for pumping. The wells may not be located close together but might still be referred to as a wellfield for administrative purposes. Tucson Water currently operates four major wellfields – Central, Southside, Santa Cruz and Avra Valley. A fifth wellfield is being developed further north in the Avra Valley, to recover recharged water from the Central Avra Valley Storage and Recovery Project. Tucson Water delivered approximately 114,000 acre-feet of groundwater in 1996. Figure 3-1 shows how

Figure 3-1 Contribution of Tucson Water wellfields to total groundwater supply.



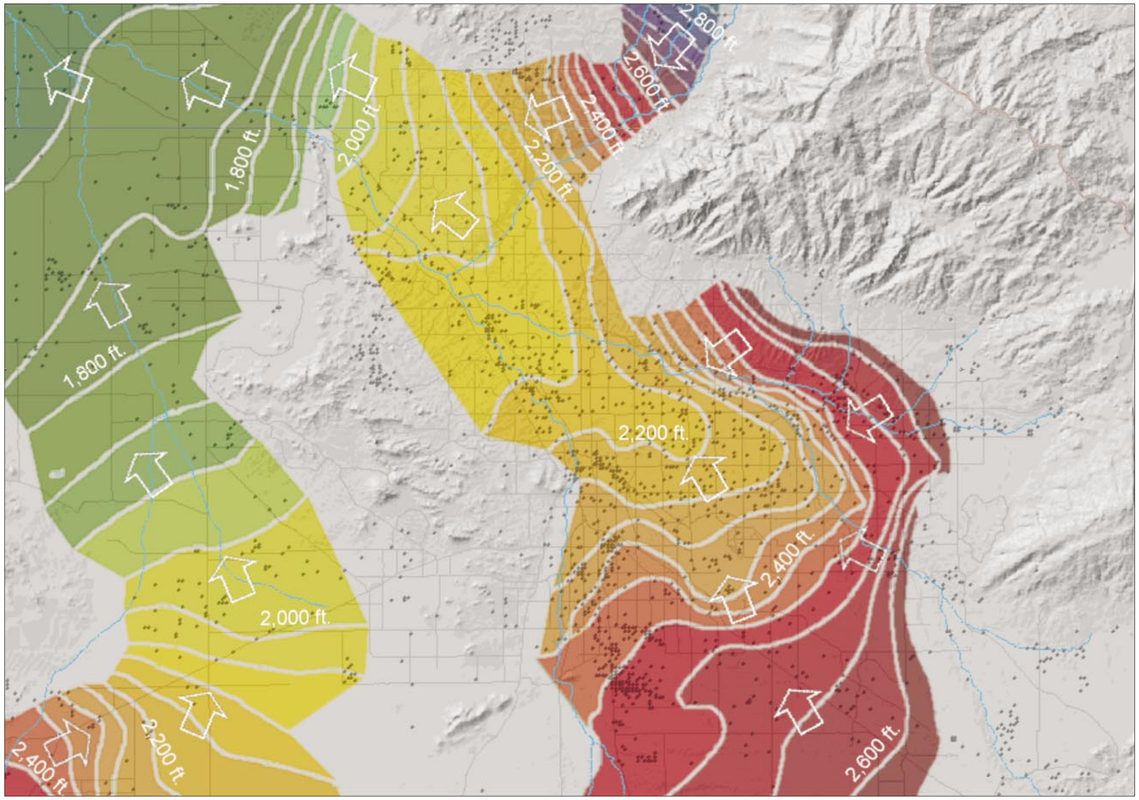
Source: Tucson Water.

WHAT IS GROUNDWATER?

Groundwater is water that fills spaces under ground, between grains of sand or rock or in subterranean cracks. The area where groundwater occurs is the "aquifer." The top level of the aquifer saturated with groundwater is the "water table." The most productive aquifers consist of water stored in sand and gravel. These areas are typical of ancient floodplains (alluvium) where water, rocks and sand were deposited at about the same time. Water and soils flowing from mountains over long periods of time created some of Tucson's most productive aquifers.

Openings between the subterranean storage areas must be interconnected for water to flow freely. Over the years, water moves slowly downward to the aquifer and also spreads out, moving generally northwest in the Santa Cruz Valley. At some point, the water will reach solid rock or a layer of clay. When such an impermeable layer is near the surface, water may occur as surface flow or springs. If the water table is relatively close to the surface, rivers can flow. Excessive pumping from aquifers causes the water table to recede, and surface flow is no longer possible except during rainy periods. Another impact of pumping is that grains of sand or rock compact as water is withdrawn. Percolating water then is much less likely to refill the spaces, especially at greater depths. Tucson's water table has significantly dropped throughout most of the region.

Figure 3-2 Elevation of water table and direction of groundwater flow.



Sources: Arizona Department of Water Resources, Water Resources Research Center.

much each wellfield contributes to total pumping.

The distance from land surface to the water table is termed "depth to water." The present depth to water in the Tucson area ranges from less than 50 feet to more than 700 feet. In certain parts of the Tucson Mountains, it is as much as 900 feet. Depth to water is greatest in the foothills of mountain fronts and shallowest in the Altar, Brawley and Cañada del Oro washes and near Rillito Creek and the Tanque Verde Wash. In the Tucson area groundwater generally flows slowly to the north and northwest, at an average rate of only about several hundred feet per year, or a foot or two per day. (See Figure 3-2.)

The figure on the inside cover of this document shows changes in groundwater levels since 1940. Between the 1940s and 1995, groundwater levels declined over 150 feet northwest of the Green Valley/Sahuarita area as a result of pumping by copper mines. Water

WHAT'S AN ACRE-FOOT?

An acre-foot is enough water to cover an acre of land to a depth of one foot. An acre-foot contains 325,851 gallons.

levels declined more than 200 feet in parts of the Central Wellfield and over 100 feet in the Southside Wellfield due to pumping by the City of Tucson. Current declines in the Central Wellfield are averaging up to four to five feet per year.

Water levels have declined over 150 feet in the southern Avra Valley. The City of Tucson retired farmland in this area, and water levels have rebounded at some locations. Water levels have continued to decline in other parts of southern Avra Valley, in areas where the Tucson Water is pumping water for municipal use.

Groundwater levels, however, are no longer declining from municipal pumping in the lower part of the Cañada del Oro area, after drops of about 50 feet. Water levels that dropped from agricultural pumping southeast of Marana are now rising, partly because of effluent recharge, increased natural recharge and decreased agricultural use. Water levels have also increased along the Santa Cruz River because of above average flood flows since the late 1970s.

Thus, the broad pattern of steady, region-wide groundwater level declines is seen at a greater level of detail to be a more complex pattern of rising and dropping groundwater levels, influenced by local water uses and recharge, and by the impacts of wet and dry years.

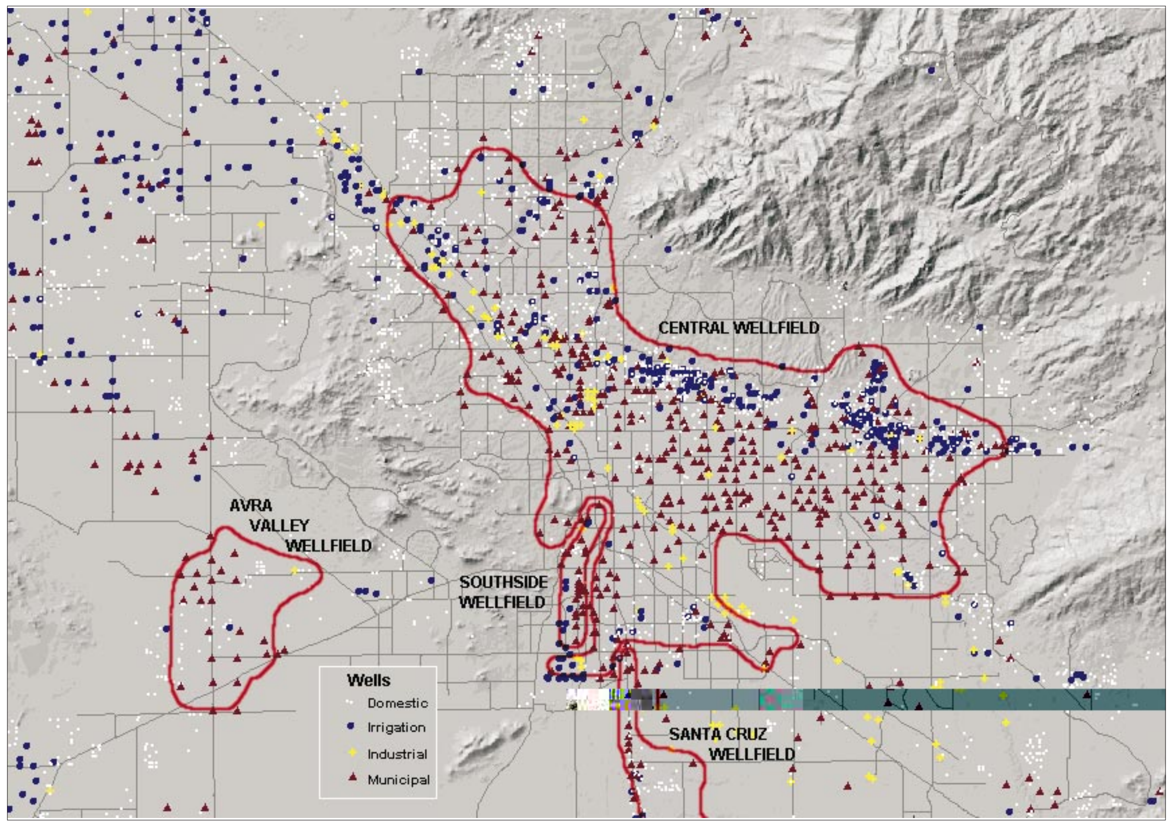
IMPACTS OF EXCESSIVE GROUNDWATER PUMPING

There are several major impacts associated with continued groundwater pumping in excess of the rate of natural recharge. The most far-reaching and potentially destructive is land subsidence and earth fissures. Other impacts include increasing costs of pumping groundwater and generally decreasing quality of groundwater pumped from greater depths.

Subsidence

A consequence of water level declines is land subsidence. 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." In Arizona, subsidence usually results from excessive groundwater pumping. As water is pumped from an aquifer, the water occupying spaces between rock particles is removed,

Figure 3-3 Map of wells and Tucson Water wellfields.



Sources: Pima County, Arizona Department of Water Resources, Tucson Water, Water Resources Research Center.

and the water level or water table drops. Without the buoyancy of the groundwater, the particles become more tightly packed together; i.e., the particles compact and consolidate. Continued pumping of groundwater without adequate recharge causes sediments to become increasingly compressed, and the land surface to settle or subside. (See Figure 3-4.)

In most cases, subsidence resulting from groundwater pumping occurs at about the same rate over large areas and can be difficult to detect. However, abrupt changes in conditions below the land surface can cause the rate of subsidence to vary considerably over a short distance. This "differential subsidence" is more likely to cause damage to houses, commercial buildings, or infrastructure such as water and sewer lines or roads.

A related phenomenon, an earth fissure is a visible, and sometimes even spectacular manifestation of land subsidence. Fissures usually are noticed first as land cracks or crevices, a break in the earth's surface. They can then grow considerably as water erodes the fissured area. Gullies or trenches may be up to 50 feet deep and 10 feet wide, with the fissure extending hundreds of feet below the surface. The fissure may range in length from a few hundred feet to over eight miles. "El Grande" fissure system is ten miles long and is located in the Picacho Basin, northwest of Tucson. The average length of a fissure is measured in hundreds of feet. In the Tucson area fissuring has occurred west of the Tucson Mountains in Avra Valley.

Figure 3-4 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.

**RENEWABLE VS.
NON-RENEWABLE SUPPLIES**

In this report "renewable supply" refers to water that is naturally replenished, and "non-renewable supply" refers to stored groundwater. Thus rainfall is renewable whether it is used directly or whether it adds to the stored groundwater through recharge.

Arizona ranks third nationally in land area affected by subsidence, after California and Texas. More than 3,000 square miles of the state have subsided, with hundreds of fissures occurring since the 1950s. The occurrence of subsidence in south-central Arizona is a major concern because it is a core area of the state, with major agricultural and urban centers. The Phoenix and Tucson metropolitan areas are located within this area, as well as agricultural production areas within Pinal and Maricopa counties.

Urban areas are especially vulnerable to the damaging effects of subsidence. Cities are dense areas of population, with large numbers of buildings and facilities. Also within urban areas are the varied projects and structures — bridges, highways, electric power lines, underground pipes, etc. — that make up the urban infrastructure. Railroads, earthen dams, wastewater treatment facilities and canals also are prone to damages from subsidence. Sewer lines, laid at precise gradients, can have their slopes reduced or even reversed, with serious consequences. Any structure built across the path of a fissure likely will suffer serious damage. Careful and expensive construction procedures were worked out to protect the CAP canal from subsidence damage in certain areas. Despite these precautions, the canal was damaged by an earth fissure in Pima County in 1988.

The U.S. Geological Survey (USGS) reports that since 1940 groundwater levels in Central Arizona have dropped over 220 feet, with Central Tucson subsiding at least one foot since 1950. Meanwhile the rate of subsidence in the

Figure 3-5 A fissure can appear as a deep gash in the earth. The above fissure is southeast of Phoenix. Photo: Ray Harris.

area is increasing. Satellite images show that sections of central Tucson are sinking at the rate of 2 centimeters or 0.8 inches per year. USGS monitors water level changes and subsidence at 19 southern Arizona sites. Some USGS sites are in Tucson.

NPA Satellite Mapping is a company that uses satellite images taken over a period of years to plot subsidence. Satellite imagery coupled with a technique called interferometry determines the subsidence rate. This procedure was applied to identify a large subsidence area in central Tucson, centered at the intersection of East Speedway and Country Club Road. This marks the spot of the greatest subsidence activity in the Tucson area.

USGS models predict levels of subsidence likely to occur in Tucson wellfields. Assuming that groundwater pumping and natural recharge rates continue at 1986 levels through 2025, and based on other assumptions about the aquifer material being compacted, USGS models indicate that maximum subsidence could range from 1.2 to 12 feet in the Central Wellfield by the year 2025. (See Figure 3-6.) Under the same assumptions, subsidence in the Santa Cruz Wellfield could reach up to 4 feet by the year 2025. For northern Avra Valley, maximum subsidence potential is estimated to range from 0.9 to 14.7 feet by the year 2025, assuming that pumping levels and natural recharge rates continue at 1970s levels. If subsidence approaches the maximum level projected for the year 2025 in the Central Wellfield, the risk of differential subsidence is significant, especially near downtown Tucson.

Subsidence can be halted by ceasing or limiting groundwater withdrawal in an area. Also, under the right conditions, overdraft may be reduced through artificial recharge, thus slowly decreasing the danger of further subsidence. In most cases, subsidence is termed inelastic because the sinking of the ground is permanent, and recharge would not reverse the process.

Well-injection recharge is likely to be more effective than other types of recharge at ensuring that water is recharged close to the compacting layers. Surface water recharge projects may be effective at restoring the water table. In most cases, however, once subsidence occurs, the water storage capacity of the aquifer is permanently reduced. In some cases, recharge projects may even worsen subsidence, as the weight of the water applied at the surface compacts the underlying aquifer materials even more.

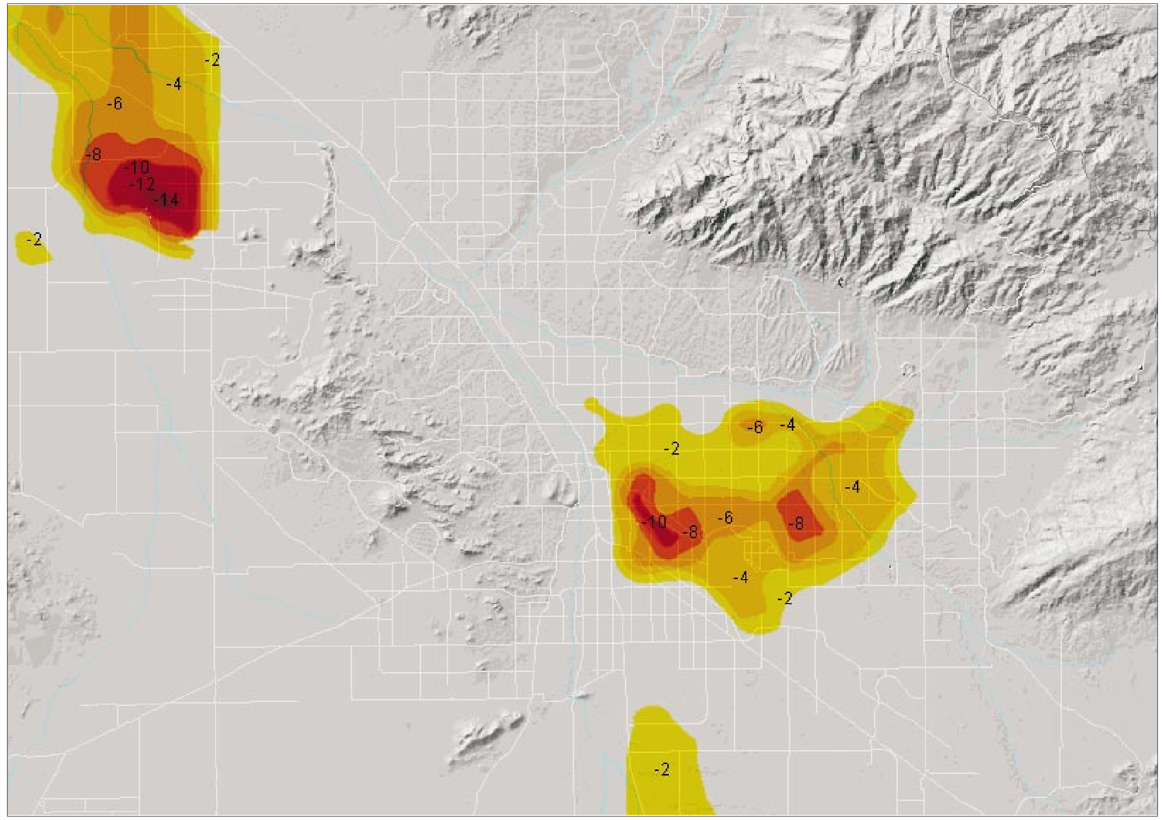
Increased Pumping Cost

In those areas with the most pumping, water level declines may lead to lower productivity because as the water is pumped from greater depths, the aquifer materials become more compacted and hold less water. For example, well yields in the Santa Cruz and Southside Wellfields have decreased over the years. Average yield for wells in the Santa Cruz Wellfield in 1992 was less than a third of what it was in 1958. Average yield in the Southside Wellfield in 1992 was about half of what it was in the late 1960s. Further decreases are expected for both wellfields, if pumping continues at current rates and groundwater level declines continue. If the same amount of water is to be pumped, loss of productivity in wells means higher pumping costs for water utilities. Costs can further increase if older, shallower wells need to be replaced with deeper ones.

Decreased Water Quality

The quality of water pumped also is expected to generally decline as it is pumped from greater depths. The total dissolved solids (TDS) of Tucson area groundwater currently averages about 300 parts per million, although TDS measurements in some areas are much higher. An increase in TDS shortens the useful life of many water-using appliances and water pipes because of accelerated corrosion.

Figure 3-6 Maximum potential subsidence in feet.



Sources: United States Geological Survey, Arizona Department Water Resources.

RENEWABLE SUPPLIES

Central Arizona Project Water

CAP water is the largest renewable water supply in the Tucson area. CAP water is lifted some 2,900 feet through 14 pumping plants and transported through open canals, siphons and pipes a distance of 336 miles from the Colorado River at Lake Havasu through the Phoenix area and then south to Pima County. CAP was designed to deliver up to 1.5 million acre-feet of water annually to central Arizona.

Over 215,000 acre-feet of CAP water are allocated to entities in the Tucson area, with approximately 38,300 acre-feet subcontracted to Indian users. Appendix B lists the CAP allocations of all the local water providers. Additional CAP water that is available to the Arizona Water Banking Authority and the Central Arizona Groundwater Replenishment District could be recharged in the Tucson area.

The City of Tucson has the largest allocation of CAP water in the state: 138,920 acre-feet. This is Tucson's total allocation after the recent agreement between the City of Tucson and the Metropolitan Domestic Water Improvement District (Metro Water) that transfers 9,500 acre-feet of Tucson's allocation to Metro Water and Oro Valley. In the early 1990s, the City of Tucson intended to use increasing amounts of its allocation by directly delivering treated CAP water to its customers and to other municipal water providers on the northwest side, and recharging additional amounts for later use. CAP water was first delivered to approximately 60 percent of Tucson Water customers starting in 1992. Direct deliveries were suspended for some of those customers in September 1993 and halted indefinitely for all customers in November 1994, after problems arose with the taste, odor and color of the water, and pipes and water-using appliances were damaged.

The aborted effort to introduce CAP water caused city residents to be wary of the resource, and in 1995 they approved the Water Consumer Protection Act. This voter initiative prohibits direct delivery and injection recharge of CAP water unless stringent water quality criteria are met. As a result of the initiative, the city has switched its CAP use strategy from mostly direct use to recharge. After declining from a peak of approximately 52,000 acre-feet in 1993 to 10,200 acre-feet in 1995, CAP water deliveries to the Tucson Active Management Area (TAMA) have grown to 19,800 acre-feet in 1996 and 34,200 acre-feet in 1997. Almost all of the water was delivered to direct recharge projects or Groundwater Savings Facilities (See section on recharge, below).

Some municipal providers with CAP contracts, such as those in the Green Valley area, cannot use their allocations directly because the canal does not reach them. To better service them, a group of water users in the Upper Santa Cruz basin studied the possibility of extending the CAP canal from its current end point near Interstate 19 and Pima Mine Road south of Tucson to the Green Valley/Sahuarita area. In a 1998 study, the group identified possible alignments for the canal and estimated costs. Other municipal providers who cannot use their allocations directly plan to recharge their CAP water to offset some of their groundwater pumping.

Treated Effluent

Treated effluent is water that has been used in homes and businesses and then collected by the sewage system and treated at a wastewater treatment plant, for various water uses. Some 85 to 90 percent of households in the Tucson metropolitan area are connected to the central sewage system. Effluent is considered a renewable supply because it extends our stored groundwater supply. Generally as population increases, so does the supply of effluent.

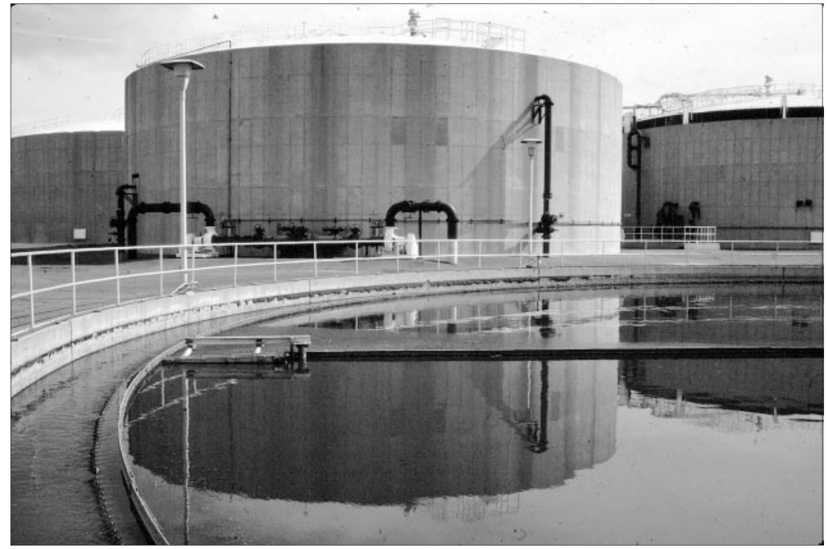


Figure 3-7 Tanks from a Pima County wastewater treatment plant. Photo: Barbara Tellman.

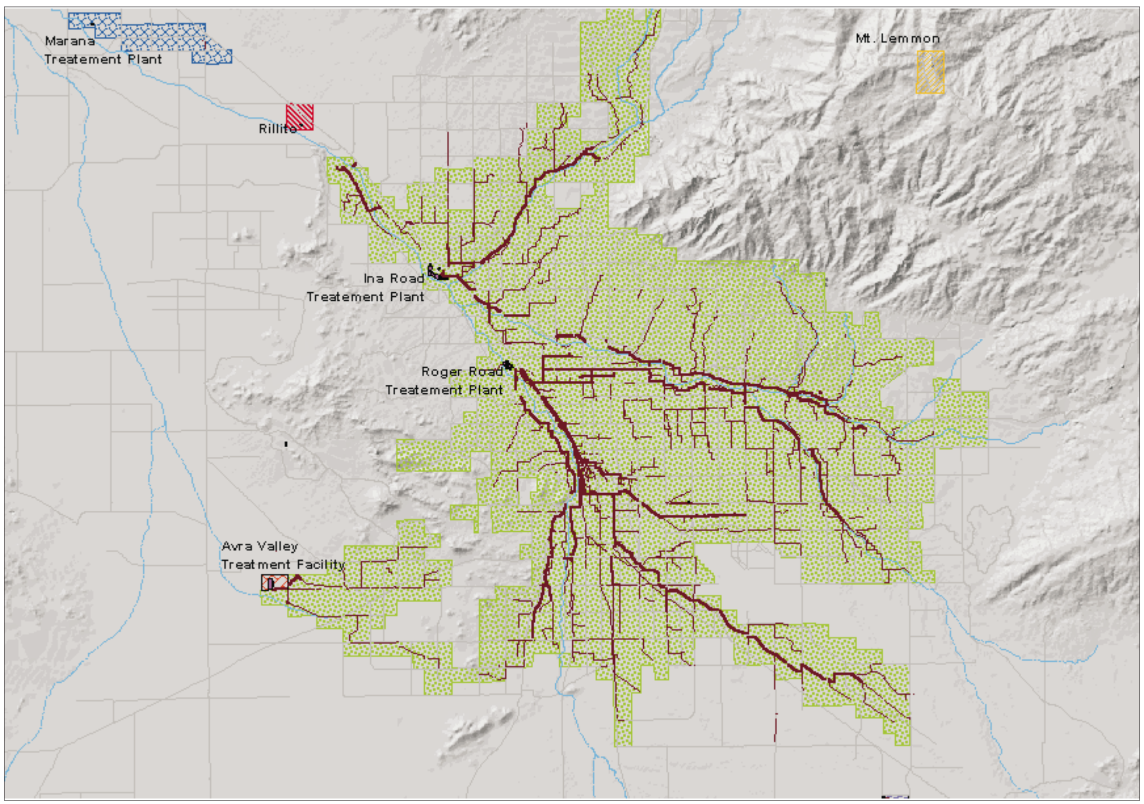
Total treated effluent production from wastewater treatment plants in the Tucson AMA (TAMA) was 70,100 acre-feet in 1996, or approximately 63 million gallons per day (mgd). Almost all the effluent came from the Ina and Roger road treatment plants. Nine other small treatment facilities are located in Pima County, and an estimated 11 percent of single family residences have septic tanks. Total effluent flows in Pima County are projected to reach 103 mgd, or 115,760 acre-feet, by the year 2025.

Wastewater delivered to the Ina and Roger road treatment plants undergoes primary and secondary treatment processes at treatment facilities to meet state and EPA water quality standards. Of the approximately 69,400 acre-feet of secondary-treated effluent produced at these plants in 1995, approximately 4 percent was delivered directly to farms and another 2 percent was delivered directly to turf facilities such as golf courses. Another 13 percent was sent to Tucson Water's reclaimed water facilities, located next to the Roger Road Wastewater Treatment Facility for additional treatment involving filtration through sand filters or soil and additional disinfection. Reclaimed water then is delivered for use or is recharged at the Sweetwater Underground Storage and Recovery Facility, to be pumped out when needed to meet peak irrigation demands during summer. (See Chapter 5 for more information on the use of effluent.)

The remaining 84 percent of the effluent is released into the Santa Cruz River channel. Approximately 96 percent of released discharges eventually infiltrates the river channel to the underlying aquifer within TAMA. The remaining 4 percent evaporates or is used by riparian vegetation.

The Regional Effluent Planning Partnership has listed 20 effluent projects and potential alternatives as of January 1999 (See Appendix B). Of these 20 projects, three presently exist, seven are in the process of being built and ten are proposed for the future. Two of the proposed projects would create recharge credits for the existing discharge to the Santa Cruz River. If these projects are approved, the state would grant credits for 50 percent of the amount of effluent recharged. These credits could be used to allow groundwater pumping elsewhere in the TAMA, partially nullifying the contribution of the existing effluent discharges towards safe yield calculations for TAMA. An assessment also is currently being conducted to determine potential impacts of any changes in effluent discharge on the riparian area downstream of the wastewater treatment plants.

Figure 3-8 Wastewater treatment facilities and distribution system.



Sources: Pima County Technical Services, Pima County Wastewater.

At least seven constraints may limit full use of effluent. None of these constraints are insurmountable barriers; yet they must be taken into consideration when making plans for dealing with effluent. They include:

- A water rights settlement with the Tohono O'odham Nation obligates up to 28,200 acre-feet of effluent produced at metropolitan area wastewater treatment facilities to the U.S. Secretary of the Interior for the Indian Nation.
- Of the effluent remaining after the Secretary's share is subtracted, the City of Tucson has control of about 90 percent of the effluent produced at metropolitan area wastewater treatment facilities, under a 1979 intergovernmental agreement. Pima County processes all of the wastewater but controls 10 percent
- ADWR has complex rules for how much effluent use or recharge counts toward meeting Assured Water Supply Rules. Recharge of effluent through a constructed facility, for example, counts more than "managed" recharge of effluent in a streambed, while direct reuse has the highest value.
- ADEQ and EPA have strict water quality rules for discharge to streambeds and for various uses of effluent. As wastewater treatment plant permit conditions have become stricter in recent years, Pima County has urged that standards be relaxed or that streambed releases be discontinued.
- The cost of building distribution systems for use can be high, especially for golf courses or other facilities far from the treatment plant

and usually requiring uphill pumping. Tucson currently sells effluent for $475 per acre-foot, which is about$100 per acre-foot less than the full cost of treating and delivering it. Pima County sells effluent for a fraction of that cost at $11, but does not provide tertiary treatment and delivers effluent to customers downhill, not too distant from the treatment plant.

- A 1989 Arizona Supreme Court decision (Arizona Public Service v. John F. Long) left regulation of effluent unclear, and the Arizona Legislature has never dealt fully with the matter. Effluent, however, is regulated with regards to its water quality.
- Although effluent is treated, it still contains some contaminants that can affect groundwater. These include nitrates which have been found in groundwater in the Marana area and are probably the result of both agricultural activity and effluent. Excess nitrates can cause serious problems for infants.

AUGMENTING THE WATER SUPPLY — RECHARGE

In Tucson — in fact, in most of the heavily populated areas of Arizona — depletion of the aquifer is a problem and is the underlying concern for much public policy. Recharge is an important tool in managing groundwater levels in the Tucson area and has attracted much attention from government agencies, university researchers, concerned citizens and others. Passage of the Water Consumer Protection Act in 1995, which directed the City of Tucson to use its CAP water allotment for recharge or to trade with area farms and mines instead of direct delivery to homes, has increased attention paid to development of recharge projects in the area.

Recharge generally refers to the addition of water to groundwater already in the aquifer. In order to recharge the aquifer, water usually must first infiltrate the soil or ground surface and then percolate though the unsaturated zone of the aquifer (referred to as the vadose zone) to reach the water table. The water table defines the top part of the aquifer which is saturated with groundwater. An important distinction exists between infiltration and recharge. Infiltration is entry of water into the soil and the movement of water from the soil into the vadose zone. Recharge is addition of water to the part of the aquifer which is saturated with groundwater and can be pumped.

Recharge of an aquifer occurs in three ways: natural recharge resulting from precipitation and runoff; incidental recharge from water that seeps into the ground after various human uses, such as irrigation; and artificial recharge by constructed or managed projects designed to put water in the aquifer. These three types of recharge help maintain a balance of water use and supply.

Natural Recharge

Natural recharge is the addition of precipitation and streamflows to groundwater supplies in the aquifer. Water from precipitation and runoff infiltrates mainly along mountain fronts and in stream channels and also as direct underflow from joints and other openings in rocks. Snowmelt and mountain precipitation often infiltrates at the foot of mountain ranges. Mountain-front recharge in TAMA averages about 39,000 acre-feet annually. Stream channel recharge in the Tucson area occurs as a result of infrequent, but occasionally large stream flow events. Some of the water that flows in streams after heavy rains infiltrates the streambed to recharge the groundwater aquifer. Total stream channel recharge in TAMA averages approximately 38,000 acre-feet per year. (See Chapter 4 for more information.)

Underground flow of groundwater also is included in calculating natural recharge to an area. Groundwater generally moves slowly (at a rate of a couple hundred feet per year) to the north and northwest in the Tucson area. On average approximately 9,000 acre-feet per year of groundwater flows underground into TAMA from the south every year and about 25,000 acre-feet per year leaves TAMA by flowing underground to the north.

Incidental Recharge

Incidental recharge is water that reaches the water table after human use. The amount of incidental recharge in TAMA depends mostly on the extent and water use efficiency of certain human activities, such as irrigated agriculture, mining and the discharge of effluent into stream channels. ADWR has estimated that annual incidental recharge in TAMA totals about 81,000 acre-feet, based on water use levels projected for the year 2000. Most is effluent discharged by the two large wastewater treatment plants.

Artificial Recharge

Artificial recharge of either CAP water or effluent is an important method of utilizing renewable supplies in TAMA. Artificial groundwater recharge generally involves constructing facilities to control the movement and rate of infiltration. The following discusses artificial recharge as a way of replenishing the aquifer. Using artificial recharge as a water treatment method is discussed in Chapter 6.

The State of Arizona's Underground Water Storage, Savings and Replenishment Program allows two types of recharge facilities: Underground Storage Facilities (USFs) and Groundwater Savings Facilities (GSFs). USFs, or direct recharge facilities, can include "constructed" projects, such as spreading basins, structures placed in a stream channel to increase percolation into the stream bed, or injection wells, as well as "managed" projects, where water is applied to stream channels without constructed facilities (See side bar for discussion of the types of direct recharge facilities). In the case of constructed projects, the rate of application of water is regulated through facility design and operating procedures to control the rate at which water reaches the aquifer and to ensure that quality is not impaired. Through GSFs, or "in lieu" recharge facilities, incentives are provided to encourage farms or other entities to use renewable supplies such as CAP water instead of groundwater. (See Chapter 5 for a discussion of CAP water use by Tucson area farms through GSFs, and Chapter 7 for additional explanation of GSFs and USFs.)

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 evaporation. The state requires the other five percent to remain in the aquifer as permanent recharge. Municipal providers can use long-term storage credits to help meet their Assured Water Supply requirements and to help prove the physical availability of an assured water supply.

Little of the CAP water recharged in TAMA so far has been pumped for use, although the City of Tucson is constructing a wellfield to allow recovery of water stored at the Central Avra Valley Storage and Recovery Project (CAVSARP) in the near future. Generally, recovery of recharged water is permitted if it is recovered in the area where the water was originally stored, or in an area to which it migrated after storage. Recovery of water outside this "area of impact" is permitted under certain conditions to ensure that recovery of water does not occur in areas with substantially declining groundwater levels.

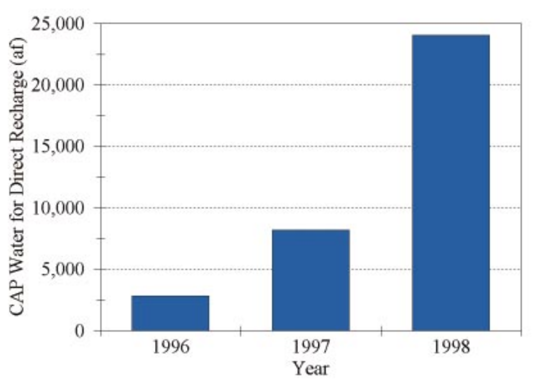
Figure 3-9 The Pima Mine Road recharge basins. Photo: Central Arizona Water Conservation District.

Figure 3-11 is a map of existing and proposed direct recharge facilities in TAMA. Four direct recharge facilities are currently operating in TAMA. These include CAVSARP, Pima Mine Road Recharge Project, Avra Valley Recharge Project and Sweetwater Underground Storage and Recovery Project. All of these projects utilize off-channel spreading basins to recharge CAP water, except the Sweetwater facility, which uses basins to recharge reclaimed effluent.

Figure 3-10 shows the amount of water stored at direct recharge facilities over time. The amount of water stored at Tucson area projects is small compared to the total renewable supplies available. Not including CAP water used at groundwater savings facilities, about 7,800 acre-feet of CAP water was recharged in TAMA in 1997, compared to approximately 215,000 acre-feet of CAP water available under sub-contract to entities in TAMA.

Direct injection is the most certain method of recharge because water can be directed to a specific location within an aquifer. For this reason, local recharge experts believe that direct injection may be the most effective tool in mitigating subsidence. With direct injection, water can be added as close as possible to the layers of the aquifer that are being compacted. The extent to which subsidence can be limited with this method, however, is uncertain, depending in part on the type of aquifer materials. Tucson Water stored approximately 4,000 acre-feet of CAP water using two pilot injection wells in 1993 and 1994. The Water Consumer

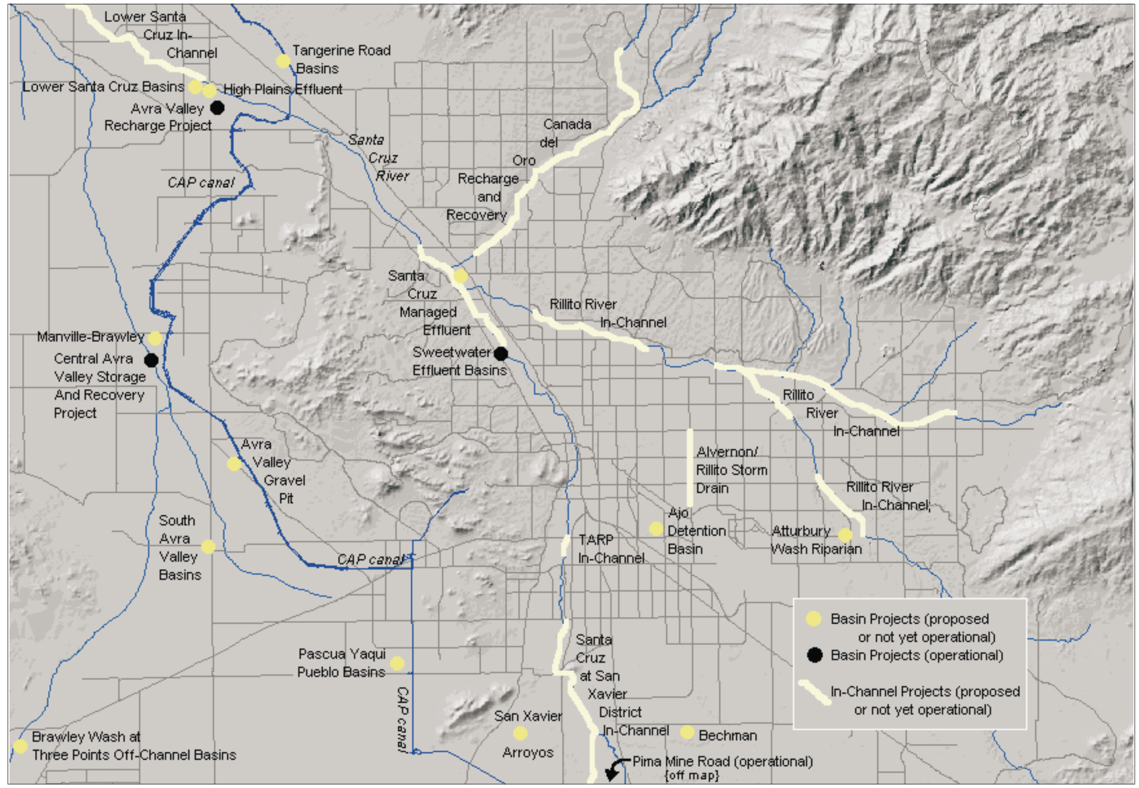
Figure 3-10 CAP water deliveries to direct recharge projects in the Tucson AMA*.



* Total CAP delivery to direct recharge projects - not adjusted for evaporation or cut to the aquifer.

Source: Central Arizona Water Conservation District.

Figure 3-11 Existing and proposed direct recharge projects.



Source: Arizona Department of Water Resources.

Protection Act, however, allows direct injection only if the water meets or exceeds the water quality of Avra Valley groundwater in terms of hardness, salinity and dissolved organic materials and is free of disinfection by-products. Costs of treating CAP water to the Avra Valley groundwater standards would be prohibitively expensive. Entities in the Tucson area other than Tucson Water are not bound by WCPA but have not attempted direct injection.

New direct recharge projects are being planned. (See Figure 3-11.) A facility permit has been issued for the Lower Santa Cruz Replenishment Project, which is projected to have a capacity of 12,000 to 13,000 acre-feet in its first phase. The facility will be located along the Santa Cruz River in northern Avra Valley. The proposed Cañada del Oro Recharge Project could add another 30,000 acre-feet of direct recharge capacity in northwest Tucson near the Town of Oro Valley. A study of the technical feasibility of the project is currently being conducted. Total direct recharge capacity on non-Indian land in TAMA is projected to be

TYPES OF ARTIFICIAL RECHARGE

In-Channel Artificial Recharge

Artificial recharge facilities operate either in-channel or off-channel. *In-channel constructed facilities* are recharge facilities built into a river or stream bed to retain water while it infiltrates through the stream bed into the underlying aquifer. These structures include inflatable dams, gated structures, levees and basins, or other devices designed to impede water flow. Levees are the least expensive of these alternatives, but are the most subject to damage from flood flows. Also operating in-channel, *managed facilities* allow water to infiltrate the stream channel without the aid of structures to impede flow.

Off-Channel Artificial Recharge

Off-channel artificial recharge facilities include *shallow spreading basins*. These basins are dug up to 20 feet deep to reach more permeable layers and are usually constructed with earthen berm walls to hold water in place. During operation, the depth of water usually does not exceed five feet. Basins are operated on a wet/dry cycle to allow periodic scrapings or other techniques to maintain high infiltration rates.

Deep basins or pits also can be used for off-channel recharge. These facilities are usually converted from other uses, such as gravel pits. During operation, water levels up to about 10 feet are usually maintained. Operating costs are usually low, since basins are drained and maintained only once every year or two. Infiltration rates, however, are usually low due to build up of organic matter.

Also operating off-channel, *injection wells* are usually existing water extraction wells converted to allow injection of water directly into the aquifer. Water injected must normally meet drinking water standards (Maximum Contaminant Levels). The Water Consumer Protection Act effectively prohibits the City of Tucson from using injection wells unless the water injected is treated to the same standards as Avra Valley groundwater and is free of disinfection byproducts.

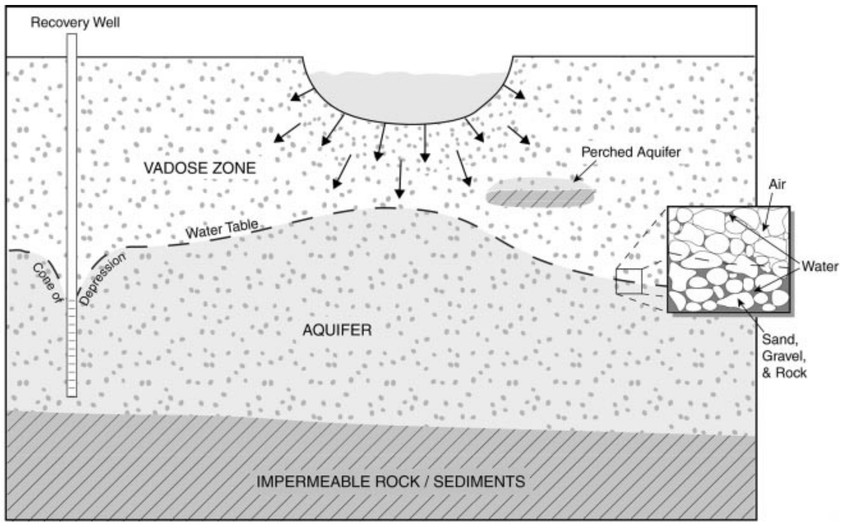
49,000 acre-feet in the year 2000, possibly rising to 131,000 by the year 2007 with the addition of a full-scale Lower Santa Cruz Replenishment Project, the Cañada del Oro Project and expansion of existing projects to full-scale. Proposed recharge projects on Indian land could add up to an additional 41,000 acre-feet of direct recharge capacity by 2007.

Recharging the Central Wellfield

The highest rate of groundwater decline in TAMA is occurring in the Central Wellfield, and USGS models project that subsidence in that part of TAMA could greatly increase. Artificial recharge has been suggested as one way of stopping declines of groundwater levels in the Central Wellfield, and the WCPA directs the City of Tucson to recharge the Central Wellfield. Although artificial recharge could help reduce groundwater level declines in the Central Wellfield, determining the best method of recharging the area is difficult, and recharging large amounts of water requires extensive facilities. With current withdrawals from the Central Wellfield ranging from 60,000 to 70,000 acre-feet per year and natural recharge estimated at 17,000 acre-feet per year, 43,000 to 53,000 acre-feet per year of recharge would be required to stop the decline of groundwater levels. This is a great deal of water to recharge every year in central Tucson.

One possible way of recharging the Central Wellfield is by releasing CAP water into the Rillito Creek, Tanque Verde Creek and the Pantano Wash. These stream channels generally overlap the Central Wellfield, although most of their flows are to the north-northwest, not toward the Central Wellfield. The high infiltration rates in local stream channels would seem to support the premise that large amounts of CAP water could be successfully recharged using such channels to replenish the Central Wellfield. The long-term recharge rate, however, often differs from the short-term surface infiltration rate. The short-term rate is the rate at which water enters the coarse-grained channel alluvium. Water generally infiltrates this alluvium very easily. The long-term recharge rate is the rate at which water actually reaches the aquifer, and is determined by basin fill deposits closer to the aquifer. Because these deposits are less permeable than the recently deposited alluvium near the surface, the long-term recharge

Figure 3-12 Movement of recharged water through the aquifer.



rate is lower than the short-term infiltration rate. If water were released in the stream channel over a long period of time (perhaps greater than a year), water would mound up in the channel alluvium. Water then would eventually rise to the stream channel, and water released at the surface would infiltrate at the long-term rate, or be rejected as subflow or surface flow.

A panel of hydrologists and other technical experts formed by ADWR in 1996 estimated the maximum long-term average annual volume of artificial recharge possible in stream channels generally overlying the Central Wellfield (Rillito Creek, Tanque Verde Creek and the Pantano Wash). The panel concluded that the maximum long-term average annual volume that could be effectively infiltrated through those channels is approximately 29,000 acre-feet. When the volume of natural recharge is considered, total maximum potential average annual volume of artificial and natural recharge in the stream channels is approximately 50,000 acre-feet per year. Some of these stream reaches have landfills, however, containing contaminants that could pollute recharged water. After excluding stream reaches with known landfills, the maximum long-term average annual volume of artificial and natural recharge would be about 27,000 acre-feet, or only 38 to 44 percent of present annual withdrawals from the Central Wellfield.

Recharge experts also have pointed out that some of the water which infiltrates the stream channels generally overlying the Central Wellfield may not reach the underlying aquifer. This is because some of the water applied to local stream channels would likely move downstream as subsurface groundwater flow just beneath the streambed instead of recharging the Central Wellfield. This subflow would travel downgradient to the alluvium underneath the Santa Cruz River after its confluence with the Rillito Creek and move towards Pinal County. Any of this subflow eventually reaching the aquifer would be too far from the Central Wellfield to benefit it. Preliminary results of attempts to date groundwater based upon isotopic analyses indicate that groundwater located a couple miles south of the Rillito is hundreds or thousands of years old. This suggests that limited recharge of the Central Wellfield is occurring.

The City of Tucson is planning to address water decline problems in the Central Wellfield by pumping instead from CAVSARP. The projected full-scale capacity of CAVSARP is 60,000 acre-feet per year. If enough water is recovered annually from CAVSARP to offset current annual pumping in the Central Wellfield, most of the Central Wellfield groundwater pumps could be shut off. Groundwater level declines could then be stopped or slowly reversed with the help of natural recharge. Water recovered from CAVSARP would be sent though the Hayden-Udall (CAP) Treatment Facility before being delivered to homes.

USGS has begun a project to study the location and timing of recharge in the 12-mile stretch of the Rillito Creek from Craycroft Road to the Santa Cruz River. Approximately $635,000 is budgeted to collect the needed data and build groundwater models to investigate various recharge scenarios. This study is expected to greatly improve assessment of the feasibility of artificial recharge in the Rillito Creek to benefit the Central Wellfield. (For more information see Chapter 4.)

OTHER STRATEGIES

In response to our ongoing water worries, various strategies have been proposed to increase regional water supplies of our region. Options for increasing water supplies in Tucson, however, are limited. Using CAP water is currently Tucson's only major strategy for increasing water supplies. Whether it is used directly in municipal systems or by agriculture or mines, or whether it is recharged for later use, CAP water can add considerably to the basin supply. Use of effluent does not bring new water into the basin, but does help prolong the water supplies by reducing the need to use stored groundwater.

Following is a discussion of various strategies for increasing water supplies in the Tucson Basin. A few obviously require a large-scale investment of funds and other resources; others can be done by individuals in their homes and communities. A few appear doable; others seem far-fetched.

Import Water From Outside the Basin

CAP has not been the only project designed to import water from outside the basin to increase Tucson's water supplies. Its distinction is that it was the only such project to be built. Over the years, other strategies have been proposed to bring water here from elsewhere. One scheme offered in the 1970s would have brought water from the Yukon, through Canada to the Great Lakes and ultimately to the Southwest. Another heroic scheme would have imported water from the Pacific Northwest to California and Arizona. Both strategies were found to be excessively costly, not to mention being unacceptable to people in the Northwest and Canada.

Figure 3-13 The Pacific Northwest Water Plan of the 1970s proposed bringing water from Canada to a wide region including Arizona. Photo: Barbara Tellman.

The City of Tucson tried a much less ambitious scheme in the 1960s when it purchased land with water rights north of Benson along the San Pedro River, with the intent of building a pipeline to Tucson. A lack of funds and a questionable supply of water, coupled with opposition from residents, stopped this project, and Tucson sold the land. Another effort to capture San Pedro water was the Charleston Dam, originally part of the CAP system. This, too, was defeated when Cochise County residents opposed the idea.

Other ideas for obtaining additional water include desalinating seawater, either along the Gulf of California or near San Diego and piping it to Arizona. A fanciful proposal in the 1980s suggested towing icebergs from Antarctica to the California coast and piping the melted water to Arizona. Neither of these projects appeared feasible or cost-effective.

Capture Floodwater

To many people, allowing flood water to drain out of the basin represents a lost resource. Heavy rain showers occur occasionally in the desert, filling arroyos and river beds with abundant and vigorously flowing water. Capturing more of this flow could augment our supplies, whether used directly or recharged. With Tucson riverbeds seeming to offer promising sites, Tucson water history during the twentieth century includes various references to plans for capturing runoff. At times, suitable locations to capture and control mountain runoff have been proposed. Tucsonans looked to the dams along the Salt River as models, but the Santa Cruz River and its tributaries offered no comparable sites suitable for large storage dams. Studies are underway to determine whether other methods such as inflatable dams can be effective. (See Chapter 4 for a discussion of this topic.)

Vegetation Management

In the 1960s and 1970s, removing vegetation along watersheds was considered a promising way to increase water supplies for cities. This strategy was based on the fact that vegetation uses water that otherwise could be put to human uses. Some experiments were conducted; chains, cables and chemicals were used to remove chaparral and piñon-juniper forests. Ponderosa and mixed conifer forests were harvested. While initial results often showed an increase in streamflow, long-terms results were not conclusive. Grasses often took over areas denuded of trees, using about as much water as did the trees. Where vegetation did not have a chance to regrow before heavy rains, erosion took away topsoil.

Some people have advocated removing cottonwoods along rivers such as the San Pedro because of the water they use, but the results would be mixed at best. Some gains would be offset by the loss of shade to cool the water and reduce evaporation and by the loss of a root system to help hold soil in place. The increased importance that people place on riparian vegetation for habitat and recreation further advises caution when considering vegetation management practices. This approach to increasing water supplies has generally fallen out of favor in Arizona.

Weather Modification

Advocates of weather modification look to the clouds as a source of water to augment current supplies. Arizona's interest in weather modification evolved over time, from early cloud seeding experiments to the adoption of sophisticated computer modeling techniques that simulate climatological phenomena and test weather modification premises. The evolution reflects a change in attitudes, from an optimistic expectation of immediate results to a more cautious, even skeptical regard about the potential of weather modification.

Clouds consist of small water droplets that, despite below-freezing temperatures, remain liquid. The water's purity and the lack of foreign particles in the atmosphere prevent the droplets from freezing. These "supercooled droplets" form supercooled clouds. As temperatures decrease, the droplets form ice crystals around small atmospheric particles such as dust. Cloud seeding introduces additional particles or nuclei into the atmosphere, causing more ice crystals to form. Silver iodide compounds or dry ice are the usual cloud seeding agents. Aircraft or ground-based generators introduce the agents into the atmosphere. The ice particles grow and attract nearby water vapor and droplets. The enlarged ice particles eventually fall as snow. Clouds which form over mountainous areas are preferable for seeding because they last longer, and weather modification experiments can be more readily arranged.

A number of legal, social and environmental issues would have to be resolved before weather modification could be used on a large scale, even if it proves to be effective. Who is liable for damages from floods or other weather events resulting from weather modification? How are the rights of those who want rain to be reconciled with the rights of those who prefer sunshine? What if precipitation increases in a basin in which cloud seeding occurred but decreased during the same period in another basin? Has the latter basin been wrongfully deprived of its precipitation?

And there are other questions: How is it determined that precipitation was in fact the result of weather modification? How is the amount of new water to be quantified for credit and distribution? On what basis is the new water induced by weather modification to be allocated among water users? How can those who pay for the weather modification be ensured that they will in fact receive their share of the new water?

Environmental problems also may arise. For example, increased precipitation might mean increased weed growth, and a heavier snowpack could disrupt the winter food habitat of large mammals. Concern has also been expressed about the effects of introducing artificial ice-crystal nuclei (e.g. silver iodide, dry ice and liquid propane) into the atmosphere. Environmental studies are obviously needed to determine the effects of cloud seeding.

STRATEGIES FOR INDIVIDUALS

Graywater reuse and water harvesting can be effective ways for individuals to decrease their use of groundwater and thus lower their water bill. Both strategies, however, probably do not contribute very much to the overall water supply picture in the basin. In areas connected to the central sewage system, use of graywater reduces the amount of effluent produced and consequently the amount available for reuse or recharge. Water harvesting also reduces the need to pump groundwater and may help relieve flooding problems. At Casa del Agua, a water conservation demonstration house that was supported by the University of Arizona, Tucson Water and ADWR, UA researchers tested and evaluated various water saving devices and strategies, including graywater use and water harvesting.

Use of Graywater

Graywater is water from the bath, shower, washing machine or bathroom or kitchen sinks in homes. Graywater can supply most, if not all the irrigation needs of a domestic dwelling landscaped with vegetation of a semiarid region. Along with its use in outside irrigation, graywater can be used in some situations for toilet flushing. Metro Water, a utility serving northwest Tucson, recently conducted a survey that found nine percent of its customers use some portion of their graywater.

Graywater systems vary from simple low-cost systems to highly complex and costly units. The technology involved in such systems ranges from the sophisticated to the crude, from engineered systems with filters and pumps to a washing machine draining directly onto oleander bushes.

A permit is technically required to install a graywater system although few people bother. Although ADEQ regulates graywater use in the state, the agency allows counties to issue permits. Any request that involves an exception to what is allowed in the regulations, however, must go directly to ADEQ for consideration. Some observers believe this splitting of regulatory authority for graywater use adds undue complicates the process of obtaining a permit.

The main concern of regulations is that graywater use will result in water quality problems and pose a threat to public health. Regulations prohibit graywater systems from being connected to potable water systems and do not allow surface applications of graywater. Instead graywater must be released below the surface, as underground landscape irrigation, to prevent human contact with it. Many advocates claim the regulations are needlessly complex, and the expense is a deterrent to graywater use.

Despite regulatory requirements estimates indicate that there are several thousand graywater systems in the metropolitan area, and virtually none are permitted. Some residents merely drain their washing machines to water their shrubs or trees.

Some researchers question whether graywater really poses a significant health risk. If the health risks are not as high as some fear, graywater might gain more acceptance as a water source, and regulations could be eased.

With an ADWR TAMA Conservation Assistance Grant, the Water Conservation Alliance of Southern Arizona (Water CASA) is conducting a study to determine what health risks, if any, result from the low-tech methods of graywater use now occurring. Water CASA is in the process of analyzing several "wildcat graywater systems," to accurately analyze and evaluate their water quality, soil chemistry and system design. The intent of the study is to raise public awareness, provide information not available elsewhere regarding graywater quality

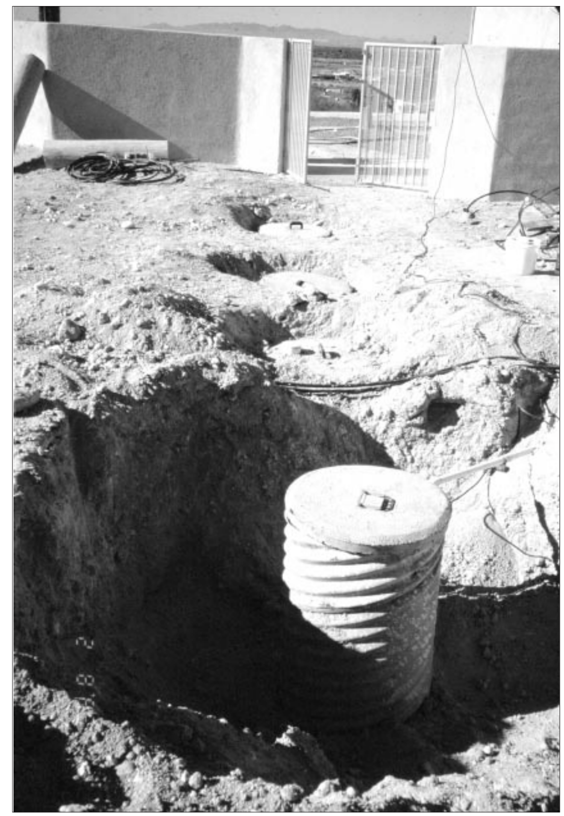


Figure 3-14 Cistern installed as part of a graywater reuse system. Photo: Val Little.

and its effect on soil, collect data on actual, feasible residential graywater system design and determine the potential graywater has to increase water use efficiency.

Water Harvesting

Rainwater harvesting is collecting rainfall to meet water needs. A rainwater harvesting system concentrates and collects rain falling on house roofs and grounds for direct use and storage.

Water is collected or harvested from concrete patios, driveways and other paved areas. Also harvested is the flow from the roof and from catchments such as gutters. Houses can be designed to maximize the amount of catchment area, thereby increasing rainwater harvesting possibilities. For example, at Casa del Agua, 600 square feet of additional catchment area was added to the porch and greenhouse roof to maximize runoff. This additional surface increased the amount of collected annual rainfall by more than 3,700 gallons. Downspouts are located about every 20 feet along the gutter, instead of the more common 40 feet. This ensured that heavy rains were not likely to overflow the gutter and instead would flow to catchments.

Collected and stored rainwater can be used for evaporative cooling, toilet flushing, car washing, chlorinated swimming pools, and surface irrigation, especially in food gardens. In the United States harvested rainfall mostly is used for irrigation, with limited other domestic uses. At Casa del Agua, where the landscape was almost entirely irrigated by graywater, rainwater primarily was used in the evaporative cooler, with a limited amount used for toilet flushing. Casa del Agua's rainwater storage capacity was about 8,000 gallons.

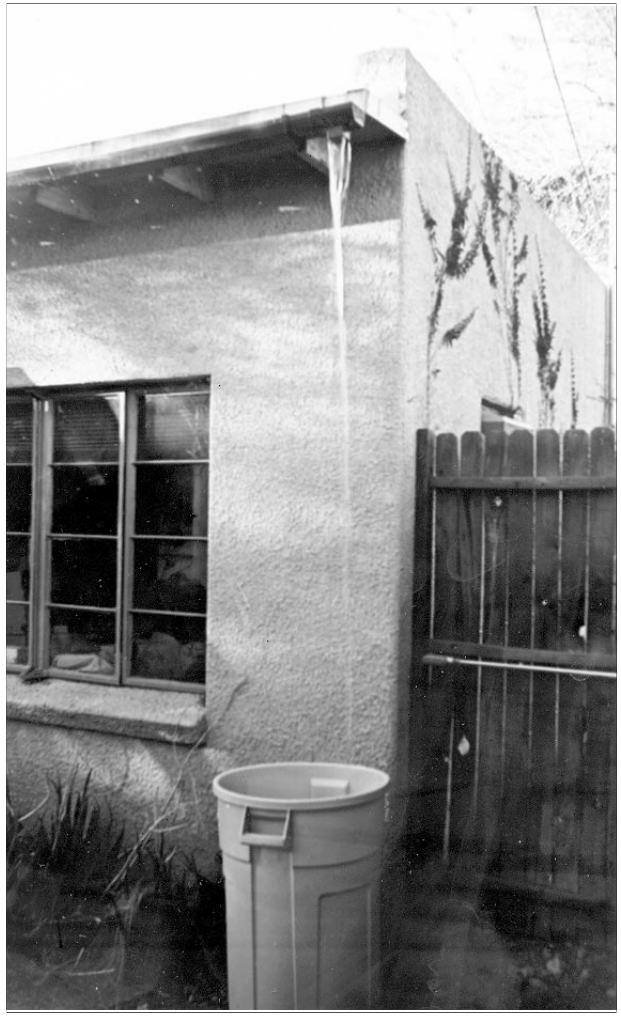


Figure 3-15 A do-it-yourself water harvesting system collects rain from roof for use to irrigate a home garden. Photo: Barbara Tellman.

Rainwater harvesting systems vary from the simple and inexpensive to the complex and very costly. Directing rainfall to plants located at contoured low points is a very simple rainwater harvesting system. No rain escapes property boundaries. More complex rainwater harvesting systems include water storage.

Rainwater harvesting is an everyman's water augmentation method. Any container capable of holding rain dripping from roof or patio can be a rainwater harvesting system, but may also breed mosquitoes unless kept covered. A plastic garbage barrel is sufficient. Sturdier and more elegant containers create a more pleasing effect and some are built using backyard technology, such as small ferro cement tanks collecting water at the base of down spouts. The least expensive rainwater storage system uses an above-ground swimming pool, with a lid or cover to reduce evaporation. Rainwater then can be stored for about .07 cents per gallon.

Harvested rain raises some water quality concerns. Rain in certain urban areas may contain various impurities absorbed from the atmosphere, including arsenic and lead. Certain desert conditions also can cause rainwater quality concerns. Desert rain is infrequent and, therefore, bird droppings, dust and other impurities accumulate between rain events. They then occur in high concentrations in runoff when it does rain. As a result, the quality of harvested rainfall needs frequent monitoring especially if used for potable uses. To confront these problems some systems reject the initial rooftop runoff.

Chapter 4 COPING WITH FLOODWATER

Chapter Four discusses floodwater and its contribution to natural and artificial streambed recharge. A heavy rain can cause problems but also is an important part of the renewable water supply picture. Since rivers in the area are very different than they were 150 years ago, floods and natural recharge occur differently now than in the past. Increased urbanization, use of flood control structures, natural recharge and artificial recharge are interrelated issues that need careful consideration. Water quality problems can arise when urban runoff carries various pollutants from paved areas to riverbeds; some of the runoff could then enter the groundwater and become part of Tucson's water supply.

FLOODING, THEN AND NOW

What is a flood? According to Webster's dictionary, a flood occurs when water overflows onto normally dry land. In this arid region the term often is used to describe a situation when an unusual amount of water flows in usually dry rivers, whether or not it overflows the banks. In Arizona an unusual amount of water flowing in a river with sufficient force to erode its banks is almost invariably referred to as a flood.

Floods provide both benefits and problems. Floods can be beneficial when they recharge groundwater, but the same flow also can damage buildings and roads, erode land, and carry pollutants that may reach the groundwater.

Years of bountiful rain and snow alternate with years of little precipitation. Heavy river flows occur occasionally and are essential for the growth of riparian vegetation. During flood years new cottonwood seedlings sprout and take hold. Traditional farming took advantage of the summer rainy season when water overflowed river banks bringing both moisture and nutrients to the soils. River flows replenished the groundwater table that remained near the surface. The water table was sufficiently high along most of the Santa Cruz River, from San Xavier to the Cañada del Oro, that cottonwood forests thrived. Such forests also were located along parts of the Rillito Creek, Tanque Verde Wash and Pantano Wash. A giant mesquite bosque flourished south of San Xavier.

Changed river conditions have destroyed much of this riparian habitat, and developing new riparian habitat would be a difficult challenge, even using CAP water and effluent. Some even argue that conditions have deteriorated to the point that many riparian areas are beyond restoration. Construction along riverbanks and flood control structures have radically changed natural river conditions. Instead of meandering and spreading out onto floodplains to benefit riparian vegetation, floods now often are contained within deep channels.

Figure 4-1 Observers watching the 1983 flooding of the Santa Cruz River in area just north of St. Mary's bridge. Photo: Peter Kresan©

***Figure 4-2 The 1983 flood destroyed homes along the Rillito Creek at First Avenue. Photo: Peter Kresan*.©**

The occurrence and intensity of flooding in southern Arizona appears to have increased during the last 30 years. While periodic changes in weather affect floods to a degree, human factors have played a greater role in determining flood damage. Floods that occur in wilderness areas are hardly noticed because humans usually are not affected. Floods that occur in urban areas, however, can affect large numbers of people and thus attract attention.

Urbanization is an important factor to consider when assessing the intensity of floods in Arizona. As Tucson has grown, much of the natural land surface of the area has been graded and covered with impervious surfaces – buildings, roads, sidewalks, parking lots, etc. – increasing runoff. In a natural desert environment only about three percent of the rainfall reaches the washes. In an urbanized area, about 18 percent of the rainfall flows to washes. The additional water in rivers and washes means that downstream flows increase in quantity and velocity. Channels enlarge, becoming deeper and wider, with erosion posing a greater threat.

As Tucson urbanized, flooding became more menacing. Along their urban reaches, the Rillito Creek and Santa Cruz River have become deeply incised, with their channel bottoms as much as 40 feet below their banks. Waters no longer overflow the banks as they did when the rivers were shallow streams. Meanwhile homes and businesses have been constructed along river banks in the belief they are safe from floods. In reality, however, many areas become subject to bank erosion that can threaten structures. Soils that are dry most of the year quickly break up when water flows swiftly against them. Erosion is most likely to occur on bends in the river where water flows swiftly towards the bend, striking it with great force. In the 1983 flood, for example, bank erosion caused buildings to fall into the Santa Cruz River south of Ajo Way and into the Rillito Creek near First Avenue (See Figure 4-2).

Some natural resource managers stress that floods, although now influenced by human activities, are natural and often beneficial occurrences, neither bad nor dangerous. Humans, however, have put themselves in harm's way, by building on floodplains and encroaching on flood-prone areas. Floods then threaten human life and property and are perceived to be an intimidating menace to be confronted with administrative and technical ingenuity. In response, public officials devise and implement flood control measures to protect life and property. Measures that are adopted to control flooding, however, often have unintended consequences.

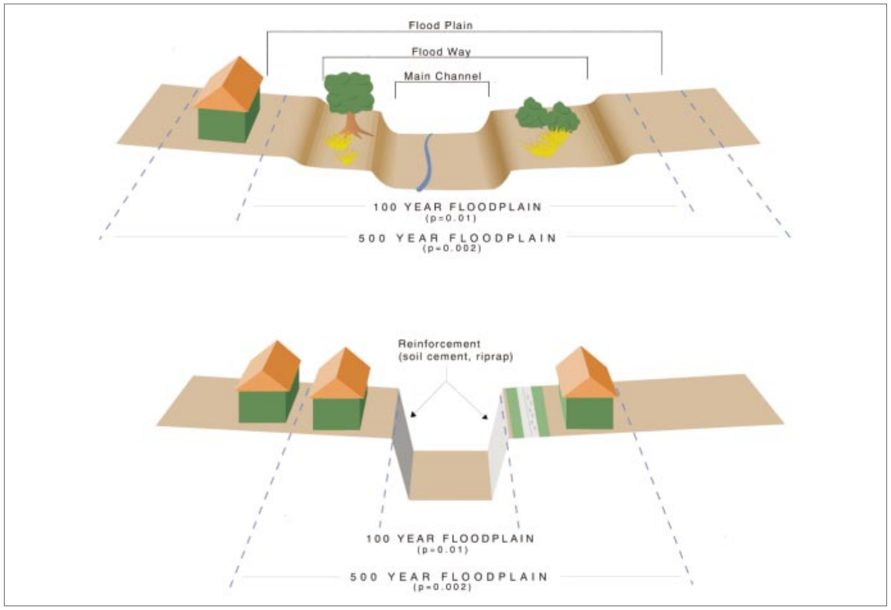
COPING WITH FLOOD HAZARDS

A comprehensive approach to flood management may encompass physical structures to protect bridges and other facilities, programs and ordinances to regulate the use of floodplains and purchases of flood prone land.

Structural Strategies

A structural approach consists of physical modifications to adjust and change the flow of floodwaters. For example, stormwater often was considered best managed and controlled if made to flow expeditiously from an area. Structural methods were adopted to widen, straighten and channelize waterways in efforts to reduce damage. Structural methods included such measures as levees, channel stabilization and storage reservoirs. These methods often

Figure 4-3 Effects of bank protection on a riverbed.



were applied to prevent bank erosion, Tucson's priority flood damage problem.

Between the 1950s and the 1970s, vegetation was often removed from channels that would then usually be straightened and coated with concrete. This was done to quickly direct water from an area. Examples of this approach can be seen at Kino Boulevard south of Broadway and at 12thth Avenue south of I-10. This operation protects the immediate area, but is liable to increase the rate of flow downstream, causing greater downstream damage. Channels subject to this procedure are not suitable recharge sites.

Starting in the 1970s, Pima County adopted a new technique and stabilized river banks with soil cement along the Santa Cruz River and Rillito Creek. (See Figure 4-5.) Soil cement is made from a mixture of cement and river soil and is applied to the banks of a channel. In some areas, large rocks are held in place along banks with wire meshing, to stabilize the banks. Called rip-rap, this construction needs regular maintenance to prevent it from deteriorating and being washed away. Both of these methods allow for recharge in the channel bottom, but not along the previous floodplain.

Such structural methods for controlling floods may successfully resolve a local concern but may result in other flood-related problems downstream. For example, with bank stabilization in place, erosion may be controlled and even eliminated along a stretch of a waterway. More runoff, however, then flows downstream with greater force, resulting in increased erosion of banks and, therefore, greater downstream flood damage. Also, the force of the water flow may move the site of natural recharge to downstream areas where it may not benefit major wells.

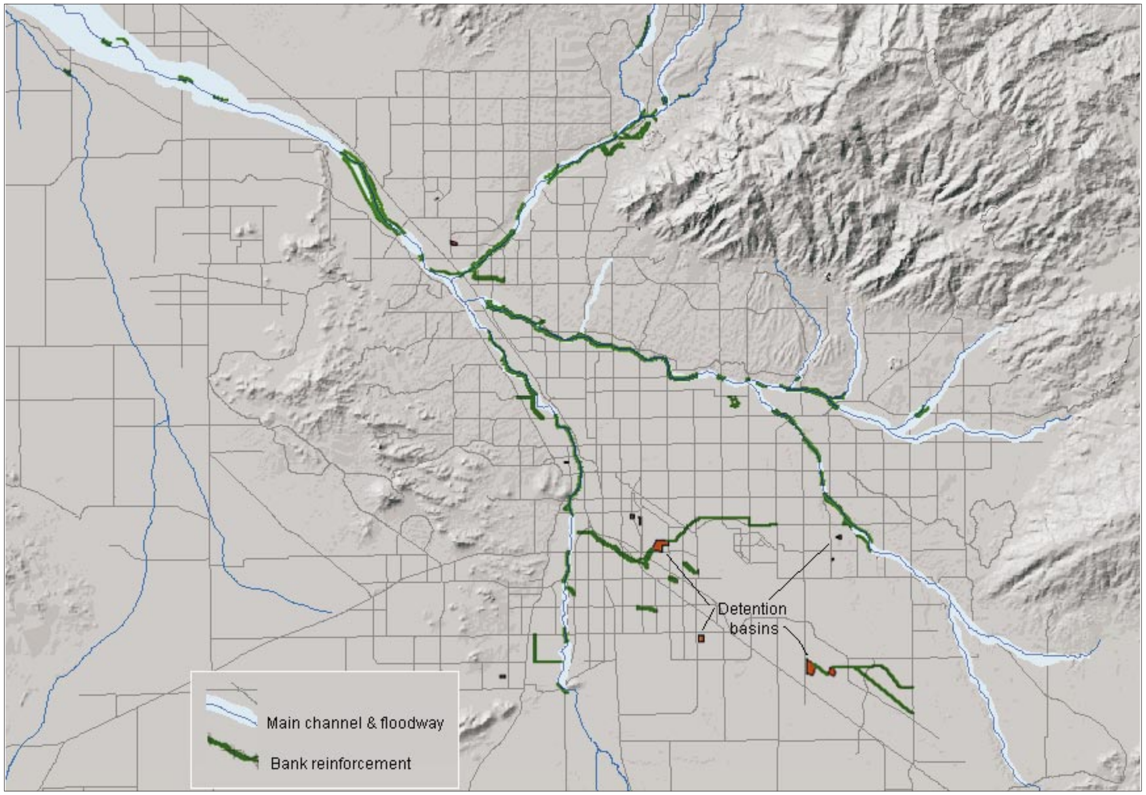
Nonstructural Measures

As the result of above-mentioned concerns – many of which are now the focus of political debate – flood control strategies that rely on nonstructural methods have grown in importance. Such methods avoid physical modifications of the environment and instead maintain the natural conditions of river channels. Nonstructural measures generally encourage society to adapt to natural flood conditions when occupying or modifying a floodplain.

Floodplain management is the full range of codes, ordinances and other regulations adopted for minimizing flood damage, including zoning codes, building codes and subdivision regulations that may either prohibit

Figure 4-4 Bank stabilization structure under construction west of Campbell Avenue. Photo: Peter Kresan.©

Figure 4-5 Main floodway and bank reinforcement.



Sources:Tucson Water; Pima County Technical Services.

construction in flood-prone areas or allow some construction under certain conditions. Floodplain regulations also may be enacted to prevent consumer fraud by requiring disclosure of possible flood hazards. It can also include flood forecasting, information and education, disaster preparedness and assistance, warning systems, evacuation, flood insurance and floodproofing.

Arizona law requires cities and counties to have flood management programs. Both Tucson and Pima County, however, go further than the state requires and have ordinances to encourage leaving floodplains as natural as possible, including the use of native vegetation. The Federal Emergency Management Agency (FEMA) requires communities to adopt approved floodplain maps and to regulate use of the identified floodplains for residents to qualify for flood insurance. EPA requires management of urban stormwater to minimize pollution, and both Tucson and Pima County have approved stormwater management plans. A full discussion of these requirements is beyond the scope of this report, although some additional information is contained in Chapter 7.

Floodplain Acquisition Since the 1980s Pima County has actively acquired flood-prone lands to keep them from being developed in order to minimize downstream flood problems and reduce flood rescue costs. These areas can then be used for open space recreation and wildlife habitat. Cienega Creek, a perennial stream south of Saguaro National Park East, is a prime example of this approach. Pima County owns a portion, and most of the upstream area is also public land under ownership of the U.S. Bureau of Land Management and the U.S. Forest Service. Tucson and Pima County also have acquired flood-prone lands and developed linear parks, often in cooperation. Much of the land along the Santa Cruz River, both upstream and downstream of the downtown area, is now in public ownership and used as a linear park. The City of Tucson's Multiple Benefit Water Projects propose ways of using CAP water to develop areas along the Santa Cruz River for wildlife habitat and recreational purposes.

Tucson's Stormwater Master Plan

A watershed is a geographic area defined by the flow and movement of surface water, with all flow feeding one watercourse. The Colorado

River watershed is made of many smaller watersheds, including the Gila River watershed, which in turn is made up of many smaller ones, including the Santa Cruz River watershed. Encompassing the flow of runoff within an area, a watershed is a hydrologically appropriate unit to determine the management of stormwater. Without such an approach, land use policies upstream may not be coordinated with the principles for managing stormwater runoff downstream.

The City of Tucson's Stormwater Master Plan is an ongoing effort to develop a comprehensive stormwater management plan with a regional, watershed focus. A comprehensive program covering an entire watershed provides a much more favorable basis to plan present and future runoff management needs. A "system" or watershed approach also enables the city to minimize its reliance on structural stormwater control solutions and better preserve and enhance natural water courses.

To help accomplish its goal, the master plan has identified 59 urban watersheds within six general hydrologic units or areas with similar geographic and hydrologic characteristics, all located within Tucson. In this context, a watershed is defined as a geographical area which contributes stormwater runoff to a particular point.

During Phase II of the stormwater study a database was established that included information on the physical characteristics of the drainage systems in each of the city's 59 watersheds. The study established a prioritization scheme to identify how individual watersheds ranked with regards to the potential for stormwater quality problems. Watersheds were examined by looking at human and natural considerations affecting them. Factors considered include estimated contaminant loadings, locations and extent of industrial and commercial areas as well as the existence of riparian areas.

Figure 4-6 Floods damage the Ina Road Bridge. Photo: Peter Kresan.©

Santa Cruz River Watershed Basin Project

An ongoing Santa Cruz River Watershed Basin study is addressing flooding and other issues. The Santa Cruz River watershed covers approximately 8,600 square miles in Southern Arizona. The watershed study is concentrating on the portion of the Santa Cruz River system within Pima County.

The intent of the project is to address a cluster of public concerns including environmental resources, floodplain management, regulatory activities, erosion control, wastewater management, groundwater management and flood control. The goal of the study is to develop a basin management plan for the Santa Cruz River system. This plan is to guide future projects attempting to balance watershed concerns of environmental protection/restoration and economic development. Projected benefits of the project include a flood control river plan; land-use and regulatory tools for balancing competing uses; a protection and management guide for existing and future riparian areas; a river maintenance guide to maintaining flood conveyance and storage capacity while protecting environmental resources; and water quality identification and recharge opportunities.

The U.S. Army Corps of Engineers is conducting the study, with the involvement of state, county, city and other federal agencies, San Xavier District of the Tohono O'odham Nation, International Boundary and Water Commission and various public and private interest groups. The study is expected to cost $2 million, to be shared between federal and non-federal partners, and to be completed January 2000.

CAPTURING RIVER FLOW

For many years people have looked for ways to keep more river water in the area, rather than letting it flow downstream to Pinal County. They noted the construction of dams along the Salt River which retain water in reservoirs to be released for later use. A major difference between the Santa Cruz watershed and the Salt River watershed, however, is that no practical sites for large storage dams are located along the Santa Cruz River or its tributaries.

In recent years, the U.S. Bureau of Reclamation, the U.S. Army Corps of Engineers and Pima County have looked at the feasibility of using inflatable dams to detain water temporarily so that it will infiltrate the riverbed and seep underground. Inflated to capture runoff, the dams can be deflated when major flooding could pose a threat to the structure. So far no project has been built.

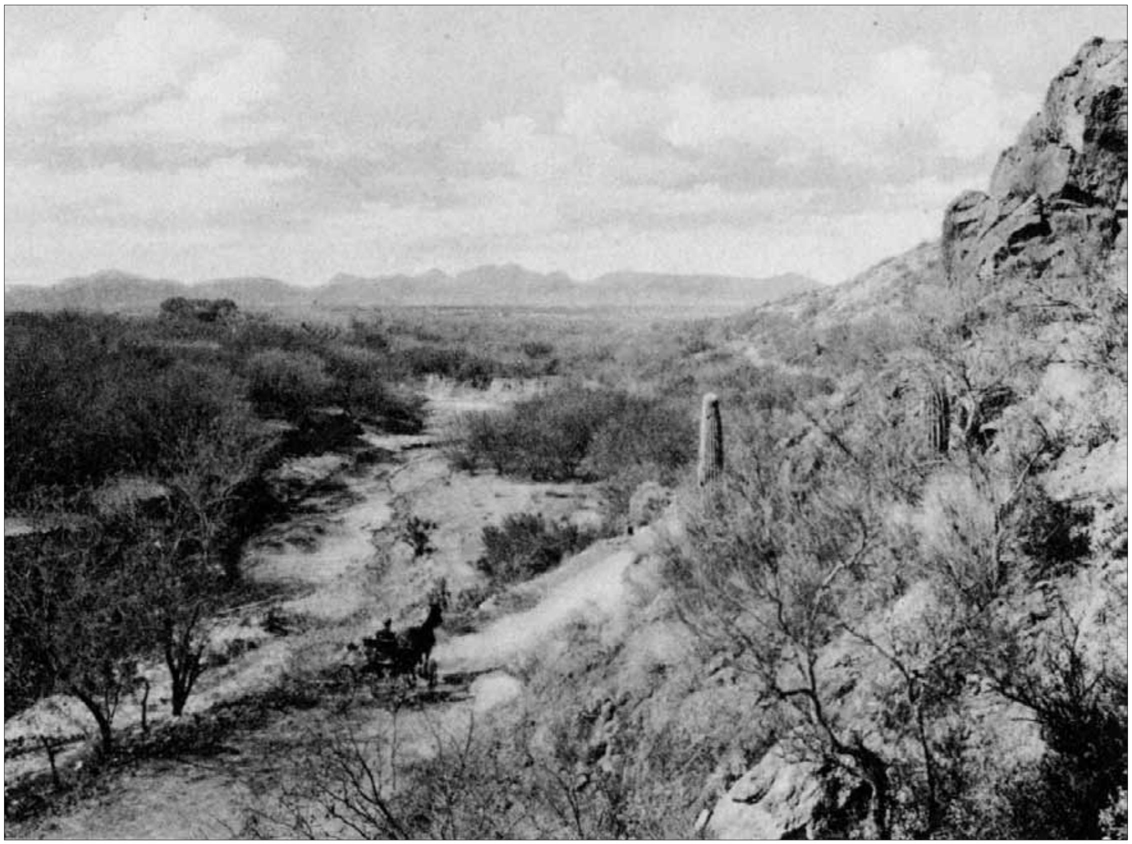


Figure 4-7 A view towards the Santa Rita Mountains around 1900, showing the Santa Cruz River and part of its watershed. Source: Tucson Souvenir Portfolio about 1904.

Artificial Instream Recharge

Artificial recharge is discussed in Chapter 3. In this section we look at the possible impacts of instream recharge projects on rivers. Many people view streambeds as ideal locations for artificial recharge since streambeds generally provide the best sites for natural recharge. Artificial recharge in riverbeds may even be seen as recreating historic conditions of river flow. While streambed recharge has many benefits, projects must be carefully designed so that they do not lead to increased flood problems downstream. If the river is already flowing at the time of a large flood event, flood impacts may increase, depending on the quantity of the cumulative flow.

If the flood event occurs when the channel alluvium and basin fill are saturated with water, mounding of recharge water may cause less storm water to infiltrate in the area of the recharge project and more recharge to occur downstream instead. In some cases it will occur out of the range of the major wells. Streambed recharge projects also may increase vegetation in the channels as a result of more available soil moisture. This vegetation could increase the risk of flood damage because it reduces the amount of water that the stream channel can carry. This vegetation, however, also can have many advantages from an aesthetic point of view, as wildlife habitat and for recreational use.

The issues are obviously complex, and proposed artificial recharge projects should be carefully studied both for their recharge potential and for their impacts on flooding. Each instream recharge project must be evaluated individually, since conditions vary so much from site to site that no generalizations about the impacts of recharge on flooding will apply to all situations.

WATER QUALITY

The variety of solutions to flooding problems has improved flood and erosion protection in many areas, but also has affected recharge in rivers. Before urbanization, flood waters spread out over a broad area and moved slowly downstream. This enhanced natural recharge, with more flood waters reaching the aquifer. With waters now often confined within rigid, usually impervious channel walls, much of the water moves swiftly downstream without recharging.

Also, more of the desert area now is covered with roads, parking areas, and buildings constructed on land where water once soaked into the soil. Impervious surfaces generally cover approximately 20 percent of a suburban watershed area which usually has two houses or less per acre. In a highly urban watershed impervious surfaces cover approximately 70 percent or more of the surface area. Highly urban watersheds contain six or more houses per acre, and include commercial, industrial and multiple dwelling uses, with extensive drainage improvements.

Flowing rapidly and temporarily flooding streets, this water can pick up a wide variety of pollutants, carrying them to rivers. Because of infrequent rains, oil tends to build up on Tucson streets. During the first big storms of summer, Tucson streets tend to be slippery from this oil that flows with the flood waters. More auto accidents occur at this time than later in the rainy season when the streets have been partially cleansed by flowing water. More information is needed to determine whether pollutants in stormwater runoff have a significant impact on groundwater quality.

Because of the various urban conditions, less recharge occurs during big storms than would occur if conditions were more natural. Not only is water that could possibly be recharged leaving the area, but some of the stormwater that does recharge may be polluted from urban conditions. Old landfills located along river channels can be the source of further pollution entering the groundwater during flooding.

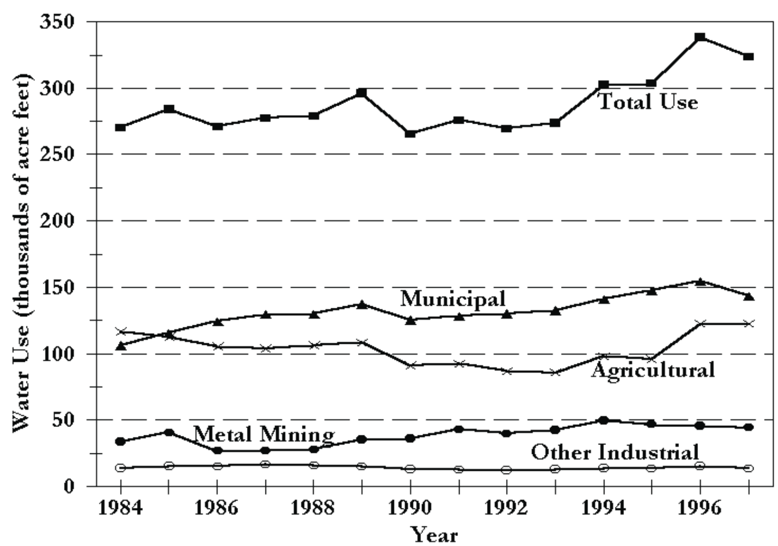
Chapter 5
THE MANY USES OF WATER

In a complex society water use is varied, from municipal and agricultural to mining and other industrial uses. This chapter discusses these broad categories of water use, describing activities that are included within each category. For example, municipal water use includes diverse activities, from plant watering to toilet flushing. Data are provided to show how much water is consumed by various types of water users. The cost of water also is discussed since cost is an important consideration when analyzing water use. Each section ends with possible ways to reduce water use.

WATER USES

Water is used for many purposes, including growing crops, producing copper, generating electricity, watering lawns, keeping clean, drinking and recreation. Balancing the water budget comes down to increasing the supply and/or decreasing the demand. In Chapter 3 we discussed the supply side of the water budget. Reducing demand involves reducing how much water each person uses, limiting the number of people using water (or slowing the rate of growth), and/or replacing some uses with other uses. To understand what these choices are, we must first understand how water has been used in the past and how it is used today.

Figure 5-1 Annual water use by sector, Tucson AMA.



Source: Arizona Department of Water Resources, 1984 - 1997 Annual Withdrawal and Use Summary, Tucson AMA.

There are three major groups of water users: homes and businesses, agricultural interests, and industry (including mining). The increase in municipal water use during the 1980s was offset by decreasing agricultural use, with total water use in the Tucson area holding steady during this period at about 275,000 acre-feet. (See Figure 5-1.) Agricultural use has risen since 1993. That, coupled with rising municipal use, pushed total water use to 323,000 acre-feet by 1997.

Agriculture has historically consumed the largest share of water of any sector in the Tucson area. After reaching a plateau between 1955 and 1975, however, agricultural water use declined during the 1980s and early 1990s. Municipal water use has increased since 1984 as the population has grown – both in total acre-feet used and in percentage of total water use, and now consumes a larger share than does agriculture.

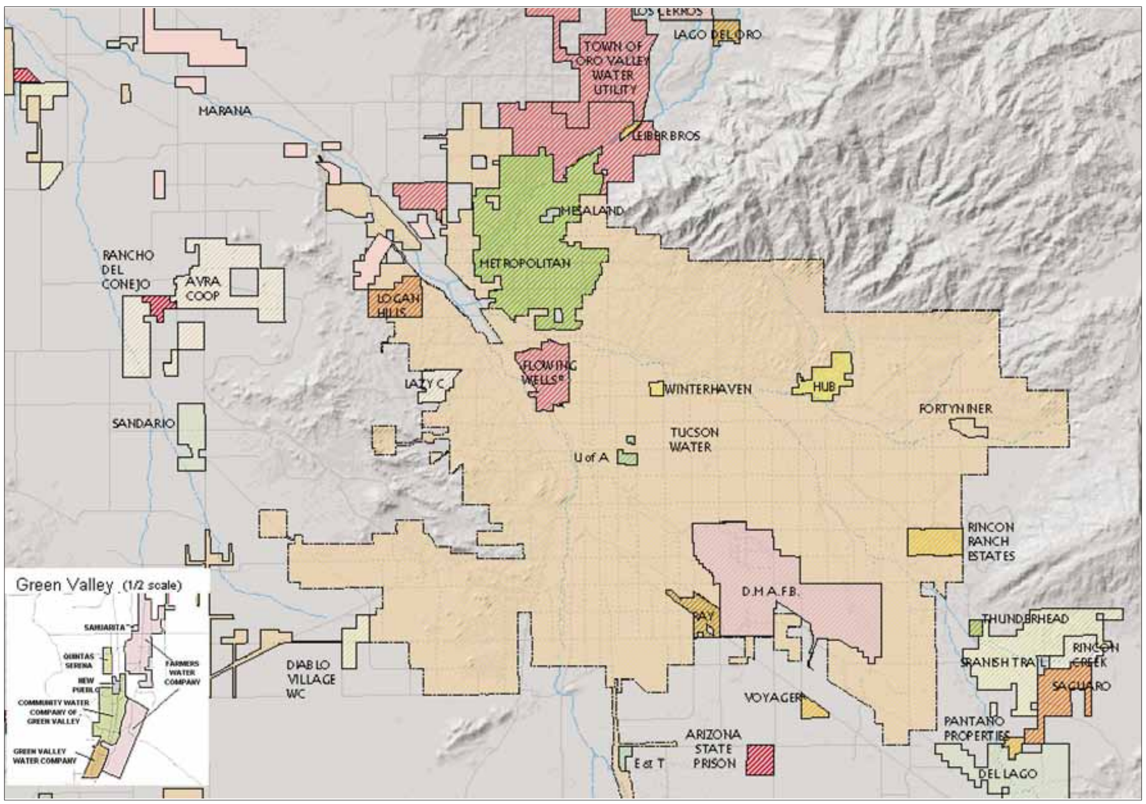
MUNICIPAL WATER USE

Population growth has caused municipal water use to be the fastest growing water use sector. Total municipal water use in the Tucson Active Management Area (TAMA) increased from approximately 116,000 acre-feet in 1985 to about 154,000 acre-feet in 1997.

One hundred and fifty-one municipal water providers operate in the Tucson area. Of this number, 19 large providers serve over 96 percent of total municipal demand. The service areas of the major water providers are shown in Figure 5-2. See Appendix B for a complete list of municipal water providers and number of customers served.

Tucson Water is by far the largest municipal provider in TAMA, serving approximately 75 percent of total municipal demand. Approximately 40 percent of the population served by Tucson Water resides outside of the city limits, mostly in unincorporated areas of Pima County. Tucson Water's service area is projected to continue to grow, but the rate of growth has been slow. Metropolitan Domestic Water Improvement District (Metro Water) serves the next largest population. Other water providers closer to the edges of the Tucson metropolitan area, such as Oro Valley, Avra Water, and Metro Water, tend to be the fastest growing. Rapidly growing service areas generally are areas of rapid population growth and newer homes. These homes are likely to have water-saving fixtures and smaller yards, but are also more likely to have certain water consumptive facilities such as swimming pools.

Figure 5-2 Municipal water provider service areas.



Sources: Pima County Technical Services, Arizona Department of Water Resources, Water CASA.

TYPES OF MUNICIPAL WATER USE

Tucson Water's total water usage rate in 1955 was 172 gallons per capita per day (gpcd) including both residential and non-residential customers. It has remained fairly constant since 1985, ranging between 176 and 169 gpcd. Some changes in use relate to different weather conditions. For example, people tend to use more water during hot, dry summers than during relatively cooler, wetter ones. More homes having swimming pools and other water-using features increases water usage while installing low-water use toilets can decrease consumption.

Residential customers (single family and multi-family) are considered municipal water users along with businesses and institutions. Water use characteristics generally differ for each category of demand, with residents consuming most of the water in the municipal category. Residential demand for Tucson Water has remained fairly consistent at about 110 gpcd from 1985 to 1995. The average residential consumption rate for other large providers is higher, averaging about 121 gpcd. A number of factors explain the higher consumption rates of these large providers, including the age of the housing within the service area, the availability and effectiveness of conservation programs, income levels and water rates.

Table 5-1 Selected water providers in the Tucson metropolitan area (1995 data).

WATER PROVIDER	POPULATION SERVED	GROUNDWATER DELIVERIES (af)	RESIDENTIAL GPCD
Tucson Water	559,602	109,927	110
Metro Water	42,861	8,557	148
Oro Valley	23,229	5,707	116
Flowing Wells Irrig. Dist.	14,951	2,842	127
Community Water Company of Green Valley	12,819	2,063	112
Avra Water Co-op	5,663	771	105
Ray Water	4,617	599	106

Residential Use

Single family residents account for approximately 75 percent of residential demand in the Tucson area. Multifamily residential demand makes up the balance. These include apartment complexes, duplexes, triplexes, townhouses and condominiums. Their use is typically about 60 percent of the single family residential use rate. Multifamily complexes use less water per person in part because landscaping is generally limited to common areas, and some water uses occur away from the residence; e.g., apartment dwellers are more likely to use and car washes.

During the 1970s and 1980s new housing construction shifted towards multifamily dwellings. This increased construction of lower water-use housing promised to reduce gpcd rates. This trend, however, did not continue. Economic expansion and much lower mortgage rates caused single family home construction to rebound. In addition, the majority of multifamily units being constructed are more luxurious units which are more likely to have large turf areas, pools and other water-using amenities.

Older homes tend to consume more water both indoors and outdoors than newer homes. They generally use more water outdoors because of larger lots with more turf and landscaping. They use more indoors because they are less likely to have low-water use fixtures such as ultra low flush (ULF) toilets designed to use 1.6 gallons per flush. Homes built after 1975 are less likely to have lawns, and homes built after 1989 are required to have ULF toilets.

Nonresidential Use

Non-residential demand generally consists of turf facilities (golf courses, cemeteries, etc.), water features in public rights-of-way and commercial establishments. Non-residential demand for large providers averaged 41 gpcd in 1995. Tucson Water's non-residential demand decreased by six gpcd from 1985 to 1995. For other large providers, however, non-residential demand increased by 11 gpcd. Tucson Water has been able to reduce its gpcd rate by switching some golf courses and other facilities to effluent. (Although considered water, effluent does not count in the official calculations.) Other large providers are serving an increasing number of golf courses but do not have access to reclaimed water. As a result, their water use appears greater. Some areas served by large municipal providers are experiencing a transition from bedroom communities to areas with more retail and commercial activity, a change that is reflected in their water use.

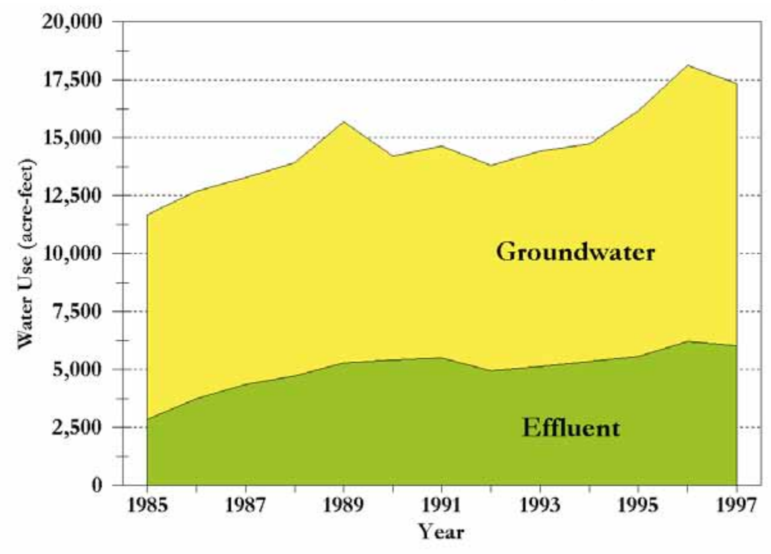
The 35 golf courses in the area account for about ten percent of municipal water use in TAMA. The total amount of water used on TAMA golf courses has increased from 11,700 acre-feet in 1985 to 17,000 acre-feet in 1997. (See Figure 5-3.) Of the total amount of water used on golf courses in TAMA, the share of effluent increased from 24 percent in 1985, peaking at 38 percent in 1990, and has since fallen to 35 percent in 1997.

The number of holes of golf in TAMA has increased by 35 percent since 1985. Golf course design in the area has shifted towards more desert-like courses, incorporating fewer water hazards and significantly more low-water use plants along fairways instead of turf. In addition, the average number of acres of turf per hole has decreased from 5.9 in 1985 to 4.8 in 1997. However, reductions in water use resulting from these changes have been offset by a large increase in the percentage of golf course turf which is overseeded with winter rye grass, from 21 percent in 1985 to 66 percent in 1997. The water use per hole of golf has increased over time since 1985, in part due to variations in weather.

Other large-scale turf facilities include parks, cemeteries and schools. For legal reasons Arizona Department of Water Resources (ADWR) divides turf facilities into industrial and municipal categories according to whether or not they are served by municipal water providers. All these turf facilities use about 20,000 acre-feet of water, about 33 percent of which is effluent. The remainder is groundwater.

Patterns of water use for retail and commercial establishments vary widely, but often include water for sanitary and landscaping needs. The number of employees often is a significant factor in business water use. Partly because water use patterns vary significantly among businesses, water audits tailoring conservation measures to particular needs are an effective strategy for reducing business water use.

Figure 5-3 Water use on Tucson AMA golf courses.



Source: Arizona Department of Water Resources, Tucson AMA.

CONSERVATION RULES

Under the Groundwater Management Act, ADWR sets goals for per capita water use by municipal water providers, but cannot regulate individual customers. Large providers can choose among four water conservation programs. Most often selected is the Total GPCD program, which sets targets for reductions in per capita water use for each water provider based on an analysis of conservation potential for that provider. Tucson Water and Metro Water have selected the non-per capita conservation program; they do not have to meet specific per capita water use targets, but must implement a range of conservation measures. Small providers, which account for four percent of total municipal water use, are regulated differently than large providers. Small providers are required to reduce waste and encourage conservation, but they generally lack the resources to implement conservation programs.

Other ways ADWR tries to balance supply and demand include requiring developers to demonstrate that renewable supplies are available to serve the development; that water use is consistent with TAMA's management plan and goal; and that the developer has the financial capability to construct needed water facilities. These Assured Water Supply (AWS) rules are designed to work with the conservation programs to reduce mining of groundwater.

USE OF RENEWABLE SUPPLIES

Historically, Tucson has been largely dependent on groundwater, a mostly non-renewable supply. In the past twenty years, however, effluent use has increased and CAP water has arrived in the area.

Central Arizona Project

CAP is potentially our largest renewable water source, although the only current direct use of CAP water in the municipal sector occurs for treatment plant maintenance — about 200 acre-feet in 1997. CAP's potential as a water source obviously is not fully realized.

Effluent

Effluent use currently meets about five percent of municipal water demand. Of the 69,400 acre-feet of effluent produced at the Ina Road and Roger Road wastewater treatment plants in 1998, about 13,000 acre-feet was reused, with the rest discharged to the Santa Cruz River channel, where some 96 percent eventually recharges the aquifer within TAMA. Of the amount reused, approximately 1,200 acre-feet was delivered directly to turf facilities and some 3,000 acre-feet was delivered to the Cortaro Marana Irrigation District. This effluent only has secondary treatment and is mostly delivered downstream via gravity.

The City of Tucson processed approximately 8,700 acre-feet of secondary treated effluent at its reclaimed water facilities located next to the Roger Road Wastewater Treatment Facility. This effluent receives further treatment (tertiary treatment) by filtration through sand filters or soil and additional disinfection. The reclaimed water then is delivered for use or is stored at the Sweetwater Underground Storage and Recovery Facility (recharge facility) to meet peak demands in the summer, primarily to irrigate golf courses.

Reclaimed water flows through a different set of pipes, separate from the potable water system. So far, $66 million has been spent building the system, including the reclamation facilities, the recharge facility and the distribution system. Tucson charges $475 per acre-foot for reclaimed water. Full cost for production and distribution of reclaimed water is about $558 per-acre foot, with $323 covering debt service and capital costs and $235 covering operation, maintenance and overhead costs. The price charged for reclaimed water is substantially lower than the wholesale price Tucson Water charges for potable water. This is done to further encourage the use of effluent.

Figure 5-5 shows Tucson's 85-mile reclaimed water system, which has about 200 users. New users pay the cost of connecting to the system. This cost can be quite high, due to the expense of extending pipe to carry the effluent to the new user and modifying the user's delivery system to handle effluent.

Figure 5-4 Treated effluent at a golf course. Photo: Barbara Tellman.

A City of Tucson ordinance requires the use of effluent on new golf courses where possible. Since 1983, all new golf courses served by Tucson Water have been connected to the reclaimed water system. Currently, 12 of 16 courses in the Tucson Water service area are using reclaimed water, and one is using groundwater until effluent can be delivered. The three other courses use water from their own private wells. There is no current authority to prohibit their use of groundwater. Pima County's 1995 zoning code amendments require that all new golf courses use effluent or CAP water for turf-related watering where available. The expense of constructing pipelines usually is the limiting factor. A new ordinance passed in March 1999 requires the use of CAP or effluent at all new golf courses within three miles of a treatment plant or CAP water line. Owners of golf courses outside those areas now have to find a way to recharge CAP water to replace the groundwater they use on golf courses. Attorneys are looking at whether this ordinance also applies to 13 existing golf courses in the county.

ADWR incentives encourage the use of effluent. The most important incentive allows municipal providers to exclude effluent used on golf courses from their gpcd calculations (although the same total amount of water is actually used) which means conservation goals for individual customers can be higher.

Graywater Reuse

Graywater is water recovered after various indoor household uses, excluding toilet use. Graywater includes water from clothes washers, bathroom sinks, showers, baths, dishwashers and sometimes the rinse side of the kitchen sink. A graywater reuse system can be set up to capture and recycle such water for uses not requiring drinking water quality water; e.g., landscape irrigation. Approximately 60 to 65 percent of the wastewater generated from residential indoor use is graywater. The average resident generates an estimated 30 gallons of graywater per day. This is a significant source of water available to meet peak outdoor irrigation demands in the summer.

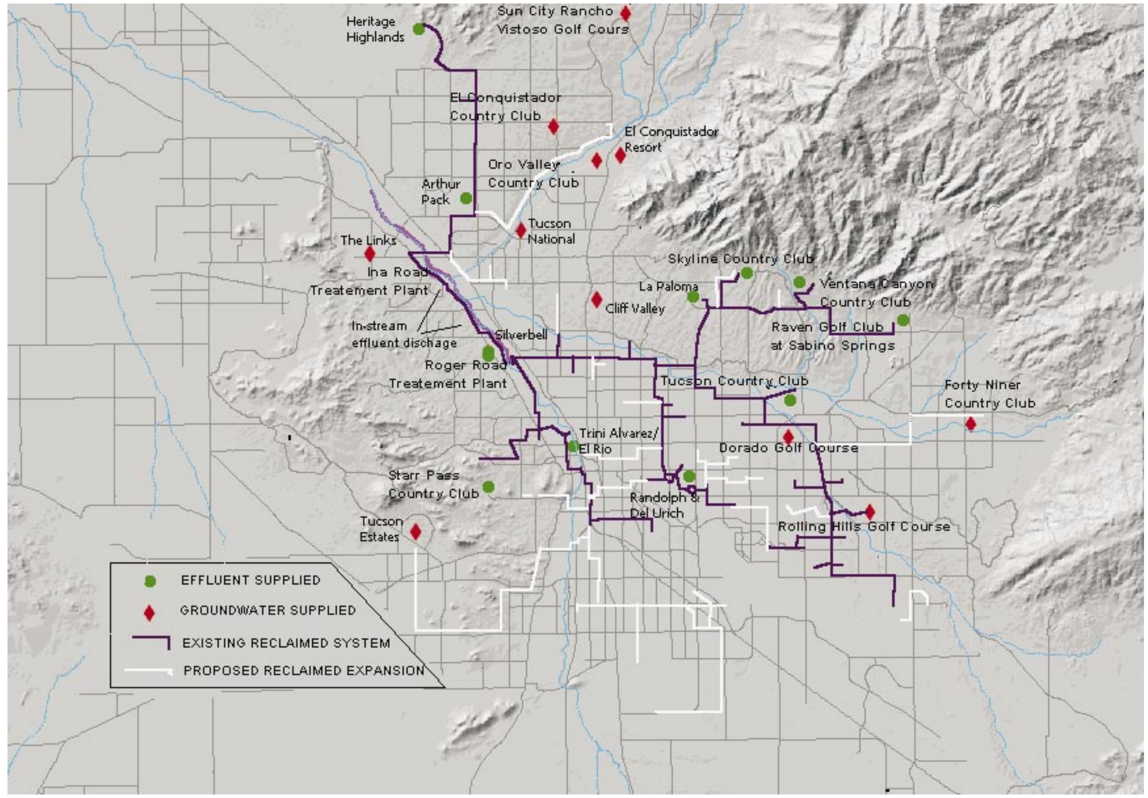
Although graywater use is common in rural areas and has been practiced by many people in urban areas for years, graywater reuse is technically illegal in many places in the United States. Plumbing codes generally require water coming from the drain to be discharged to the sewage system or a septic tank. In Arizona, a permit must be obtained from the Arizona Department of Environmental Quality (ADEQ) or the Pima County Department of Environmental Quality to operate a graywater reuse system. To issue a permit, ADEQ must approve the design and construction of the system. The system must include a settling tank to settle out grit in the water and also must have a filtration device. Water to be applied to the surface of the ground (defined as within two feet of the earth's surface) must be disinfected, meet water quality standards and be monitored. Daily testing of the samples may be required and can be expensive.

Such hurdles to legal use of graywater cause many residents to forego graywater reuse, while others become "wildcat" graywater users, applying it without official approval. A survey of Tucson Water customers in the early 1990s revealed six percent of customers had graywater reuse systems. A more recent survey of Metro Water customers showed that nine percent of households use graywater. Since graywater use is illegal, respondents may be reluctant to admit to its use, and the actual percentage of those reusing graywater may be higher than surveys show.

Concerns about public health are the biggest obstacles in legalizing graywater use. The quality varies depending on how it was used. Water from washing diapers, for example, will probably be more contaminated than water from a shower. Fecal coliform bacteria levels and nitrates have been of particular concern, although the threat is perhaps exaggerated. Salmonella and polio virus have been shown to last several days in graywater. Data accurately characterizing factors that determine graywater quality and assessing risks of use is limited. Studies are needed to develop guidelines for the safe reuse of residential graywater. The Water Conservation Alliance of Southern Arizona (Water CASA), in cooperation with ADWR, ADEQ and Pima County Department of Environmental Quality, is studying residential graywater reuse in Tucson. Study results will help determine if health risks increase with graywater reuse, and whether permitting standards can be loosened.

Graywater reuse has limited potential for helping TAMA reach safe yield. For the 85 to

Figure 5-5 Golf courses and the reclaimed water system.



Sources: Pima County Technical Services, Tucson Water, Arizona Department of Water Resources.

90 percent of homes connected to the central sewage system, water used as graywater does not enter the sewage system to be treated for reuse or discharged to the Santa Cruz River. About 96 percent of the treated water that is released into the Santa Cruz River recharges the aquifer in TAMA. The use of water at a domestic site rather than treated and used someplace else gets us no closer to TAMA-wide safe yield.

However, residential graywater reuse can be an effective tool to better manage our groundwater by matching water quality to the actual quality needed for a particular water use. Residential graywater reuse reduces the demand for groundwater. Less water will then be withdrawn from areas of serious water table declines, such as Tucson's Central Wellfield. Graywater reuse also saves the cost of moving groundwater through the water system, from disinfection to delivery to eventual sewage treatment. Further, a sizeable reduction in the waste stream going to the treatment plant could reduce its operating and capital expenses and delay the need for expanding those facilities.

RESIDENTIAL WATER USE

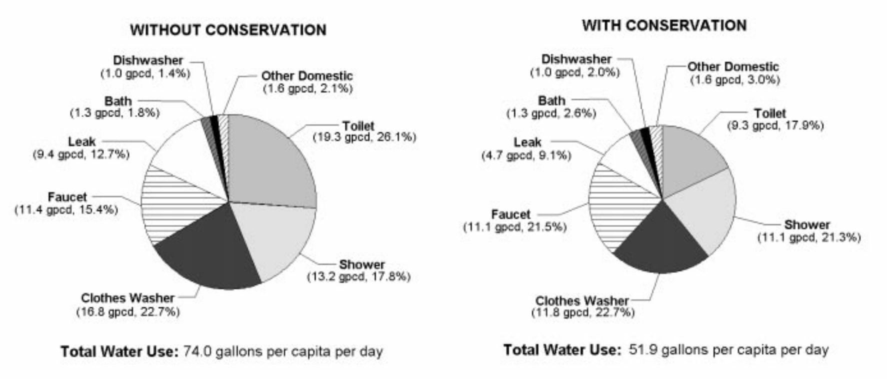
Pima County's population is projected to increase from today's figure of about 836,000 to 1.3 million by the year 2025. Most of that growth is expected to occur in the Tucson metropolitan area. As the population grows, total water use will increase.

If per capita water use rates stay about the same as today, total municipal water demand would increase from 172,900 acre-feet in 2000 to 267,100 acre-feet in 2025. The water saving potential of both new and existing housing must be examined for appropriate ways for a diverse population living in varied housing to conserve water.

Water can be conserved both indoors and outdoors. Most of the water used indoors winds up in a sanitary sewer or septic system. For homes hooked up to the sewer system, water used indoors is re-used or recharges the aquifer. Much of the water used outdoors evaporates and leaves TAMA. Therefore, saving water outdoors has a greater effect on the total water budget for the Tucson area than does saving water indoors. Saving water indoors, however, does reduce the cost of transporting water to the treatment plant and treating it.

It is important to note, however, that given Tucson's projected population growth, no level of water conservation, even if involving all types of water users, will be sufficient to ensure a balanced water budget.

Figure 5-6 Typical single family home indoor water use.



Source: Data are a copyright of the American Water Works Association and were compiled for WaterWiser, www.waterwiser.org, by John Olaf Water Resources Management.

Indoor Water Use

Indoor uses remain fairly constant throughout the year. People may wash more clothes in the summer, but in the winter the bulk of clothes washed is greater. Similarly, other indoor water uses vary little during the course of the year. This constancy is reflected in relatively flat levels of sewage water flow.

Figure 5-6 shows that the largest indoor uses of water are toilets, showers and baths, and washing machines in all types of housing. Newer models of toilets are designed to use less water than older models. Until the early 1980s, most new toilets used five to seven gallons per flush. Water-conserving 3.5 gallons per flush toilets were the standard until the early 1990s when 1.6-gallon ultra low flush () toilets became available. In 1989, both Tucson and County adopted ordinances requiring installation of ULF toilets in new construction.

Replacing older toilets with ULF toilets is one of the best ways to save water indoors. ULF toilet savings do not require a change in behavior and, if the toilet continues to function properly, will effectively save water. However, while many models of ULF toilets function very well, recent anecdotal evidence indicates that some models of ULF toilets deteriorate over time. Further, replacement parts are not readily available for some models, forcing homeowners to find alternative parts that can negate the water saving feature of the toilet. Other people continue to use ULF toilets without making repairs; this also results in less water savings. The University of Arizona's Water Resources Research Center is conducting a study to identify the extent of this problem and to determine which models of ULF toilet have not held up over time. This information can be used to rewrite plumbing codes, upgrade ULF toilet quality, and make the correct replacement parts easier to obtain.

Toilet dams and other water displacement devices can help save water in older model toilets. Toilet dams, which are placed in the tank to keep water from fully filling the tank, typically save about one gallon per flush. Water-filled bags or plastic bottles also can be used in place of dams and typically save about the same amount.

Showers and baths are another large component of indoor water use. Showers and baths typically comprise about 20 to 25 percent of total indoor water use in older homes. Low-flow shower heads also can save water. Older shower heads typically use 3.5 gallons per minute (gpm), while low-flow shower heads typically use 2.5 gpm or less.

Clothes washers typically account for between 20 and 25 percent of indoor water use. Clothes washers vary widely in their water use. Older models used about 55 gallons per load, while more water-efficient models use around 42 gallons per load. Newer, more efficient models, including horizontal axis machines, use about 30 gallons per load.

Faucet use typically accounts for around 15 to 20 percent of indoor use. Faucet aerators reduce some water use by introducing more air into the stream, thereby increasing the water's wetting action. This can save approximately one gpm over older 3.5 gpm faucets. Other faucet uses, such as filling a glass or teapot, are unaffected by aerators.

Leaks average approximately 10 percent of indoor water use. Inspection of the home for leaks as part of a water audit is often an effective way to save water. Tucson Water offers free leak detection as part of its Zanjero Program, which provides customers an analysis of the water use in their home, and information on how to lower their water use and water bills.

Figure 5-7 Water is saved when a landscape consists of desert, drought-tolerant vegetation. Photo: Barbara Tellman.

Outdoor Water Use

In the Tucson area, single family residents use 30 to 50 percent of their water outdoors, for landscape watering, swimming pools, spas, evaporative cooling and other such uses. Outdoor water use varies over the year. In the summer before the monsoon rains starts, outdoor water use peaks as plants require more water to survive and evaporation from pools is at its greatest. In the winter, outdoor water use drops dramatically, especially during the winter rainy season from January through March. Bermuda grass is dormant during this season, and only about seven percent of landscapes have winter rye grass lawns.

Peak summer water use can be up to twice winter water use. Beat the Peak, the water conservation campaign created by Tucson Water after the 1975-76 water controversy, was designed to help cut peak consumption. Water providers must design their distribution systems to meet peak demand and allow enough reserve supply for fire fighting. If peak demand is reduced, costs are reduced. A benefit is that lower peak demand has generally also meant lower total water use.

Landscape irrigation is the largest category of outdoor water demand. Most landscaping in Tucson combines grass with desert plants. A 1992 random survey of Tucson Water customers found that about 43 percent of respondents had some grass in their landscaping. Eight percent of residents reported their landscaping was mostly grass while the other 35 percent had landscapes combining turf area with other plant materials.

Since the late 1940s, the percent of new homes with lawns has generally been declining in Tucson. A 1983 random survey revealed that about half of the homes built prior to World War II had lawns. The percentage of homes with lawns declined gradually though the mid-1970s, and then declined steeply about the time of the 1975-76 water crisis in Tucson. Most evidence indicates that roughly 20 percent of homes built in the late 1980s and early 1990s have lawns.

Lawns are rarely removed once they are installed. Converting lawns to desert landscaping, however, became more common in the late 1970s and early 1980s. A sample of Tucson households in 1979 showed that up to 20 percent of households surveyed had removed their front lawns, while 15 percent had removed their backyard lawns between 1976 and 1979. This compares to essentially no lawn removal in the several years before the crisis. Average lawn size also has declined from a peak of about 2,000 square feet for homes built around 1960 to around 600-800 square feet for homes built since the mid-1980s.

Relying on a garden hose to water vegetation is the most prevalent form of irrigation in Tucson. Drip irrigation is the second most common method of irrigation and has gained significantly in popularity since the early 1980s. At that time, one percent of households had drip, compared to approximately 27 percent of households in the early 1990s. Approximately 22 percent of Tucson Water service area households reported having in-ground irrigation systems in the early 1990s. About eight percent of homes surveyed in the early 1990s did not irrigate their landscaping at all.

Which irrigation system is most efficient is unclear. Management of the system is as important as the system hardware. Drip systems and in-ground turf irrigation systems can be put on timers and programmed to deliver the right amount of water when needed. But timers need to be reset to adjust to changing seasons and large rain events. Too often such adjustments are not made. In such instances, hand watering with a hose could be more efficient. Deep, infrequent irrigation of mature landscape plants is more efficient than frequent, shallow irrigation.

Swimming pools are less common than lawns in Tucson, but the percentage of homes with swimming pools has been increasing over time. A swimming pool typically uses three to five times as much water as the same area of turf. This is due in part to the fact that most private lawns are under-irrigated, and pool consumption includes not only evaporation but also filter back flushing and occasional draining for maintenance.

As is shown in Figure 5-8, the percentage of Tucson homes with pools is a function of when the home was built, increasing from

XERISCAPING

Xeriscaping is using efficient landscape design and lower water use vegetation to create attractive landscapes — and equally important, to save water. The word “xeriscape” combines the Greek word “xeros”, meaning dry, with “scape” from “landscape.” Xeriscaping principles make use of “micro-climates” that exist in the landscape. Micro-climates are defined according to the amount of sun and shade, the slope, and air movement that characterize a landscape.

The property is divided into low, medium and high water use areas, with the highest water use areas close to the house, in areas with the most shade. These are cooler areas, and xeriscaping would limit turf to these areas. Drought-tolerant plants and native vegetation are used in low water use zones to provide attractive landscape with a variety of colorful and interesting plants.

Water harvesting techniques might be applied to capture and store rainwater for use on plants or to channel runoff directly to vegetation. Drip irrigation can be installed to water individual plants, while sprinkler systems are used for turf. Soil can be improved and topped with mulch to hold water from rainfall as well as irrigation. Taken together these practices help residents save both water and money while creating beautiful and interesting landscapes.

WHAT MAKES UP TUCSON'S WATER DISTRIBUTION SYSTEM?

Sources of Water - Water pumped from an aquifer to pipes for distribution and delivery has been the source of much of Tucson's water. Tucson's newest available source of water is the CAP, which brings water from the Colorado River. Tucson also has a system for using treated wastewater on facilities such as golf courses and parks.

Pipelines - Large pipelines ("water mains") bring water from its source to central points, and smaller pipes distribute that water throughout the community.

Reservoirs - These are storage areas that hold water until used. Reservoirs are important for balancing supply and demand and for ensuring that an extra amount of water is in reserve for fire fighting. At one time, elevated storage tanks provided adequate supplies of water. With our large population, however, huge reservoirs are needed, with capacities ranging from one million to twenty million gallons of water.

about 15 percent in homes built prior to the mid-1950s, to about 22 percent from the mid-1950s though the 1960s, and then to nearly 30 percent in newer homes. At present, almost 20 percent of all homes in Pima County have pools.

Many pools are not built at the same time as the home, but rather within the first seven to eight years after the home is constructed. And once constructed, pools are rarely removed. Pool removal can cost over $10,000 and usually reduces the value of the home. This suggests that the best time to provide outdoor water conservation messages to homeowners is soon after they've moved into a newly constructed home and before they have made landscaping and pool decisions.

Figure 5-8 Fraction of residential lots with pool by year home built, Pima County 1920-1990.

Sources: Pima County, Water Resources Research Center.

One of the few ways to reduce pool water use is covering the pool when it is not in use to minimize evaporation. A survey of newer homes in Tucson revealed that approximately 60 percent of home pools have pool covers. But pool covers are used only about half the year. Usage is at a minimum during the summer swimming season to allow convenient and frequent access to the pool. Also covers are not used in the summer because they cause the water to become uncomfortably warm. Peak cover usage surprisingly is not in winter, but in the fall and spring, when pool users are trying to extend the swim season. Lower pool cover usage in the winter may reflect a desire to protect the cover from sun damage while evaporation rates are the lowest.

Water for evaporative cooling systems accounts for around five percent of outdoor water use in Tucson. (Evaporative cooling is classified as an outdoor water use because it results in water being consumptively used and not returned to the sewage system as is the case with other indoor uses.) In 1992, approximately 79 percent of homes in Tucson had evaporative coolers. At that time approximately 59 percent of households had only an evaporative cooler; 21 percent had both a cooler and an air conditioner; and 19 percent had only an air conditioner. As air conditioners have gained popularity in new construction, the percentage of Tucson homes with evaporative coolers, along with the amount of outdoor water devoted to evaporative cooling, has declined. Approximately 85 percent of new construction surveyed in 1996 had only an air conditioner, 11 percent had both an air conditioner and an evaporative cooler, and four percent had only an evaporative cooler.

HIGHER WATER USE TRENDS

While newer homes have more low-flow plumbing fixtures and appliances and are likely to have less turf and no evaporative cooler, some trends in new construction cancel out these conservation gains. For example, newer homes are more likely to have water using amenities such as pools, spas and whirlpool tubs. Further, new apartment complexes and condominiums are more likely to have large amounts of turf and landscaping, as well as pools.

The number of homes with outdoor misting systems grew through the early and mid-1990s. These systems spray droplets of water into the air that evaporate to cool an area. Although manufacturers of misting devices claim water efficiency, few residential misting systems are as effective or water-efficient as advertised, and some are poorly designed. System emitters can scale up or corrode, producing drips instead of the intended mists. A survey of Tucson Water customers in 1992 showed that three percent had misting systems. A Metro Water survey conducted about 1995 indicated that seven percent of homes had misting systems, and a 1997 survey of new housing indicated that 12 percent of sampled homes had them. The 1997 survey showed that those systems were used an average of 3.4 times per week, and that the main use was for cooling pets left outdoors.

The trend in cooling system design is toward greater water use. The latest models of evaporative coolers are designed to prolong the life of the cooler by draining water after a certain number of hours of operation. This prevents mineral content from building up and corroding metal cooler parts and scaling up the pads. Some new coolers, however, empty the pan automatically after only a few hours of operation. This is excessive considering Tucson-area water quality. In older coolers, water collects in the bottom of the cooler and can be drained using a bleed-off valve. Some new air conditioners also use water. Manufacturers can achieve higher efficiency ratings by dissipating heat generated by the unit in an attached evaporative cooler.

Some water-using indoor appliances also are starting to use more water in settings designed to handle heavy loads. For example, *Consumer Reports* found that while new dishwashers have a greater number of settings to better match water use with job size, the power-scrubbing option available on many models means significantly higher water use. New dishwashers use between four and 13 gallons per load on normal settings, but can use significantly more when set for the dirtiest loads. In contrast, washing dishes by hand uses three to five gallons per load.

WATER RATES AND CONSERVATION

For decades water has been priced as if it were free. What people pay for is the cost of capturing the water, delivering it to them and making sure it is safe to drink. People who pump their own water pay to build and operate their wells, but they do not pay anyone for the water itself. ADWR, however, does charge well owners a small pumping fee which goes primarily toward conservation and augmentation (water banking) programs. In some states people pay an annual fee for their pumping permit which recognizes that the state owns the water and sets certain conditions for people to use it.

Many people will conserve water if the price is very high. The point at which people will respond to higher bills varies greatly, depending mostly on personal income and the percentage of total household expense the water bill represents. Some people may find a $100 water bill acceptable while others may have problems paying a fourth as much.

Water rates can be modified to encourage conservation in two very different ways:

- The rate structure can be designed to reward conservation and discourage excessive water use. For example, cost per gallon could increase as customers use more water; cost could increase at peak times of the day or year to reflect higher costs at that time; or cost could be higher for areas that are more expensive to serve.
- Rate levels can be raised to cover the cost of finding new future water supplies.

Changing Rate Structures

Tucson's first water rates in 1900 were flat rates, as are some of Salt River Project's rates today. A flat rate means people pay the same for water no matter how much they use. For many years, Winterhaven had a flat rate for water, with the expectation that people would maintain lush lawns and landscapes, although this has changed and desert landscapes are now acceptable in that Tucson neighborhood. Today almost all communities nationally meter water usage and thus charge people more for increased water use.

Water bills from all water providers in the Tucson area have two basic parts – a basic rate determined by the size of the connection (this is a fixed charge applied whether or not water is used) and a commodity rate which is charged for every unit of water used over a minimum amount. For many water providers, the minimum amount is 2,000 gallons. Some water companies charge a higher commodity rate for water use above certain amounts (referred to as an increasing block rate or progressive rate structure). This type of rate structure is designed to discourage high-volume water use. Tucson Water, Metro Water and Avra Water Co-op have increasing block rates.

Another water rate structure variation designed to encourage water conservation is seasonal water rates. Seasonal rates usually involve charging a higher commodity rate during summer months than during winter months. Higher summer rates are designed to encourage more conservation when more water is needed to meet peak demand on the water system. Metro Water has had seasonal rates since 1995. Tucson Water had seasonal rates for all customer classes from 1977 to 1995 but removed seasonal rates for the single family residential and duplex-triplex classes in 1995.

Water rates are an important signal about the relative scarcity of water and the need to conserve. If rates do not keep up with inflation, the real price of water actually declines. People may take that as a signal that water is cheap and conservation is not important. Even if the real price of water is held constant, incomes in Pima County have increased at a faster rate than inflation. This is good news for the economy, but means that water bills shrink as a relative share of the overall budget. The incentive to conserve is reduced.

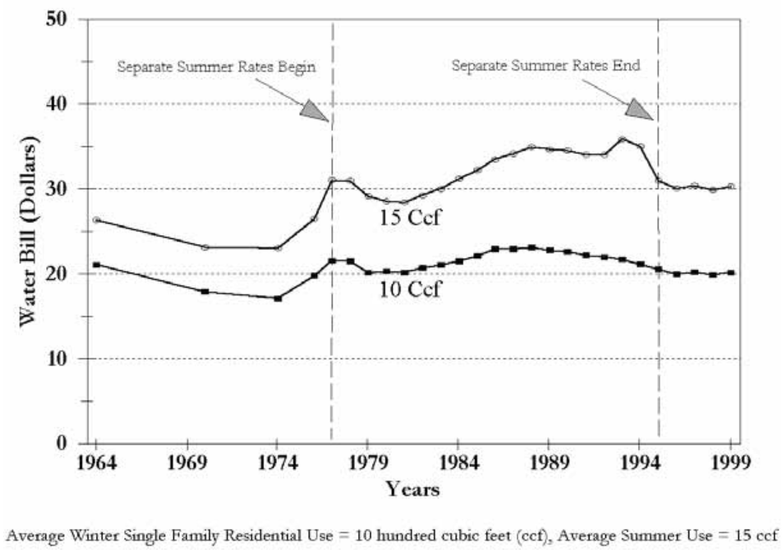
Figure 5-9 The Beat the Peak Program tried many approaches to urge the public to restrict water use during peak hours. Photo: Barbara Tellman.

Tucson Water has pursued a water rate policy designed to lower peak demand and encourage water conservation. Tucson Water instituted increasing block rates and seasonal rates as a conscious effort to discourage excessive water use. Especially after the 1975-76 water controversy (S Chapter 2), many Tucson Water customers saw significant increases in their water bills, and water use decreased significantly as the message to conserve hit home. At this time the water conservation program, Beat the Peak, was initiated.

As is shown in Figure 5-10, between 1976 and 1993 rates were updated every year. For average water use customers, bills just barely kept ahead of inflation. At least in part because the real price of water stayed about the same, and incomes in County increased at a higher rate than the rate of inflation, water use increased. In 1993, there was a significant increase in the price of water, especially the summer rate. Public reaction, however, forced a redesign of the rates and a decline in the real price of water in the summer. The real (inflation adjusted) price of water has declined since then.

Water providers must get approval to change water rates. Municipal water utilities must get approval from the city or town council. Changing the rates is much more difficult for water companies that must get approval from the Arizona Corporation Commission (). Going through this process is expensive because of the legal fees involved and costs of a rate hearing can easily reach hundreds of thousands of dollars, even for a small water company. This is required even if a company doesn't plan to raise more revenue from customers, but just change the rate structure. This

Figure 5-10 Tucson Water bill for average single family residential customer, inflation-adjusted 1998 dollars.



Sources: Water Resources Research Center, Tucson Water.

discourages many companies from changing rate structures to promote conservation.

Charging More to Pay For Future Supplies

A more controversial way to change rates is to charge more in anticipation of the need to acquire a more expensive water supply in the future. The cost of developing and delivering Tucson's new water supplies – CAP and treated effluent – are more expensive than pumping and delivering groundwater. Some economists argue that people now using the cheaper water should help pay for the future costs of developing the new, more costly supplies that eventually will be needed. According to this theory water costs should rise to build up a reserve for the future. This would make it fairer for future users who must use the more costly water, and the higher cost would encourage conservation of the existing supply. This approach is rarely adopted for many reasons. For one, it is not a politically popular approach. Also, it is virtually impossible for a private water company to acquire extra money to cover future costs through the ACC process. Municipal utilities are often run on a cost of service basis, neither making a profit nor running a deficit. Accumulation of an unused pot of money would not fit this model, although some funds can be put aside for the future.

CONTRARY VIEW

Not all Tucson citizens are committed to a water conservation ethic. Some people do not believe a water shortage exists, especially now when Arizona has more CAP water than it can use and faces the prospect of California or Nevada claiming the state's unused portion. Other people believe they have a right to as much water as they are willing to pay for, to use as they see fit. Some critics claim such people may indulge in excessive water use but, in response, they may claim theirs is an essential use of water. Not all people appreciate landscaping with low-water use native plants; some prefer green lawns all year long. While some people consider golf courses a recreational necessity or a way to raise property values, others believe such facilities waste valuable water and benefit only the few who use them.

Some people are reluctant to save water because they perceive conservation as a cynical means to justify population growth. Such skeptics argue the main reason business interests support conservation is to save water that then can be used to enable more people to move into the area. In this scenario, conservation efforts may result in reducing existing water use, but a growing population would soon consume whatever water savings are achieved.

AGRICULTURAL WATER USE

Agriculture has been the predominant user of water in Arizona in the 20th century. Since the 1940s, agriculture has accounted for about 80 to 90 percent of Arizona's water use. In the Tucson area, agriculture's share of water use in the Upper Santa Cruz Basin (which excludes the Avra Valley) was about 84 percent in 1940, shrinking to about 73 percent by 1951.

The general downward trend in agricultural water use has resulted mostly from a reduction in cropped acreage. Cropped acreage in Pima County reached a plateau in 1955 and remained fairly constant until 1975, at about 50,000 to 60,000 acres. Irrigated acreage declined after 1975 as farmland was developed for

Table 5-2 Summary of water use in major irrigation areas in the Tucson AMA.

IRRIGATION AREA	IRRIGATED ACREAGE	1987-1995 AVERAGE WATER USE (acre-feet)	WATER SOURCES
Cortaro Marana Irrigation District	10,543	33,439	Groundwater, CAP, Effluent
Avra Valley Irrigation District	11,360	26,240	Groundwater, CAP
Farmers' Investment Co.	5,909	28,026	Groundwater
Red Rock Area	3,843	n/a	Groundwater, CAP

Source: Arizona Department of Water Resources, Draft Third Management Plan, Tucson Active Management Area, 1998.

urban use along the Santa Cruz River floodplain, including the Marana area. The City of Tucson purchased over 20,000 acres of farmland in the Tucson area from the 1950s to the early 1980s, taking that land out of agricultural production in order to use its water rights for municipal purposes.

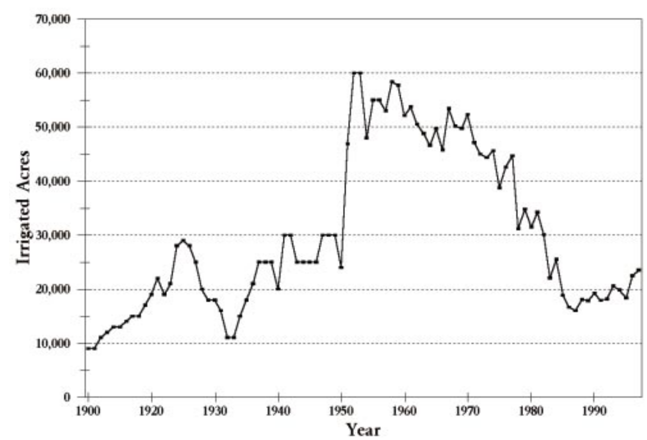
After declining through the 1980s and early 1990s, agricultural water use increased to 132,700 acre-feet in 1997. Use in 1997 includes 25,100 acre-feet of CAP water used in-lieu of groundwater under the groundwater savings program set up by the State of Arizona (See discussion below). Reasons for the increase in agricultural water use are not clear. Rules for participation in the groundwater savings program allow use of renewable water supplies only in place of groundwater that otherwise would have been pumped. Other reasons for the increase that have been cited include better market conditions and the passage of the Federal Agriculture Improvement and Reform Act of 1996. This act removed federal price support programs and increased pressure on farmers to plant as many acres as possible to cover overhead costs.

Agricultural water use in TAMA is regulated under the Groundwater Management Act of 1980 (GMA). The GMA regulates agricultural water use in several ways. First, no new agricultural land can be developed for irrigation. Second, farms are given a maximum annual allotment of groundwater to be used for irrigation. This is based on the historic amount of irrigated acres on a farm in the five years before the GMA and an amount of water to be used per acre, called a water duty. This irrigation water duty will be reduced over time as increasing water application efficiencies are required (See Chapter 7 for more detail).

Farms using less than their groundwater allowance are given a credit for the difference between their actual water use and the groundwater allowance. These credits are accumulated in a flexibility account and can be used in future years, if needed, to meet conservation requirements. There is no limit to the number of flexibility credits that can be accumulated.

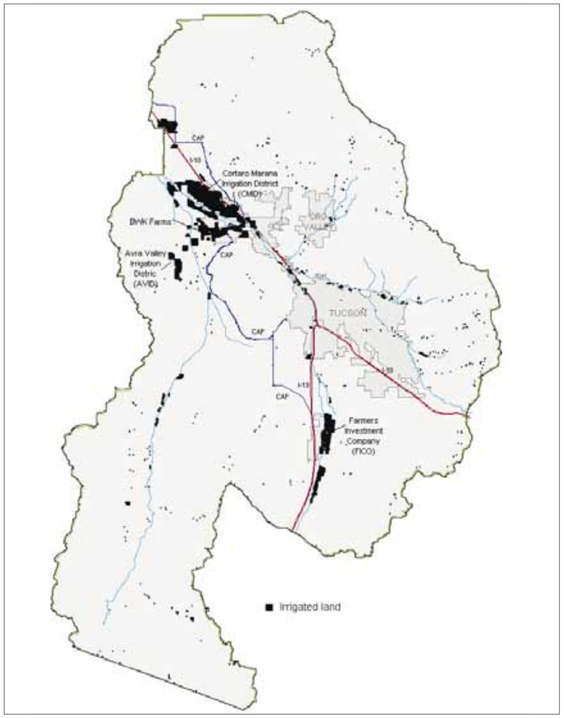
Annual groundwater allotments were set near the historic peak of irrigated acreage; thus much more groundwater than is needed is legally available to farmers each year. With irrigation efficiencies increasing on farms and significant amounts of farmland out of production, many farms have accumulated large flexibility account balances. On average, TAMA farms were using 50 to 60 percent of their groundwater allowances. ADWR projects that, even as required irrigation efficiencies are raised to 85 percent, most farms will still accumulate credits. The ex-

Figure 5-11 Irrigated acreage in Pima County, 1900-1997.



Sources: Arizona Agricultural Statistics 1966 - 1997, Arizona Agriculture 1942 - 1965, Arizona Academy 10th Arizona Town Hall, 1967.

Figure 5-12 Irrigated acreage in TAMA.



Source: Arizona Department of Water Resources.

istence of large flexibility account balances hinders the ability of agricultural conservation requirements to affect agricultural water use.

As shown in Figure 5-12, four main groups of farms are clustered in three agricultural areas remaining within TAMA. Two irrigation districts are operating in TAMA: Cortaro Marana Irrigation District (CMID), located north and west of the Town of Marana, and Avra Valley Irrigation District (AVID), located generally just south of CMID, southwest of the Santa Cruz River. Irrigation also is occurring in what is referred to as the Red Rock area, in the Pinal County portion of TAMA. Farms within the Farmers Investment Company (FICO) near Green Valley account for most of the rest of TAMA agricultural land. Agricultural water use in other areas of TAMA, such as the Tucson area, the Altar Valley and farmland in the Arivaca area, accounts for less than three percent of total agricultural water use in TAMA.

The San Xavier (south of Valencia Road) and Schuk Toak districts (western Avra Valley) of the Tohono O'odham Nation have CAP allocations, which may be applied to restore historic farmlands and add additional farmland. Projections show that about 5,000 acre-feet of CAP water may be used on the San Xavier District by the year 2005. The Schuk Toak District currently is developing a farm which is expected to use 10,800 acre-feet of CAP water per year by 2010. A pipeline to supply CAP water to the San Xavier District is now under construction.

Cotton is the predominant crop grown in TAMA, accounting for about 75 percent of planted acreage. Other crops grown include wheat, barley, sorghum, alfalfa hay, vegetables, nuts, millet and lettuce. Pecans are the predominant crop grown at FICO.

The cost of pumping groundwater for TAMA farmers depends mainly on the depth to groundwater and energy costs. With access to low-cost hydropower generated at Hoover Dam, CMID has about the lowest pumping cost in TAMA. The district controls well pumping and supplies water to farmers at a cost of $30 per acre-foot, plus an annual assessment of $40 per acre for every acre in the district. Individual farmers within AVID have their own wells and control water use decisions. Pumping costs for wells in the district were about $40 to $50 per acre foot in 1995, including operation, maintenance and repair costs. Average pumping cost for FICO wells was recently reported to be $28 per acre foot.

To encourage farms to use renewable supplies such as CAP water the cost of such supplies needs to be comparable to the cost of pumped groundwater. When originally offered to irrigation districts in Arizona, CAP water cost more than pumped groundwater. As a result, fewer irrigation districts than expected signed subcontracts for CAP water. Many irrigation districts that did sign subcontracts faced a financial crisis, if not bankruptcy, until the State of Arizona offered incentives to increase CAP water use by agriculture. The state offered irrigation districts who had signed a CAP subcontract a reduced price for the water in return for irrigation districts giving up their long-term right to use CAP water. Since none of the irrigation districts in the Tucson AMA signed subcontracts to use CAP water, they were not eligible for these favorably priced allotments of CAP water.

TAMA farms, however, are eligible to use CAP water under another incentive program designed to encourage CAP water use. Under the Groundwater Savings Facilities (GSFs), otherwise known as in-lieu recharge facilities, municipal water providers offer CAP water to farmers at prices below the cost of pumping groundwater. Farms use this CAP water in lieu of groundwater that otherwise would have been pumped. Municipal providers get credits for this "saved" groundwater. The credits then can be used in the future to offset groundwater

Table 5-3 Water delivered to Groundwater Savings Facilities (acre-feet).

GROUNDWATER SAVINGS FACILITIES	1993	1994	1995	1996	1997
BKW Farms	250	2,014	4,235	7,080	8,648
Cortaro Marana Irrigation District	2,650	0	5,902	9,581	9,746
Kai Farm at Picacho	–	–	–	0	6,701
Total In-Lieu Recharge	2,900	2,014	10,137	16,661	25,095

Source: Arizona Department of Water Resources, Draft Third Management Plan, Tucson Active Management Area, 1998.

pumping in efforts to meet state groundwater pumping restrictions.

As is shown in Table 5-3, CAP water use through the groundwater savings program has grown from about 10,000 acre-feet in 1995 to 25,000 acre-feet in 1997. CAP water use through GSFs continues to expand as new facilities are added and existing facilities are permitted to take more water. For example, CMID used almost 10,000 acre-feet of CAP water as a groundwater savings facility in 1997 and has increased its state permit to take up to 20,000 acre-feet per year of CAP water in the future. A groundwater savings facility located within AVID includes several farms. The AVID GSF is permitted to take up to 12,513 acre-feet per year of CAP water. FICO does not use any CAP water currently but is investigating the use of CAP and/or effluent. Use of CAP water at FICO could occur through a GSF with a possible capacity of up to 20,000 acre-feet per year. Kai Farms at Picacho, in the Red Rock area, converted from pecan trees to row crops in 1997, and irrigation with CAP water began under a groundwater savings project arrangement. Total CAP water used at the Kai Farm at Picacho GSF in 1997 was 6,701 acre-feet. The facility is permitted to take up to 11,231 acre-feet per year of CAP water.

A small amount of treated effluent is used on farms in the Tucson area. CMID purchases an average of about 3,000 acre-feet of effluent per year from Pima County. The effluent is delivered via a ditch from the Ina Road treatment plant and is blended with groundwater for delivery to farms.

Reducing Agricultural Water Use

ADWR has goals for increasing water use efficiency on farms. In 1980, water use efficiency in TAMA averaged about 65 percent of water applied. This means that the average amount of water applied to crops was 35 percent greater than the calculated water need for those crops after accounting for the consumptive use requirement for the crops, the amount of precipitation available for plant growth, any additional water for special needs for crops — such as water needed for germination of lettuce — and a leaching allowance to prevent buildup of salts in the soil. The water use efficiency goal set for farms to reach by the year 2000 is 85 percent efficiency. ADWR reports that many farms have already reached this goal, but other farming operations are not certain whether this goal is attainable.

Flood irrigation on sloped fields is the most common irrigation method in TAMA. Some farms have saved water by laser-leveling their fields (a method of leveling and slightly sloping fields so that water spreads evenly across the field) or installing systems to pump back water that accumulates at the end of the field. Installation of drip irrigation systems is generally considered too expensive for irrigation in the Tucson area.

Figure 5-13 Irrigation made it possible to grow a great variety of crops in the desert.

ADWR also is requiring farms to make their distribution systems more efficient. Farms can save water by lining their water distribution canals with concrete or other materials. Under ADWR's Second Management Plan, farms were required to either line all their canals or operate their delivery systems to keep lost or unaccounted water at less than ten percent. The agency reports that most of the largest irrigation districts in TAMA are meeting this requirement.

One of the biggest factors in reducing agricultural water use in the Tucson area has been purchase of agricultural land for subdivision use, especially in the Marana area. As municipal development continues in the Tucson area, more farmland will likely be converted. Whether or not the new land use will ultimately consume more water depends on many factors. In situations in which farmland is converted to apartment or business use, the total water use will probably be less than the agricultural use. In situations in which farmland is converted to high-water uses such as golf courses, total water use may be higher.

Another strategy for reducing agricultural water use is to buy agricultural land and the attached water rights to either convert rights to municipal use or permanently retire the water rights. The City of Tucson bought many acres of farmland from the 1950s through the 1970s, and mining companies also purchased farmland in the 1970s to secure water rights. The GMA has provisions for state purchase of farmland to retire agricultural water rights starting in the year 2006 but no source of funds has been identified to accomplish this goal.

INDUSTRIAL WATER USE

Industrial water users in the Tucson AMA include metal mines, sand and gravel mining facilities, electric power producers, dairy operations, and other industrial users. As is shown in Figure 5-14, metal mining is the largest water user in the industrial sector, accounting for approximately 70 percent of the total. classifies some golf courses and other turf facilities with their own wells as industrial for legal reasons. All turf uses, however, were previously discussed as municipal uses.

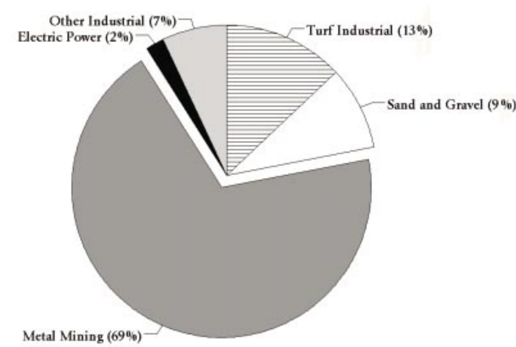
Mining

Four active metal mines operate in TAMA. The Cyprus Sierrita and Cyprus Twin Buttes mines are located adjacent to each other, south of Tucson and west of Green Valley. Water use at theses two mines totaled 26,165 acre-feet in 1997. The ASARCO Mission Mine is located several miles north of the Cyprus Sierrita/Twin Buttes mines. Copper and molybdenum are mined at two open pits and an underground mine at the site. A substantial amount of silver also is recovered as a by-product. Water use at the Mission Mine was 13,042 acre-feet in 1997. The ASARCO Silver Bell Mine straddles the TAMA boundary due west of Marana. Copper is mined in an open pit. Water use at the site was 575 acre-feet in 1997. On-site production capacity has been expanded with the mining of a new deposit and the addition of a new processing plant.

Most mining in the Tucson AMA is open-pit mining followed by milling and flotation. The ore extracted from the pits is crushed and delivered to the mill, where it is crushed again and mixed with water to form a slurry. The slurry is discharged to flotation cells. Here chemicals are added that cause the materials to float to the surface for removal. Waste rock remaining in the flotation cells is sent to thickener tanks. The solids settle in the tanks and the water is recovered. The tailings mixture, which usually is 46 to 55 percent solids by weight, is transported via pipeline to the tailings pond. The tailings slurry is deposited in the tailings impoundment with a spray, leaving standing water in the impoundment which is skimmed off and recycled back to the mill. At the Mission Mine and the Sierrita/Twin Buttes facility, approximately 30 percent of water sent to the tailings is recovered.

Copper also can be leached from piles of certain types of ore using sulfuric acid. The leachate is then piped to another facility for recovery of copper. Another form of leaching

Figure 5-14 1995 industrial water use, Tucson AMA.



Source: Arizona Department of Water Resources, Draft Third Management Plan, Tucson AMA, 1998.

Figure 5-15 Open pit copper mine. Photo: Barbara Tellman.

from buried ore, known as "in situ" leaching, has recently come into use. Both types of leaching use less water than milling and flotation, but "in situ" leaching has been applied only on a pilot scale in Pinal County, and both forms require the right kind of ore.

ADWR funded a study to analyze possibilities for additional water conservation in mining. Increasing the density of the tailings slurry was one of the most effective steps available to decrease groundwater withdrawals. For every one percent increase in the tailings density, 500 to 800 acre-feet of groundwater can be saved per year. Average tailing densities may be able to be increased from 48 percent to 50 percent at ASARCO Mission and from 52 percent to 54 percent at Cyprus Sierrita by installing smooth plastic piping to reduce friction and by pumping the slurry instead of relying on gravity. In addition, seepage of groundwater underneath the tailings ponds can be reduced by depositing fine-grained tailings on top of native soils before tailings are delivered to the ponds. Evaporation of water in tailings impoundments can be reduced by installing multiple decant towers to more quickly decant the water.

The 1997 study also examined the possibility of using renewable supplies instead of groundwater at the mines. The study found that the use of renewable supplies at the mines is unlikely to include effluent, due to the great distance between existing effluent lines and the mines. Use of CAP water was deemed theoretically possible, but several obstacles currently prevent use of this water source. First, the mines have the legal right to pump groundwater, and groundwater is significantly cheaper than CAP water. While total water use at these sites in 1997 was 39,207 acre-feet, the mines have rights to withdraw a total of 62,188 acre-feet of groundwater per year. Mines were originally expected to use CAP water in the Tucson area, but no mining facilities signed subcontracts for CAP water. The best incentive for mines to use CAP water would be if its price was lowered to equal the cost of pumping groundwater. This price adjustment likely would have to come as a subsidy from other water users. The cost of pumping groundwater, including energy and maintenance costs, was reported to be $84 per acre-foot at the ASARCO Mission Mine and $163 per acre-foot at Cyprus Sierrita in 1997.

Another obstacle to mines using CAP water is its quality. If mines use CAP water instead of groundwater, the process of recovering metals from the ore would not be as efficient. Tests conducted by the mines show that use of 100 percent CAP water resulted in declines in copper and molybdenum recovery. More study is needed to assess the potential impact on recovery rates when using a blend of CAP and groundwater.

Yet another obstacle to CAP water use is the question of CAP delivery reliability. Mines need water for ore extraction 24 hours a day, seven days a week. CAP water delivery interruptions would cause fluctuations in the quality of water delivered to the mill storage reservoirs and result in a need to readjust the rates at which chemicals are added to maintain mineral recovery efficiencies. Emergency outages present the greatest problem in adjusting to changes in water quality because of the lack of advance warning.

A final obstacle is that mines are concerned about the spread of polluted water. By pumping groundwater mines have created a cone of depression that confines polluted water to the area near the mines.

Mining in TAMA is projected to remain at approximately the current level into the near future, and total water use is estimated to increase slightly to 47,500 acre-feet per year by 2025. The level of future production and water use in the mining sector, however, is difficult to predict. The health of the mining sector is highly dependent on the fluctuating price of copper and molybdenum and advances in mining technology. Proven reserves at Cyprus Sierrita are reported to be 20 years at current production levels and extraction technology. Producers continue to add to capacity, such as the expansion at Silver Bell Mine, but water use efficiency also is increasing.

Sand and Gravel Facilities

The approximately 15 sand and gravel facilities operating in TAMA used 5,176 acre-feet of groundwater in 1995. This is projected to increase to 7,000 acre-feet per year by 2025. Most sand and gravel facilities recycle much of the water used for washing mined stream deposits. Facilities can save additional water by reducing water use for dust control and other clean-up related activities. Sand and gravel facilities could theoretically use CAP water, effluent or poor quality groundwater. Secondary effluent could be an inexpensive and feasible alternate supply. Because sand and gravel operations are able to pump groundwater at relatively low cost, switching to CAP water would not be economical without a subsidy.

Other Industrial Uses

Other industrial uses include water for electric power generation and dairy facilities. In 1995, the electric power industry used 1,609 acre-feet, and the only remaining dairy in TAMA used 73 acre-feet in 1995. Since little power is generated locally, electrical usage is not expected to go up over time. Other miscellaneous industrial users consumed 4,026 acre-feet in 1995. Cooling towers and large-scale power plants may be able to switch to effluent.

RIPARIAN AREAS AND WILDLIFE HABITAT

For many years official studies did not recognize wildlife habitat or riparian vegetation as a legitimate use of water. Diversion from streambeds is what counted, whether for use by humans, cattle or to irrigate crops. The Santa Cruz River through Tucson once had enough water to support cottonwood-willow forests and bosques of giant mesquite that provided habitat for creatures such as muskrats, beaver, edible fish and wild turkey. All of these creatures are gone from the area today, as are most of the riparian forests. Human demand for water outweighed the values of flowing streams and riparian habitat. In recent years, however, this attitude has begun to change. Proposals have been made to allocate a certain percentage of CAP water for establishing some riparian vegetation along the Santa Cruz River, Rillito Creek and Cañada del Oro Wash.

Riparian Water Needs

A riparian area in our desert environment needs a reliable supply of water year round (base flow), and it needs occasional spring floods. The base flow may sometimes be just below the surface. Spring floods are needed so that seeds can germinate in the moist soil, then begin to extend their roots downward as the flood waters recede. Even in a natural system, spring floods don't always set the stage for young trees to get started. In an artificial environment, such as the area along the Santa Cruz River through Tucson, even if trees do get

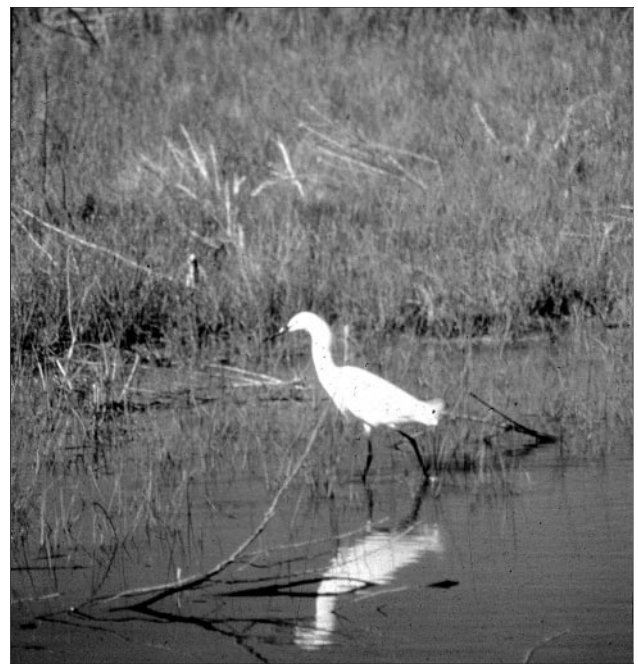


Figure 5-16 Riparian areas are vital to some 85 percent of Arizona's wildlife, including migrating birds. Photo: Barbara Tellman.

started, they may not have enough base flow to support their continued growth.

If the groundwater is at the surface, a variety of wetland plants might grow, such as cattails or rushes. As the water table drops, plants needing constant water are the first to die. Shrubs and trees can survive in areas where groundwater is available down to ten feet below the surface. Mesquite can survive in desert areas without a constant supply of water to the roots, but they grow into very large trees in areas where their roots can reach groundwater. Large mature trees have roots that can go down more than 50 feet to reach water.

If the water table is so far below the surface that roots cannot reach water, the plants may still be able to survive if water is available from other sources such as wastewater from a treatment plant. Downstream of Nogales, for example, a rich riparian area survives on effluent from the Nogales International Wastewater Treatment Plant. The effluent provides the base flow that groundwater would have provided and normal variations in rainfall provide the spring floods needed for seedlings. CAP water could also augment flood water in this way.

Riparian Vegetation Water Use

Quantifying how much water is used by riparian vegetation is difficult. A mature cottonwood tree can use a lot of water in the growing season, but uses very little when leaves fall in the winter. As a result some people argue that if cottonwood forests were cut down along streams such as the San Pedro, more water would be available for human use. Others counter that this is only partly accurate, because trees and other vegetation perform important functions, some of which actually help to conserve water in the region. For example, the roots of the riparian vegetation hold soil in place, helping to control erosion. Vegetation slows rushing flood waters so that more water remains in the immediate area for recharge. Finally, vegetation provides shade, keeping the water temperature lower than would be the case in the blazing sun, reducing evaporation. The overall impact of tree removal on water resources available for human use is a debated issue, in need of further research.

Figure 5-17 Hikers enjoy a visit to Pima County's Cienega Creek Preserve. Photo: Barbara Tellman.

Establishing Riparian Areas & Creating Wetlands

Water can be used to create wetlands off the stream or to establish vegetation and habitat in the stream channel itself. A stream, however, needs more than water to form a healthy riparian area. A stream in its natural state tends to meander and over time changes its course over a wide flood plain. Cottonwoods may germinate along a new channel, while mature cottonwoods still grow along an old channel. Terraces tend to form and different vegetation is found on successively higher terraces. These conditions often are not possible in a populated area such as downtown Tucson, where buildings exist along the banks, and flood control structures constrain the river within a narrow channel.

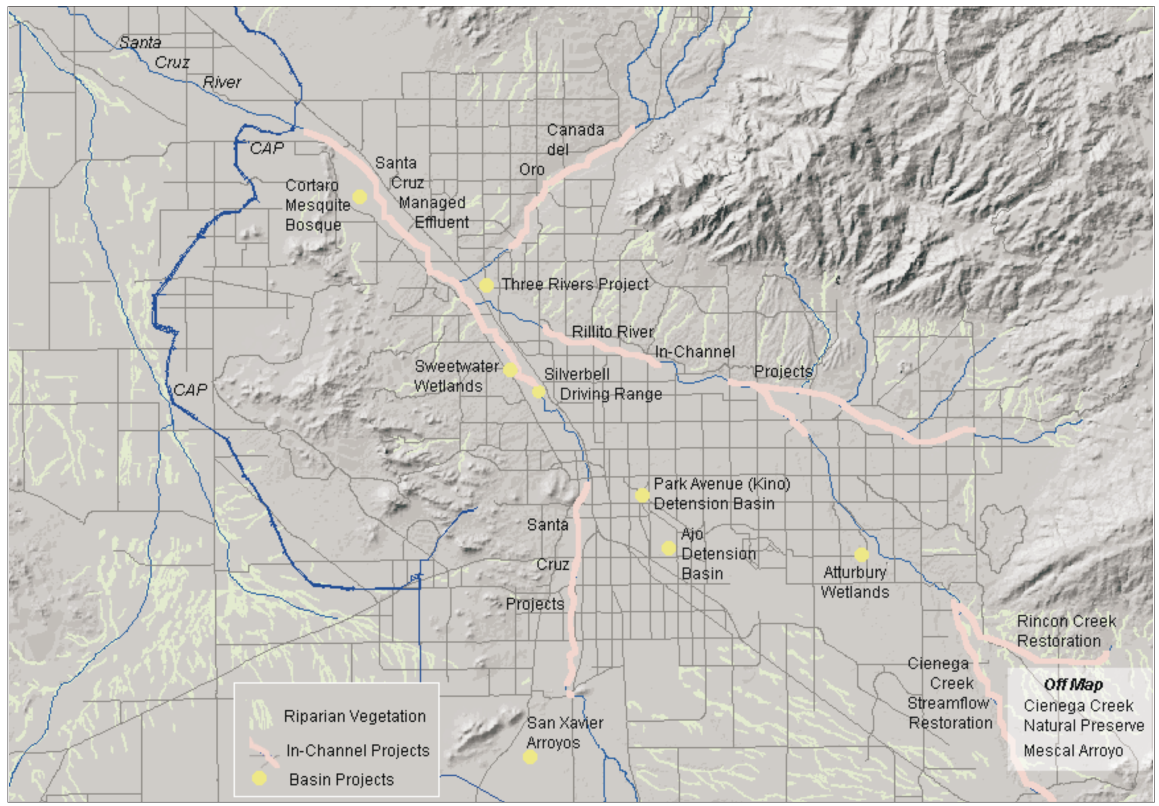
Where the stream channel is in a relatively natural state, as is the case with many washes, restoration does not pose great difficulties. The addition of water may be all that is needed. The Rillito Creek at Craycroft Road, for example, had a lush cottonwood and walnut forest until very recent times. Pumping has depleted the aquifer to the point that the trees are stressed. Cessation of pumping would probably very quickly lead to restoration of a vigorous riparian habitat. Similarly, the Tanque Verde and Pantano washes have areas where pumping has lowered the water table, but conditions are still good for restoration if pumping levels decline significantly. When water was added to the Santa Cruz River north of Nogales, the riparian vegetation came back quickly. The river in that area is shallow, and a broad flood plain stretches out on both sides of the river where flood waters can spread out onto farm land and meander in changing channels. The Santa Cruz River between El Camino del Cerro and Ina Road has a riparian habitat dominated by willows. Effluent from the Roger Road Wastewater Treatment Plant waters this area.

Where the stream channel is deeply incised, however, and/or where the banks have been stabilized to prevent erosion, establishing a riparian area is much more difficult. The Santa Cruz River, through the downtown Tucson area, is not only deeply incised, but has soil cement on both sides of the river, keeping the waters within steep banks. This part of the river is no longer conducive to spontaneous development of cottonwood willow forests merely by creating a flow. In the San Xavier District, the U.S. Bureau of Reclamation built a rock structure to encourage the growth of riparian trees within the channel along one side of the river, even though the banks are steep and subject to erosion. Downstream of the downtown area, effluent from the wastewater treatment plants supports a small riparian area, that is interrupted, however, by bank protection. The Rillito Creek, similarly, is incised and has bank protection along much of its length. The best possibilities for riparian habitat are probably in the upstream areas and along certain washes.

Tucson Area Riparian Restoration Projects

A number of water-based projects which have riparian restoration benefits are being developed or considered in the Tucson area. Many of these projects involve one or more governmental entities and are included as part of the City of Tucson's "Multiple Benefits Water Projects" or County's "Sonoran Desert Conservation Plan." Figure 5-18 shows a number of the current and proposed projects, extending from Pima Mine Road to Marana and from Avra Valley to Tucson's east side. In some cases proposals are being developed

Figure 5-18 Projects which include riparian and wildlife benefits.



Sources: Pima County, City of Tucson.

jointly by the city and county and are included in both plans.

The county's water-related restoration projects include a recharge project along the Santa Cruz River in Marana that will enhance the riparian area by using treated wastewater. A proposed project will restore a higher water table along the Rillito. A detention basin along Arroyo Chico at Park Avenue is to provide urban wildlife habitat through alteration of the current flood control structures. Additional proposed projects include restoration of riparian habitat along the Cañada del Oro using CAP water.

Tucson's Multiple Benefit Water Projects include a number of water-based projects which would provide recreational opportunities, wildlife habitat as well as recharge of groundwater.

Four of the recharge projects have essentially no restoration component (Central Avra Valley, Pima Mine Road, Rillito Recharge Project, and Santa Cruz Managed Underground Storage Facility). The Sweetwater Wetlands, which has a rich habitat, is a constructed wetland located a slight distance from the Santa Cruz River channel. The Atturbury Project uses reclaimed effluent for riparian habitat restoration. The Kino Sports Park involves a lake incorporated into a golf course area, while the Silverbell Driving Range Project involves a small constructed wetland to treat restroom water. The Tucson Airport Remediation Project is a pollution remediation facility, and its water could be made available for riparian habitat development along the Santa Cruz River. However, community approval would be needed and legal constraints surmounted. Three projects are primarily stream restoration (Rillito Creek, Santa Cruz River, and San Xavier). The Rio Nuevo Project near downtown Tucson is also part of this plan.

If the city decides to dedicate a portion of its CAP allocation to habitat establishment, long-term community support is needed. An increase in population could eventually justify using the entire CAP allocation to serve human needs. Whether the Tucson community would agree to this reallocation or would insist that a portion of the city's CAP allocation continue to be used to maintain riparian areas is unclear.

Chapter 6
ENSURING SAFE DRINKING WATER

Our health and well being depend upon having a supply of safe drinking water. In much simpler times this might have meant having a good well or a stream nearby. Today the issue is a lot more complex. To supply a large urban population we dip into various water sources: surface water, groundwater and imported water–e.g. CAP water–each with its own water quality concerns. Also we are more aware of different contaminants in water and the need to control or remove them to ensure the safety of our water supply. (If early settlers from those simpler times knew what we know about microbial contaminants they might have been wary of their wells and the nearby streams.) In response to this situation, various water treatment methods have been developed. We are sufficiently privileged that our water quality concerns focus not only on public health matters, but also consider the aesthetic characteristics of our water supply; i.e., its taste and odor.

TUCSON WATER QUALITY

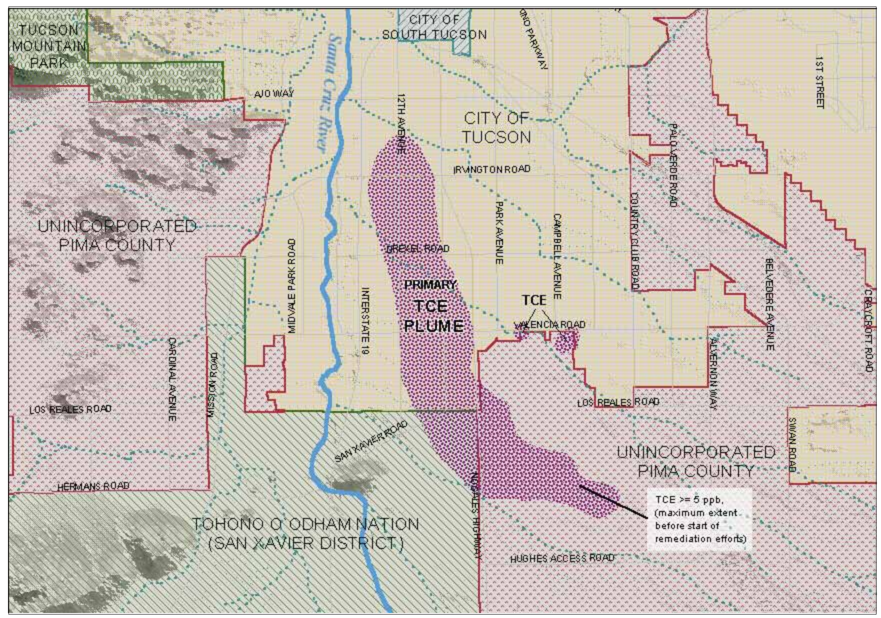
For the most part, the quality of the groundwater in the Tucson area is excellent, although problems exist in a few areas. Some water quality problems such as radon and hardness are naturally occurring, but most problems are the result of human activity. In most cases, where pollution occurs, the level is very low and does not constitute a health problem. In seriously contaminated areas, commercial drinking water wells with dangerous levels of contamination are not in use, but private well-owners may still be drawing from contaminated sources. Some of most serious pollution problems have been designated as federal Superfund (CERCLA) or state Water Quality Assurance Revolving Fund (WQARF) sites and some of those problems are being mitigated. The laws and regulations that help protect our water are described in Chapter 7.

GROUND-WATER POLLUTION

TCE Problem

In Tucson a few incidents of health problems have occurred due to water pollution. The best documented incident involves the occurrence of a plume of trichloroethylene (TCE) in groundwater that extends northwest from the Tucson International Airport. In 1981, an unusual cluster of health problems was

Figure 6-1 Maximum extent of the TCE plume.



Sources: Pima County, U.S. Environmental Protection Agency.

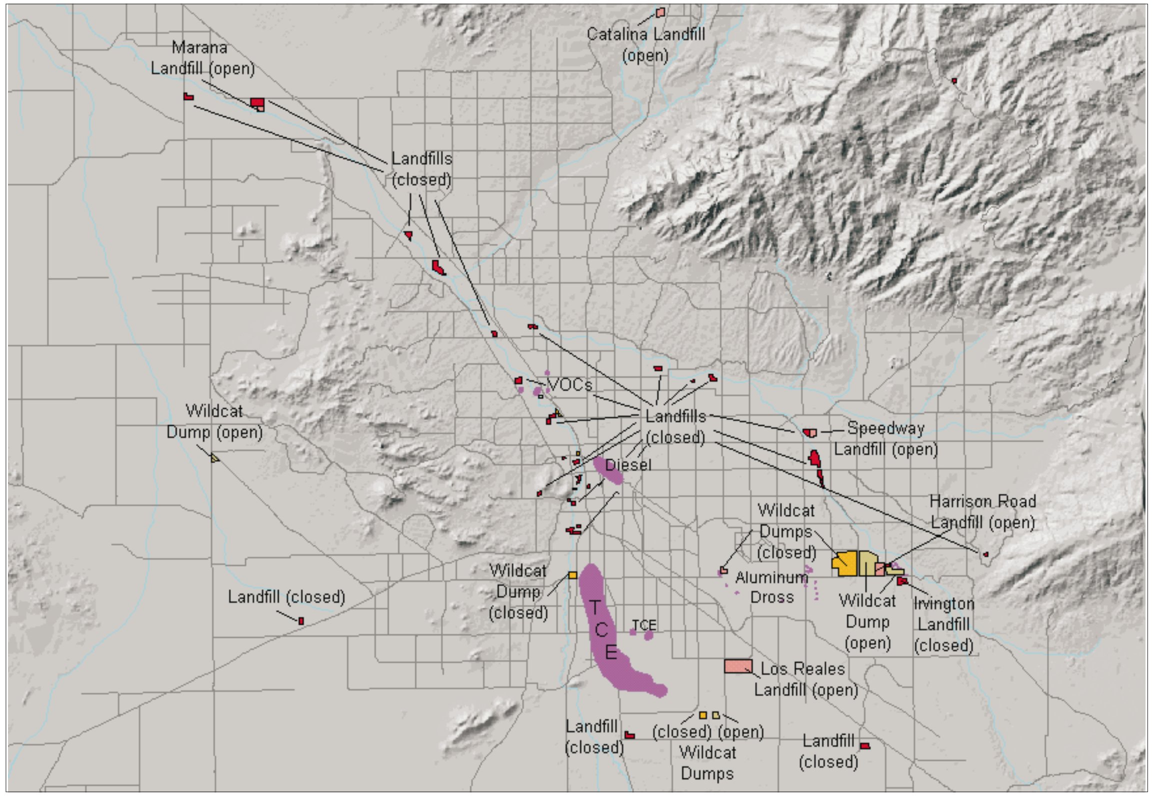
TESTING FOR POLLUTANTS

Testing for a full range of pollutants is costly because different pollutants must be tested by different methods, and the amount of pollutant to be detected is generally very small, perhaps as little as one part pollutant in a billion parts water. Routine water testing is generally conducted for common pollutants such as coliform bacteria, nitrogen or sulfur compounds. Where reasons exist to suspect other pollutants such as TCE, tests for those pollutants become part of the testing routine. There are now well over 230 priority pollutants for which water supplies must be tested at least once a year. Standardized testing is unavailable for many uncommon potential pollutants.

identified in the area west of the airport. Tests indicated a high level of TCE in the water. Health officials investigated to determine if a connection existed between the polluted water and the reported diseases. They found sufficient evidence to cause Tucson Water to shut down wells in the area and supply residents with water from other parts of the system.

Officials then took on the issue of what to do about the contaminated area. They first had to determine who was responsible for the cleanup and what methods were best to use. Most of the aircraft companies responsible for the problem had ceased operations years earlier. Ultimately, Hughes Aircraft (since purchased

Figure 6-2 Landfills and major identified hazardous plumes in groundwater.



Sources: Pima County Department of Environmental Quality, Pima County, Pima Association of Governments.

by Raytheon) built a treatment plant to deal with the problem beneath its property. As a result of a consent decree and agreement, the Tucson Airport Authority, U.S. Air Force and others built a treatment plant for the water downgrade from the airport. Operated by Tucson Water, the Tucson Airport Remediation Project (TARP) is located on the east side of the Santa Cruz River near Irvington Road. Nine extraction wells and five miles of transmission mains transport water to the plant. TARP has three 35-foot air-stripping towers with air emission controls that remove the volatile compounds to avoid air pollution problems. The plant also disinfects the water and adjusts its pH. Treated water is tested weekly, and no detectable amounts of TCE have been found. TARP costs $780,000 annually to operate. Raytheon, U.S. Air Force, McDonnell Douglas

Table 6-1 Identified groundwater contamination sites in Pima County.

CONTAMINANT	LOCATION	SOURCE
Sulfates	Green Valley	Mining
Nitrates	Green Valley	Natural
Radon	Tucson, various locations	Natural
Nitrates	Santa Cruz River	Agriculture, Sewage Effluent
Chromium	Near downtown	Manufacturing
PCE and TCE	Broadway/Pantano	Landfill
Petroleum	Davis-Monthan	Leaking Fuel Tanks
23 VOCs	El Camino del Cerro	Landfill
VOCs/Metals	ESCO - Tucson	Hazardous Waste Site
VOCs (PCE, TCE and others)	Los Reales Landfill	Landfill
TCE, PCE, Freon and others	Miracle Mile, Silverbell Jail Annex	Landfill
Diesel, PCE, TCE and others	Mission Linen	Dry Cleaning, Leaking Underground Storage Tanks
TCE and chromium	Airport	Solvents in Aircraft Cleaning
Chromium, TCE and others	Hughes (Raytheon)	Waste Disposal
Arsenic	Various	Natural

PCE - perchloroethylene; VOC - volatile organic compounds; TCE - trichloroethelyne

Source: Arizona Department of Environmental Quality, Arizona Water Quality Assessment, 1996.

Corp. and the Tucson Airport Authority pay the cost of operating the facility.

Officials also had to decide what to do with the treated water. Under a Consent Agreement, approved by EPA, Tucson Water blends the treated water with other water and distributes it in the city water system. The treated water currently goes to customers downtown, and the near northwest side. Although this water meets all EPA drinking water standards, some customers objected to its use. In 1995, when voters approved the Water Consumer Protection Act to limit the city's use of CAP water, they also restricted the city's use of this treated water since it originated from a "polluted source." Tucson Water, however, still must meet the conditions of the legally binding EPA consent agreement and continues to put the treated water into the municipal system until a solution is worked out.

Some customers are very wary of drinking water that once was contaminated with TCE, eve if it now meets drinking water standards. Several options exist for using the treated water as part of the city's drinking water supplies, subject to approval by the EPA and other parties to the consent agreement, and subject to interpretation of the Water Consumer Protection Act. These include releasing it into the Santa Cruz River; using it to create artificial wetlands; or injecting it underground with injection wells. Others argue that after the expense of purifying the water, it is wasteful to pollute it again by discharging it into the river. They argue that since the city does not have to pay to treat the water it is essentially free water. Also, they argue that the treated water is actually the cleanest water in the city system and the most frequently tested.

Pollution From Landfills

Another identified source of groundwater pollution is old landfills built before current regulations about landfill construction were in place. Some historic wildcat landfills pose problems in determining what actually was dumped there. Officials are concerned about such wastes

ESTABLISHING RISK LEVELS FOR POLLUTANTS

Of all the chemicals produced in the world today, only a fraction have been studied for their possible harmful effects. Also, each year more new chemicals are produced, although their effects may not be understood. EPA has studied only the more common chemicals, especially pesticides and herbicides, mainly concentrating on whether they cause cancer or birth defects.

A great deal remains unknown. Meanwhile we confront a dilemma : Do we take a risk on the assumption that a substance has not been proven harmful or do we avoid substances that lack completed studies of their potentially harmful effects? Do we assume that any level of a harmful substance is to be avoided or do we set acceptable limits that allow a limited amount of the substance to be in our water?

as pesticides, dry cleaning solvents, paints or discarded car batteries containing lead. Also, decaying organic material can release methane. Officials are most concerned about landfills located near riverbeds where flood waters can leach materials out of the landfills into the water table. Recharge projects must not be located in such areas.

One significant landfill pollution site is on Tucson's east side, along the Pantano Wash between Broadway and Speedway Boulevard. This is the location of a 130-acre landfill that the city and county used from 1959 to 1974. Concern exists that landfill gases may be moving either in solution or by diffusion and pressure gradients toward the water table. A plume of contaminated water is moving westward at about one and half feet per day. This rate increases when the demand for water is high because, as the nearby five wells pump water, the contamination plume moves forward. These five wells, however, are only used as a last resort when summer demand is high. The water from these wells meets water quality standards. The concern in this area is that the plume which contains PCE will migrate towards a cone of depression in an area where Tucson Water has active wells. If recharge were to occur along or near the Pantano Wash in that area, the active wellfield could become contaminated.

Other Pollution

A large area beneath the downtown area is contaminated with petroleum products from a variety of sources, probably largely from activities connected with the railroad. Some other areas also have petroleum contamination, mostly from old leaking underground storage tanks, which the state now regulates. Water is not pumped from these polluted sources.

WASTEWATER TREATMENT

Treatment Plants

Most of the sewage generated in the metropolitan area is transported by gravity through pipes to two large Pima County wastewater treatment plants, located along the lower Santa Cruz River at Roger and Ina roads. Solids are removed and, through a bacteriological process, disease-causing microorganisms are reduced. After the treatment process is complete, the wastewater is disinfected, with most of it released to the Santa Cruz River. EPA maintains strict standards for the quality of the water released, and the water is frequently tested. The treatment process is not designed to handle toxic materials; in fact, some toxics can make the treatment process less effective by killing helpful bacteria. Pima County has a pretreatment program for businesses that produce toxic wastes. The program requires such businesses to treat or reuse hazardous substances, rather than releasing them into the sewers. Many people, however, are unaware of the problems that materials such as oil and paint remover can create and flush them down the drain. Pima County attempts to educate individuals about proper disposal of hazardous materials and has a program to collect household hazardous materials.

Some of the wastewater from the Roger Road Treatment Plant receives tertiary treatment in a City of Tucson facility and distributed for use on golf courses and other turf facilities. Tertiary treatment involves treatment through sand filters or soil and additional disinfection. Part of the effluent is taken to Sweetwater Wetlands, an artificial wetland Tucson Water completed in 1998. This wetland adds another layer of treatment before discharging the water to recharge basins. Artificial wetlands have become increasingly popular in Arizona in recent years as they serve not only to treat the water, but also provide wildlife habitat and recreation. A small amount of wastewater is taken from the Ina Road plant for agricultural use and to irrigate the county's Arthur Pack Golf Course.

Some areas, such as Green Valley, are located far from major treatment plants and have their own small facilities, almost all of which are operated by Pima County. Other areas, such as Marana, are downhill from the major treatment plants. Their sewage must either be treated on-site or pumped uphill for treatment. A few areas have privately constructed small treatment plants, with treated water applied to such uses as golf courses.

Septic Systems

An estimated 10 to 15 percent of homes in the Tucson area have their own septic tanks. Although most septic systems are in rural areas, some neighborhoods within city limits also are served by septic systems. A county permit is required to install the system, and the applicant must show that the soils are appropriate for percolation of water.

A well-designed, installed and maintained septic system can be highly effective in treating household wastewater. Conversely, a poorly designed, installed or maintained system can contribute to local groundwater pollution and can be a health hazard. This is especially true in areas with shallow groundwater. Not much information is available to determine if septic tanks in the Tucson area are in fact causing pollution problems. Evidence exists, however, that septic fields often impact drinking wells in rural areas of the state.

A traditional septic system consists of a septic tank — which receives all of the waste water from sinks, toilets, tubs, etc.—and a drainfield. Wastewater first collects in the tank, where solids are allowed to settle and break down through natural bacteriological processes. The liquid in the tank drains into a series of perforated pipes from which it percolates through gravel, sand and other permeable materials. As the liquid drains through the soil, remaining pathogens are filtered out and broken down by bacteria and other organisms in the soil.

Figure 6-3 Part of a Pima County wastewater treatment plant. Photo: Barbara Tellman.

Exceeding the capacity of the septic system is one of the most common ways systems fail. High water-use appliances and leaky faucets can cause problems, as can heavy rains. If the soils are constantly saturated, the efficiency of the microbial activity is reduced. Other situations that result in septic problems include failure to expand the septic system when the house it serves is expanded. Even short-term stresses such as visitors can overload a septic system.

Though an overloaded system may show itself in slow drains or sewage backups, a failing system may simply result in incomplete treatment of the waste. Viral contamination, and nitrate and phosphate "plumes" can jeopardize nearby wells. This is particularly troubling since many of the Tucson homes on septic systems also have their own drinking wells.

Failure to have settled solids in the tank pumped out every few years can let solids pass to the drainfield, clogging the system. Additional concerns include; soil compaction from vehicles driving over the drainfield; common household chemicals such as toilet bowl cleaners killing the microbes responsible for breaking down the waste; and lint from washing machines failing to settle in the tank, and then clogging the drain pipes. A further concern is septic tank owners adding solvents to dissolve plugged leach fields. This puts harmful chemicals into the soil.

CENTRAL TREATMENT VS. INDIVIDUAL SYSTEMS

Centralized treatment generally offers better control over water quality than small or individual systems. Centralization also offers more opportunities to reuse or recharge wastewater or for recharge, although in some areas leachate from septic tanks may help recharge the groundwater. In the past, the county has had problems with small privately owned treatment facilities installed as part of a subdivision deteriorating once the subdivision is complete. Local policy discourages such facilities. On-site use of wastewater, however, can be an efficient way of reducing groundwater pumping, without the costs of building new pipelines and pumping the treated water to an outside facility.

Table 6-2 A summary comparison of ways of treating drinking water.

DISINFECTANT	EFFECTIVENESS	PROBLEMS	HEALTH CONCERNS
Chlorine	Highly effective, but not as long lasting as chloramines	In gaseous form can be hazardous; odor and taste problems	Byproducts (THMs) may cause health problems
Chloramine	Retains residual in large distribution systems	Nitrification can lead to loss of residual	Hazardous to fish; should not be used in kidney dialysis process; produces byproducts with unknown health effects
Chlorine dioxide	Mainly used for taste and odor control		Produces inorganic byproducts with unknown health effects
Ozone	Highly effective for very contaminated water, but doesn't leave residual	Energy-intensive/costly	Produces byproducts with unknown health effects
Ultraviolet radiation	Effective, but doesn't leave a residual	Equipment has technical limitations	Not effective against some pathogens
Reverse osmosis (RO)	Can be effective in removing pathogens and minerals, but generally requires pretreatment	Generally very costly; produces brine that must be disposed of and this can waste water	None identified
Nanofiltration	Can be effective in removing pathogens and minerals, but generally requires pretreatment	Generally very costly; produces brine that must be disposed of; mostly unproven in large-scale applications	None identified

HEALTH RISKS OF VARIOUS POLLUTANTS

Water pollution can cause a wide range of health problems. Some of these problems show up within days or weeks after contaminated water is consumed (e.g., dysentery) while others may take years to develop (e.g., cancer) and still others appear in the next generation (e.g., birth defects). Cause and effect is more readily determined when the problem appears shortly after the water is used. When the problem surfaces after a long period of time, cause and effect is more difficult to establish. This is especially true in our mobile society, with people developing a disease at a location other than where they or their parents drank the contaminated

CORROSION

Corrosion of a metal pipe is a process that involves primarily oxygen gas and the spontaneous flow of electricity. Salts found in water have a secondary role in this process. Oxygen gas (O_2) is found in small concentrations in water (4-9 mg/l), as well as in the atmosphere (20 percent by volume). Both Tucson groundwater and CAP are well oxygenated waters, though CAP has higher levels of dissolved oxygen. We can explain metal corrosion by the fact that most metals are very good conductors of electricity and that they have a natural tendency to want to react with oxygen. During the corrosion process oxygen molecules combine with electrons from the metal pipe and acid from the water to form water molecules. The process results in the formation of metal oxides (rust in the iron pipes), which is soft, reddish-brown and has a metallic taste. In essence then the metal pipe dissolves during the corrosion process.

Metal pipe corrosion can start on both sides of a pipe and often does. Poorly protected iron pipes that are buried in wet or waterlogged areas can corrode faster from the outside than from the inside.

Salts and alkalinity can either accelerate or inhibit pipe corrosion by forming scale (calcium carbonates) that limits the contact of oxygen with the metal surface or by dissolving this protective scale, as previously described.

water. Appendix B lists the major pollutants regulated by EPA under the Safe Drinking Water Act and their possible health effects.

Providing Safe Water

Most water providers throughout the nation treat their drinking water in some manner. The common methods are described below. Tucson Water chlorinates most of its water, primarily to provide protection as water flows through pipes and reservoirs. Water providers such as Metropolitan Domestic Water Improvement District (Metro Water) and Flowing Wells also chlorinate their water to prevent diseases caused by microbes. Since groundwater, which is relatively free of pathogens and other harmful substances, is the main source of drinking water in the area, the use of chlorine has been adequate to protect health. Because CAP water is from the Colorado River, a surface water source, more extensive treatment will be needed. Filtration and disinfection is required of all surface supplies or groundwater under influence of surface water. More opportunities exist for contaminants to get into open bodies of water than into groundwater.

Water treatment, which is necessary to prevent diseases such as cholera and dysentery, may cause health problems, mainly because of certain byproducts. EPA has become concerned about some of the byproducts of various disinfection processes and is currently funding research to determine the possible extent that byproducts may cause health problems.

Water treatment can serve five very different functions:

- Remove disease-causing microbes (disinfection);
- Remove toxic materials such as TCE;
- Reduce corrosivity;
- Reduce hardness or TDS;
- Improve taste, odor or appearance.

Each water quality problem is very different and must be solved by different treatment methods. When determining appropriate treatment for CAP water, each problem must be examined separately. In some cases a single treatment method will deal with more than one problem, but in most cases each type of problem requires a different solution.

Filtering Out Particles

Filtration/flocculation, which removes suspended particles from the water, is basic to most forms of treatment. Filtered particles include clays and silts, natural organic matter, precipitants from other treatment processes, iron and manganese and microorganisms. Filtration clarifies water and enhances the effectiveness of disinfection. Filters may be made of a variety of materials, including sand, anthracite, aggregate or activated charcoal. Before filtration, a flocculation agent is added to cause minute particles in the water to coagulate into larger particles to enhance filtration.

REMOVING DISEASE-CAUSING MICROBES

Chemical Disinfection

Water is usually disinfected before it enters the distribution system to ensure that dangerous microbes are killed. Further, if the water travels a distance to the customer or is stored for a period of time in system reservoirs, the disinfectant must remain effective long enough to prevent disease. Chlorine, ozone, and chloramines are most often used for initial disinfection because they are very effective disinfectants. A small amount of chlorine is often added at the end of the process to retain disinfection.

Chlorine has been used throughout this century for disinfection of drinking water to protect public health from diseases caused by bacteria, viruses and other disease causing organisms. Chlorine is highly effective and has become the most widely used disinfectant throughout the world since its introduction in the late nineteenth century. The decline of typhoid and cholera in the twentieth century is a direct result of chlorination of drinking water. While chlorine is effective, there are drawbacks to its use. These include odor, which customers can sometimes detect. Chlorine tends to dissipate in air (which is why swimming pools must be repeatedly chlorinated) and does not remain stable in the distribution system for long periods of time. Also, when used to treat water, chlorine can react with organic substances to form trihalomethanes (THMs) which are toxic disinfection byproducts. Further, when stored or transported as a gas (the usual procedure for large treatment systems) chlorine can be highly toxic if accidentally released. Some water companies have switched to other forms of disinfectants because of these problems.

Chloramines, the monochloramine form in particular, have been used as disinfectants since the 1930s. Chloramines are produced by combining chlorine and ammonia. Chloramine is a weaker disinfectant than chlorine, but is more stable, thereby extending disinfectant benefits throughout a water utility's distribution system. In fact, the primary use of chloramine is as a secondary disinfectant for maintaining a disinfectant residual in the distribution system. Chloramine is not as reactive as chlorine with organic material in water, and therefore pro-

SALINITY, HARDNESS AND ALKALINITY

The mineral content of water is referred to as Total Dissolved Solids (TDS), reported in mg/L. (Mg/L is similar to parts per million.) Total Dissolved Solids are also commonly referred to as "salinity." This is somewhat misleading, however, as not all the salts found in the water are table salts. The TDS measurement includes common elements such as sodium, calcium, magnesium, chloride, sulfate, and bicarbonate that are combined with forms of sulfur and carbon with oxygen. Thus, TDS includes all the dissolved constituents of other minerals such as table salt (NaCl), gypsum ($CaSO_4 \cdot 2H_20$) and calcium carbonate ($CaC0_3$).

Hardness refers to the concentrations of calcium and magnesium ions, but is usually reported in mg/l of $CaC0_3$. Water hardness is linked to scale formation and the reduced cleaning efficiency of soaps.

Alkalinity, also usually reported as mg/L of $CaC0_3$, refers to the amount of carbonates and bicarbonates present in the water. Alkalinity helps control the pH of water. In natural water carbonates and bicarbonates (related to atmospheric carbon dioxide gas) are the major constituents of alkalinity. These naturally occurring chemicals help control the pH of water between 7.5 and 8.5. If acid is added to water the alkalinity helps neutralize the acid without significant change in pH (Alka-seltzer effect). In natural waters moderate alkalinity is beneficial, since it is composed of carbonates that can combine with calcium. Calcium carbonate forms hard stable coatings (caliche-like) inside pipes and helps control (inhibit) corrosion. However, excessive calcium carbonate scale formation can eventually clog pipes, particularly in water heaters and other appliances (e.g., evaporative coolers) susceptible to scale formation. CAP water has about 2.5 times the hardness of Tucson groundwater, but CAP alkalinity is about 10 to 20 percent lower. Therefore, the ability of CAP water to form scale may be slightly lower than that of Tucson's groundwater.

WHAT ABOUT IN-HOME WATER TREATMENT?

Many people buy home water treatment systems to further purify or soften their water. Others use bottled water for drinking. What are the choices?

- *Water softening* Soft water can be obtained with reverse osmosis (which also reduces TDS). Ion replacement systems (also called water softeners) usually replace Ca and Mg with Na or K ions. Note that ion replacement does not change the overall TDS of water appreciably. Note also that soft water with high TDS should not be used to irrigate plants. Since soft water is mostly desirable for washing purposes, an entire water system does not have to be connected to the water softener, possibly just the hot water line. Added salt in the water can be dangerous for people on low salt diets.
- *Removing pollutants* People concerned with synthetic organic pollutants such as pesticides and solvents (TCE) in the water can install activated charcoal or other types of filters on their drinking water taps. These systems work effectively if properly maintained, but bacteria can accumulate if the systems are not cleaned regularly. In order to remove some pollutants such as lead and mercury, ion exchange filters are necessary. Usually these systems are unnecessary in the Tucson area because our water already meets all federal pollutant standards.
- *Improving taste* If the taste of water is a problem, a person can install filters as described above or can buy bottled water. While generally of good quality, bottled water is not regulated by any government agency and the quality may be no different from tap water – in fact, the water may be bottled tap water. Taste is a subjective matter, and some people have definite preferences in the brand of bottled water.

One alternative to increased treatment of all city water is for individuals who want different quality water to use in-home water systems or bottled water. Everyone then is not charged extra for water that will more than meet federal standards. This approach is used in the Yuma area where a high percentage of people have water softeners and buy bottled water. One argument against this approach is that more affluent citizens would tend to have greater access to these strategies.

duces substantially lower concentrations of disinfection byproducts in the distribution system. Because the chloramine residual is more stable and longer lasting than free chlorine, it provides better protection against bacterial regrowth in systems with large storage tanks and dead-end water mains.

Chloramine, like chlorine, is effective in controlling biofilm, which is a slime coating in the pipe caused by bacteria. Controlling biofilms also tends to reduce coliform concentrations and biofilm-induced corrosion of pipes. Because chloramine is not as reactive as chlorine with organic compounds, fewer taste and odor problems occur.

Ozonation

Ozonation is the process of feeding ozone into a water supply for the purpose of decolorization, deodorization, disinfection and oxidation. Ozone, a form of oxygen, is the most powerful disinfectant, but it is not effective in controlling biological contaminants in the distribution pipes because it does not have a long-lasting residual. Ozonation destroys bacteria and viruses and requires a shorter time period to treat water than most other water treatment methods. Ozone, a reactive gas, is made by subjecting oxygen to high electrical voltages. Ozone's reactive nature allows it to readily react with and break up many organic compounds and kill bacteria and other organisms in the water supply. On-site production of ozone is energy-intensive. Ozone treatment is becoming more common in the United States as questions arise about disinfection byproducts. Ozone has been widely used in Europe for 100 years.

Membrane Filtration

Membrane filtration is a relatively recent development. Water is forced through membranes with small pores, and anything larger than the pore size is filtered out. Along with removing materials such as minerals, membrane filtration also can be used for disinfection.

Table 6-3 Comparison of source water quality to federal standards. The figures are averages. Actual quality may vary at different times and places.

WATER QUALITY CONSTITUENT	TUCSON WATER AVRA VALLEY WELLS	TUCSON WATER PRODUCTION WELLS	RAW CAP WATER	SECONDARY EFFLUENT	RECLAIMED WATER	EPA DRINKING WATER STANDARDS
Sodium (mg/l)	41.0	40.1	96.7	112	122	None
Fluoride (mg/l)	0.39	0.36	0.425	0.80	0.93	4.0 (MCL)
Total Dissolved Solids (mg/l)	210	282	611	547	655*	500 (SMCL)
Hardness (as $CaCO_3$) (mg/l)	84	129	266	141	217	None
Alkalinity (as $CaCO_3$) (mg/l)	124	129	105	229	222	None
pH	8.1	8.0	8.12	7.35	7.0	6.5-8.5 (SMCL)
Total Trihalomethanes	No Data	<5.0	<1.83	<3.24	<11.4	100 (MCL)

* Reclaimed water includes groundwater recovered from the Sweetwater US&R Facility. Ambient groundwater is high in TDS.
MCL–Maximum Contaminant Level (EPA Primary Standard) SMCL–Secondary Maximum Contaminant Level

Sources: Adapted from Regional Recharge Committee, Technical Report, Arizona Department of Water Resources, Tucson Active Management Area, 1996.

Four major types of membrane filtration systems are in use: reverse osmosis (RO); nanofiltration (NF); ultrafiltration (UF); and microfiltration (MF). The main difference between the four types is the pore size of the membrane. This influences the amount of energy needed to force the water through the membrane. The membranes must be cleaned periodically. The smaller pore membranes require the most cleaning (backwashing) which is an energy-intensive process and wastes a significant amount of water. (See the section on desalinization below for further discussion of RO and NF.)

• RO has the smallest pore size and removes a great variety of materials from the water, from salts to organic materials and very small microbes. The water to be filtered must be pretreated to prevent pore clogging. In addition, the concentrate of materials removed by the filter is highly saline, causing loss of available water as well as disposal problems. This process is not primarily used for disinfection, although disinfection is achieved in the process of desalting water.

• NF has larger pores than RO and removes, pathogens, organics and some salts. Like RO the process requires pretreatment of water with chemicals or a sand-based system. NF has not been used commercially on a large scale for drinking water.

- UF has larger pores than NF and is highly effective in removing pathogens, including parasites such as giardia, but does not remove salts. Because it has large pores, UF does not leave a saline concentrate, although filters must be backwashed to keep the pores open. It is used primarily in the food and pharmaceutical industries, rather than large scale water treatment plants.
- MF has the largest pores of the membrane systems and removes particles, but not pathogens or organics. MF may be used as a pretreatment process for RO or NF, thus reducing some of the problems of those systems.

Several methods can be combined in the treatment process. Tucson Water initially chose ozone plus chloramine to treat CAP water because officials viewed this as the most effective treatment method with the least risk to human health. The ozone performs the initial disinfection while the chloramine provides the residual to control microbes throughout the distribution system. Tucson Water chose not to use chlorine in the CAP water treatment plant because of concerns about THMs. Tucson Water and some private water companies such as Metro Water, however, use chlorine to disinfect groundwater. THMs generally are not a concern with groundwater since little organic matter is found in groundwater to combine with chlorine.

REDUCING CORROSIVITY

All types of water are corrosive to some degree. Under certain conditions, however, some water sources are more corrosive than others as was evident when CAP water was introduced in Tucson. Several factors influence water corrosivity. Table 6-4 lists these factors and suggests ways of control. CAP water also has sulfate and chloride ion concentrations four to five times higher than groundwater. Some evidence exists that the presence of these ions (in high concentrations) may slow down the formation of carbonate deposits on the water pipes, which impede corrosion. The composition of the pipes also is an important factor. Old iron and steel pipes are highly susceptible to corrosion. The treatment processes described below increase the acidity of the water, which then must be adjusted to avoid corrosion.

Figure 6-4 Concern about the quality of water provided by utilities has caused many people to seek alternative sources of drinking water. Photo: Barbara Tellman.

Maintaining a stable pH about 8.2 to 8.5 is an important factor in controlling corrosivity. The pH of raw CAP water varies, but is generally higher (more alkaline) than Tucson groundwater. When CAP water went through the water treatment process, however, the pH was lowered to a point even lower than most Tucson groundwater–from about 8 to about 7.4. Unless the pH is again raised, the scale forming a protective coating inside the pipes is stripped away, exposing bare metal to the corrosive water. When CAP water was released from the treatment plant, the pH was not readjusted, which was an important factor in corroding pipes. One study showed that the pH varied between 7.0 and 8.4 over the period of CAP water use. In July 1993, for example, the pH was under 7.4 and in August it rose to almost 8.4.

Tucson's long reliance on groundwater caused the inside of the pipes to be coated with calcium carbonate, forming a protective layer on the inside of the pipe. CAP water entering the system wore away this coating in some pipes and exposed the underlying metal to corrosion. In severe cases the pipes broke, and in less severe cases rust from the pipes entered the water, causing a reddish color.

Reducing corrosivity may be as simple as adjusting the pH and waiting for the water and pipes to reach a new balance, or it may be more complex. The three basic ways of dealing with corrosivity are:

- Increase pH by adding sodium bicarbonate, sodium carbonate or sodium hydroxide.
- Promote scale formation by adding phosphate inhibitors such as sodium

orthophosphate, polyphosphate, zinc orthophosphate or silicates.

- Replace or re-line old pipes most subject to corrosion. (Replacing old pipes must generally be done as a maintenance measure.)

Each of these methods has advantages and disadvantages, but most water chemists favor adjusting the pH.

The pH impacts the disinfection process because higher pH increases the amount of chlorine or ozone needed but does not affect the amounts of chloramines or chloride dioxide needed. Increased pH also tends to form higher levels of THMs, but lowers the formation of other byproducts. The disinfection process, in turn, alters the pH. Ozonation, for example, lowers the pH. Tucson Water added zinc orthophosphate to the CAP water to reduce the corrosion after damage had already begun. This strategy not only was unsuccessful but it actually may have contributed to the problem by further lowering the pH, preventing the water and pipes from achieving a new balance. Switching to copper, plastic or asbestos cement water mains would greatly help the situation, but old steel or iron pipes in individual homes might still be vulnerable to corrosion. Blending CAP water with groundwater has been proposed as a solution and is generally supported, but one study indicated that this may actually increase corrosivity unless pH is controlled. According to this study blending would result in a favorable reduction of the sulfate and chloride ion concentrations without significantly changing the beneficial alkalinity. As is shown in Table 6-5, however, many cities do blend Colorado River water without experiencing major corrosivity problems.

REDUCING TOXIC SUBSTANCES

Different toxic substances require different kinds of treatment. Removal of TCE through aeration is discussed above. Because neither CAP water nor Tucson groundwater generally contain problem amounts of other toxic substances, other treatment methods will not be discussed.

REDUCING HARDNESS AND SALINITY

Ion exchange processes are used to reduce hardness and also can be used to remove all

***Figure 6-5 Out of the aborted effort to introduce CAP water to the community arose a brand of CAP humor. Above is a "Fitz" cartoon that appeared in "The Arizona Daily Star" in the spring of 1994. Used with permission from David Fitzsimmons,* The Arizona Daily Star.**

Table 6-5 How some southwestern communities treat their drinking water.

CITY	SOURCE WATER	DISINFECTION METHOD Chlorine	Ozone	Chloramine	Membrane Filtration	Other	SALINITY REDUCTION
CA **Anaheim**	All Colorado River	no	yes	yes	no	hydrogen peroxide	no
Long Beach	50 percent groundwater; 50 percent Colorado River	yes	no	yes	no		no
Los Angeles	Changing blend of Colorado River, State Water Project, and groundwater	yes	no	yes	no		no
San Diego	10-20 percent local rainfall & state water project; 80-90 percent Colorado River						no
NV **Las Vegas (new)**	All Colorado River	yes	yes	yes	no		no
AZ **Buckeye**	All polluted groundwater	yes	no	yes	no	35% water loss; salt disposal in irrigation drainage canals	electrodialysis desalting
Glendale (new)	Salt River Project (SRP) water and CAP water	yes	no	no	ultrafiltration	pilot plant 1 mgd	no
Phoenix Union Hills	SRP water and CAP water	yes	no	no	no		no
Tempe 2 plants	SRP water and CAP water	yes	no	no	no	no	no

Note: Of the above plants, only the Buckeye plant does not begin it water treatment with a basic filtration/flocculation process.

OTHER COMMUNITIES CHOOSE TREATMENT STRATEGIES

The treatment strategies of three towns are described below to illustrate the importance of analyzing community circumstances and needs when choosing a suitable treatment method.

Buckeye, Arizona

Because of a long history of irrigated agriculture, the town of Buckeye's water supply was too salty to drink, having TDS (total dissolved solids) ranging from 1,500 to 4,000 ppm. The water ruined pipes and appliances and "just plain tastes bad." In 1962, the town became the first community in the United States to treat all its municipal water supply with an electrodialysis desalting plant, with a capacity of 65,000 gallons per day (gpd). In 1988, the town constructed a new 900,000 gpd electrodialysis reversal system in place of the old system. The brine from the plant is put into evaporation ponds. When the water evaporates, a saline sludge remains which is released to irrigation canals.

Glendale, Arizona

The rapidly growing City of Glendale needed to build another treatment plant to treat Salt River Project water and CAP water. Officials had four concerns:

- Land scarcity necessitated that the new water treatment plant take up as little space as possible;
- Turbidity needed to be reduced by removing particles in the water, which at times is clear and at other times murky, especially in the rainy season;
- Water had to be disinfected to meet anticipated new EPA standards for THMs;
- Taste and odor problems occurring occasionally due to algae growth in the canal had to be confronted.

Glendale officials decided to use ultrafiltration, a method to remove pathogens, particles and 20 to 30 percent of the organic matter that is a precursor of THMs. Since salinity was not a concern, nanofiltration or reverse osmosis were not considered. A pilot plant producing one million gallons a day will open this spring. If the process works well, a much larger plant will be built. The water is pretreated with chlorine, treated with alum and allowed to settle so large particles drop out. The water will again be dosed with chlorine, then put through membrane filters and finally dosed once more with chlorine in the distribution system. The use of powdered activated carbon helps to reduce occasional taste and odor problems. Glendale does not treat water for corrosivity. Construction and operating costs are acceptable to the city, especially since the cost of ultrafilters has been decreasing as this method becomes more popular, and filters last seven years or more. This type of filtration requires a smaller facility than most other methods, so land use needs were minimized.

Las Vegas, Nevada

Las Vegas gets 85 percent of its water from the Colorado River at Lake Mead and 15 percent from groundwater. The Las Vegas Valley Water District considers Colorado River water to be very high quality water needing little treatment. The treatment process in use today involves disinfection with chlorine, aeration, flocculation, filtration and more chlorine treatment to produce a residual effect in the system. Although the water readily meets EPA standards for THMs, a new treatment plant under construction will use ozone disinfection instead of chlorine to minimize the THM content and meet anticipated new EPA standards. Las Vegas' Alfred Merritt Smith Plant will be retrofitted with five 4,000 pound-per-day ozone generators, and the new River Mountain facility will use three 2,000 pound- per-day ozone generators. A small amount of zinc orthophosphate is added at the end of the process to retard corrosion and chloramine is added for residual disinfection in the pipes. Ozonation will be implemented in the year 2000 at the existing Alfred Merritt Smith Treatment Facility and at the new River Mountain Treatment Facility which will be constructed by 2002. This is the same treatment method used at Tucson Water's Hayden-Udall Treatment Plant.

types of ions, such as arsenic, chromium, excess fluoride, nitrates, radium and uranium. Different ion exchange systems are available, from those useful at the commercial level to small in-home systems. Sodium or potassium is used as the exchange agent in water softeners.

Salinity can be reduced through thermal systems (distillation) or through membrane processes. Thermal processes have been used since 4 B.C. when Greek sailors used an evaporative process to desalinate seawater. The thermal systems use heat to produce water vapor that is condensed to produce fresh water. Approximately 60 percent of the desalting systems used in the world today are thermal systems. Only between 25 percent and 50 percent of the source water is recovered, with the rest left in a highly saline brine. These systems are most useful along the coast where a water supply is not a problem, and the brine can easily be returned to the ocean.

Membrane processes include electrodialysis (ED), reverse osmosis (RO) and nanofiltration (NF). ED uses electricity to move salts selectively through a membrane, leaving fresh water behind. Because most dissolved salts are ionic (either positively or negatively charged) and the ions are attracted to electrodes with the opposite charge, membranes that allow selective passage of either positive or negative ions can accomplish the desalting. The advantage of this type of system in water-short areas is that 80 to 90 percent of the water is recovered and only 10 to 20 percent is lost to the brine.

RO and NF systems physically force water through membranes. Larger suspended solids must be removed to avoid clogging the membranes. The primary difference between RO and NF is in the size of the pores and the energy needed for pressuring the water. The smaller the pores, the more energy is needed.

In any desalting process, a saline concentrate is produced which must be disposed of in some manner. Various options have been suggested for CAP water. These include a pipeline to move the brine concentrate to the Gulf of Mexico, the Salton Sea in California or the Colorado River at Yuma. Another option is to evaporate the brine locally, leaving a solid salt which could be disposed of in landfills. Another possible option would be to join with other Arizona cities to build a desalting plant near the Colorado River. The concentrate could then be more readily taken to the ocean or Salton Sea. Since Phoenix is not interested in participating in building such a desalting plant, this may not be a feasible option. If Tucson adopts desalting as a treatment method, the community would have to accept water losses of between 15 and 25 percent as part of the process. If 130,000 acre-feet of water were desalinated, between 25,000 and 40,000 acre-feet could be lost as brine.

IMPROVING TASTE, ODOR AND APPEARANCE

If taste, odor or appearance problems still occur after one or more of the treatment methods described above, other solutions are available that treat the problem of taste or odor at the source. If the process itself is a source, such as chlorine odor, the problem can be solved through modifying the process or aerating the water. If the source is an event like an occasional algae bloom, the use of activated charcoal may solve the problem. Researchers at Arizona State University are currently researching ways to control taste and odor problems.

Blending

One way to mitigate some water quality problems is to blend water containing unacceptable levels of some contaminant with water that has little or none of the same contaminant. For example, hard water can be blended with softer water to produce water somewhere in between. Water that contains an unhealthy level of a toxic such as TCE can be blended to lower the TCE level below the danger point. Blending, however, is not always as simple as it may appear. Most studies have shown that blending would improve CAP water quality. Tucson Water's latest proposal is for a blend of approximately 45 percent CAP water with 55 percent groundwater.

Soil (Alluvium)-Aquifer Treatment

Some utilities percolate wastewater or river water through the soil for at least part of the water treatment process. The water is then pumped back up for use. Several pilot projects in the Tucson area have been conducted, and research is continuing into the ability of soil and underlying materials to remove contaminants. (The use of the term "soil" is not entirely appropriate because the soil often is scraped off to construct the basins, but since soil is the common term, it is used here.)

Experiments show that soil-aquifer treatment (SAT) removes almost all pathogens, more than 90 percent of organic matter, more than 80 percent of total halogen, and none of the volatile organic compounds such as TCE or dissolved minerals or salts. In other words, SAT can be used for disinfection but must subsequently be treated with chlorine or another disinfectant to ensure safety and to retain residual disinfection in the distribution system. The size and to some degree the composition of the alluvium particles determines such factors as rate of percolation, clogging of the pores by algae and bacterial growth. Clogging can be reduced by alternating wet and dry cycles. This provides time for any algae to die before the water is again applied. Some soils are more porous than others, and the rate of percolation may change over time as pores fill with water. Some pollutants, such as those that are found at landfills, may appear in the water. While some utilities use SAT to treat wastewater, no major utilities use the method to treat water for drinking purposes.

QUALITY OF CAP WATER

CAP water is generally of high quality. It contains no problem levels of toxic materials, and the low levels of microbes are easily treated. The water comes from the Lake Havasu section of the Colorado River. Colorado River water of similar quality is served to more than 25,000,000 people in southern California, Nevada and Arizona. In Arizona and Southern California the water may be blended with water from other sources or used without blending. Some examples of how other communities use Colorado River water are given below.

An important difference between CAP water and Tucson groundwater is the corrosivity of the water. CAP water is more corrosive than Tucson groundwater partially because it contains higher levels of sulfate and chloride. From their experience with CAP water some Tucsonans fully realize that corrosive water can seriously damage pipes and fixtures. As described above, corrosivity depends on pH, TDS, temperature and dissolved oxygen as well as the composition of the pipes.

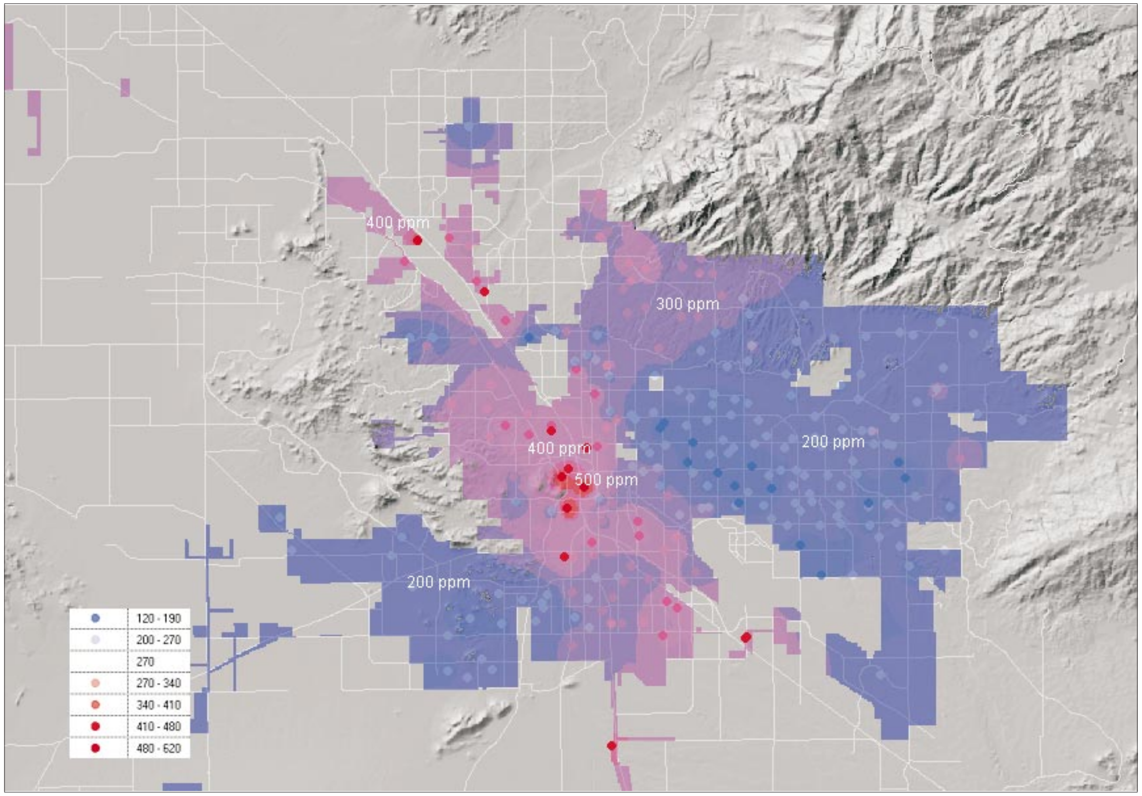
Another major difference is the level of salinitY. (This refers to dissolved minerals, generally not table salt.) Salinity of the groundwater varies greatly according to location, with average salinity in the Avra Valley about 210 mg/l and levels up to 2,500 mg/l detected in groundwater near Green Valley and the mines. As is shown in Figure 6-6, the salinity of water delivered to Tucson Water customers also varies widely. Different sets of wells serve different parts of the distribution system, causing salinity of water delivered to the customer to range from below 200 mg/l to above 650 mg/l. In general, as pumping continues and water levels decline, the salinity of pumped water is expected to increase.

The salinity level of CAP water varies seasonally and from year to year depending on flow conditions on the Colorado River. Higher than average flows generally dilute salinity. In 1995, the average annual salinity of Colorado River water below Parker Dam, when adjusted to average flow conditions, was 775 mg/l – or more than double the average of Tucson groundwater. The TDS of CAP water delivered to Tucson varies also, depending on a number of factors. (Total dissolved solids is approximately the same as salinity.)

As is indicated in Figure 6-7, Colorado River salinity comes from both natural processes and human activities. Natural processes account for much of the salinity, as the river and its tributaries pick up minerals from certain kinds of rocks and soils. Highly saline springs also raise the salinity levels. Irrigation contributes salinity by consumptively using water, concentrating the salinity of the water left behind and by returning water to the river with additional dissolved minerals from soils high in mineral content. Reservoir and canal evaporation, including the evaporation that occurs as water is delivered via the open CAP canal, increases salinity concentrations because as water evaporates, less water is left to dilute the same amount of salts.

The salinity of the Colorado River starts at about 50 mg/l in its mountain headwaters and increases to over 800 mg/l at the Mexican border. Salinity levels have been steadily increasing throughout the lower basin and Mexico as more river water is used and water evaporates from the reservoirs. As a result salinity levels have become a serious concern. Federal and state programs have been enacted to remove salt loading sources on the river and prevent further increases in TDS. These programs have removed thus far approximately 140,000 tons of annual salt load on the river. Continued Congressional funding of these programs, however, is in question. If salinity control programs are cut back or eliminated, TDS levels in the future are projected to exceed 900 mg/l at the CAP diversion point on the river.

Figure 6-6 TDS of water delivered to Tucson Water customers.



Sources: Tucson Water, Water Resources Research Center.

Salinity Concerns

Although the EPA does not consider TDS to be a health issue, TDS is of concern for several reasons. Some level of TDS is desirable in drinking water and gives it a pleasant taste, but as levels increase beyond 500 mg/l many people complain of the taste. For this reason, EPA has set a secondary (voluntary) drinking water standard for TDS of 500 mg/l.

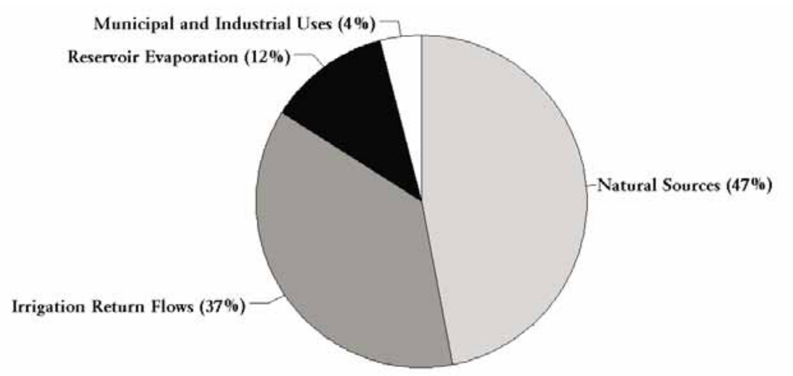
Experience in Tucson and other communities show that as TDS increases, people take action to avoid unpleasant effects. They may buy bottled water, water softeners or home treatment systems, such as charcoal filters or reverse osmosis systems to improve water taste.

Saline water supplies can corrode and shorten the useful lives of water-using appliances such as water heaters, water faucets, dishwashers, clothes washers, evaporative coolers, garbage disposals and toilet flush mechanisms. The useful lives of these appliances and fixtures shorten as TDS levels increase.

High salinity also can cause deterioration of water pipes over time. Damage can result from increased corrosion of metals that come in contact with the water and from scaling of contacted surfaces. Pipe damage resulting from salinity occurs mostly in steel or iron pipes. Damage can occur both in water mains and in domestic piping. Analysis of corroded pipe samples and interviews with Tucson Water staff after the introduction of CAP water in Tucson indicated that the most troublesome pipe was poor quality galvanized steel pipe that lost its protective zinc coating. This left the steel underneath subject to corrosion. Galvanized steel, copper and plastic (PVC or polybutylene) pipe make up a large majority of the pipe used in Tucson households. Approximately 25 percent of pipe used in Tucson area homes is estimated to be galvanized steel. Tucson water mains are mostly asbestos cement and galvanized iron. Out of 2,400 miles of Tucson water mains, 220 miles were galvanized steel or other steel in 1994. By 1998-99, approximately 140 miles had been replaced.

High salinity levels also can reduce crop yields and affect the growth rates of some landscape plants. Soil salinity is controlled by water quality and irrigation practices. For example, water TDS levels between 450 and 2,000 mg/l are considered slightly to moderately saline. Salt tolerance of vegetation varies greatly. The native mesquite, saltbush and some non-native eucalyptus have very high salt tolerance, while the native palo verde and jojoba and the non-native pomegranate and lantana have only

Figure 6-7 Sources of salinity in Colorado River water (measured at Lake Mead).



Source: U.S. Department of the Interior, Quality of Water - Colorado River Basin, 1997.

moderate salt tolerance. Citrus has low salt tolerance, but bermuda and rye grasses tolerate salts well.

Soluble salts can be removed from plant roots by adding excess water (leaching). CAP water has about 2.5 more TDS than Tucson groundwater, but most of the CAP salinity comes from salts that are benign to plants in the soil-plant environment. Dissolved gypsum and calcium carbonates, found in CAP water, are also common minerals in the semi-desert soils. These minerals quickly precipitate (form a solid) and go out of solution in the soil environment and do not raise the salinity of the soil significantly. Compared to groundwater, salt leaching estimates indicate that five to seven percent additional water may be needed to maintain the same salinity in soils when CAP water is used to water plants.

WATER TREATMENT COST

Costs Before Treatment

Your water bill reflects the various costs of pumping and delivering water, repayment of bonds to lay pipes and build reservoirs, disinfection, reading meters and sending water bills, conservation education programs and administration. Further, Tucson Water adds a CAP surcharge to cover the costs of bringing in CAP. When it sells water bonds, Tucson Water repays the principal and interest through water rates, not through taxes or the general fund. Other water providers also collect the cost of building their water systems through the water rates. The bill may also show a sewer charge Pima County.

Treatment Costs

Water treatment is currently a very small part of the water bill, but could become a significant part depending on CAP water treatment choice. Providing specific costs of treatment methods is difficult because emerging technology continues to lower the their costs. For example, the cost of membrane filters is about half what it was just a few years ago. Some generalizations, however, are valid. Adding chlorine is the least expensive treatment method and adds almost nothing to the cost of production, while desalting is the most expensive, especially when the costs of disposing of the brine are included.

Tucson Water spent more than $85 million dollars to build the existing Hayden-Udall Water Treatment Plant in Avra Valley. Customers are still paying for the plant in their water bills. If we are to use CAP water, the least costly treatment alternative probably would be to upgrade that facility using the existing ozone-chloramine system plus proper corrosion treatment. Adopting a very different method — e.g., building a new facility or changing the existing facility over to a new system — would be more expensive. Voters probably would have to approve additional bonds for any new facility.

Water treatment operating costs include the cost of chemicals, energy, salaries, and repair and maintenance. Chloramines and chlorine use almost no energy, and the cost of the chemicals is low. Ozone is energy intensive, since the ozone is produced on site. Membrane filtration is even more energy intensive since the process uses energy to force water through the membrane. The smaller the pore size, the more energy is required to operate the system. Membranes also must be cleaned out periodically since the pores become clogged, although some systems have a self-cleaning technique, which itself uses energy. Membranes must be replaced as they lose their effectiveness.

If desalting is the preferred choice, the costs of disposing of the brine can be high. For desalting systems on sea coasts, this is not a problem. The brine is usually dumped in the ocean, which is a convenient and inexpensive solution

Table 6-6 Estimated operating costs of some treatment methods, not including construction costs.

TREATMENT METHOD	ANNUAL COSTS (cents/1000 gallons)
Chlorine-Chloramines	0.4
Increased Coagulant Dose	5.2
Ozone-Chloramines	9.8
Granulated Activated Carbon (a type of filtration)	18.0 - 28.0
Membranes/NF RO (not including disposal costs)	92.0

Source: McGuire, et al., Disinfectants for Drinking Water Treatment - A White Paper, 1995.

to the problem. For land-locked places such as Tucson, however, no easy solution exists. The brine can be evaporated and the solid matter landfilled or it can be piped elsewhere as brine. In either case, between 15 and 35 percent of the water is lost, increasing water costs. Shipping the brine elsewhere would involve building a pipeline almost as long as the CAP canal itself to the Gulf of California or the Colorado River. While a federal subsidy is possible, it is not likely. If the salts are landfilled, either a new landfill for that purpose must be built or existing landfills would soon fill up. New landfills then would be needed sooner than previously expected – a cost to taxpayers, not to water rate payers. Landfilling in established landfills is not currently considered as an option for various reasons including landfill space and problems of the dried salts becoming airborne.

Although providing specific treatment costs is not possible, voters and elected officials need estimates of cost for various alternatives before choosing a water treatment method. One study found the costs of NF and RO are 10 times higher than the costs of ozone- chloramine treatment, even without considering the costs of brine disposal. According to this study the use of membranes could raise the typical residential water bill by $100 per year or more above the cost of ozone-chloramines.

Decision makers should also compare the costs of not desalinating with the costs of desalinating; e.g. what will it cost consumers to replace water fixtures or appliances that accumulate scale or corrode? What will consumers have to pay to leach salts from landscapes or to buy home treatment systems or bottled water?

ISSUES TO CONSIDER

If CAP water is to be part of the total Tucson water picture, Tucson decision makers need to determine how to deal with the water quality problems listed above. Some of the issues they need to confront are:

- Whether to use CAP water directly in the near future or to recharge it and use it later. In either case some form of treatment will be needed, since recharge does not reduce salinity or provide adequate levels of disinfection;
- Which method to use to disinfect CAP water to ensure it is safe and meets EPA primary standards;
- Which method to use to reduce corrosivity to minimize deterioration of pipes and fixtures;
- Whether or not to reduce salinity and, if salinity is to be reduced, what method should be used and how the brine is to be disposed of; and
- Determine if taste and odor of CAP water are problems and, if so, how to deal with those problems.

While decisions about specific treatment methods may be highly technical and best left to professionals, local residents need to express opinions about the levels of treatment they prefer and what they are willing to pay for CAP water.

Chapter 7
ROLES OF CITIZENS AND GOVERNMENT IN WATER POLICY

The route water takes from its source, whether that be an aquifer or the Colorado River, to its eventual flow from a faucet is a complicated journey. Much more is involved in that journey than the canals and pipes that physically convey water from source to destination. Government rules and regulations also have a powerful influence on water flow, and their workings may seem as complicated as any plumbing system, with various levels of government involved in many different water quality and water use issues. This chapter briefly summarizes the major laws and institutions that control and govern water. Some water management issues also are examined, including whether some type of basin-wide water management agency is needed; whether Tucson Water customers who live outside city limits should be allowed to participate in water decisions affecting them; and whether water service should be privatized.

THE ROLES OF CITIZENS

Over the years citizen groups and individuals have played important roles in setting water policy. People have served on advisory committees such as the City of Tucson's Citizen's Water Advisory Committee, Pima County's Wastewater Advisory Committee and the Arizona Department of Water Resources' (ADWR) Groundwater Users' Advisory Committee for the Tucson Active Management Area (TAMA).

Many non-profit groups have worked hard to support or change policies concerning water over the years. Tucsonans for a Clean Environment worked for cleanup of the TCE problem. In the 1970s, citizen groups such as Arizonans for Water Without Waste, Citizens Against the CAP and Citizens to Revise Arizona Water Law unsuccessfully opposed CAP, and specifically its use in Tucson. These groups, however, played a role in developing alternative strategies, including support of the 1980 Groundwater Management Act. The Southern Arizona Water Resources Association, on the other hand, was initially established to ensure that Tucson got its fair share of CAP water and eventually developed a much broader purpose, including providing information to the community on a wide range of topics. The Tucson Regional Water Council is another group which supports the CAP but has a broader purpose of working to ensure a long-term water supply for the area.

The importance of the "initiative process" in policy making was demonstrated in the 1995 city election when The Pure Water Coalition succeeded in reversing Tucson's policies on CAP water use by persuading voters to approve Proposition 200 and pass the Water Consumer Protection Act (WCPA). The Citizens Alliance for Water Security is following this same tradition in promoting another initiative for the 1999 ballot, which would extend the WCPA. These groups are opposed to direct use of CAP water in the municipal water system, but promote its use for alternate purposes..

Many other citizen groups such as the League of Women Voters, the Sierra Club, the Arizona Native Plant Society and others have been involved in a variety of water issues, from hazardous waste disposal to promotion of low-water use plants in landscaping.

Figure 7-1 The federal government is an important player in determining water policy, especially in water quality matters. Photo: U.S. Library of Congress.

THE ROLES OF GOVERNMENT

Over the past century, various laws and regulations at the federal, state and local levels have impacted how we manage water. In addition, interstate and even international treaties limit the amount of Colorado River water we can take. Finally, various Supreme Court decisions and legal settlements, especially those having to do with Indian water rights, affect our use of water. This chapter describes the most significant laws, regulations and court decisions that affect water decisions in the Tucson area. The annotated bibliography lists sources for more detailed information.

Managing Tucson's Water

No single entity oversees or administers all water use in the Tucson area. A combination of municipal water utilities, private water companies, irrigation districts, school districts, businesses and even individuals provide water in the area. There are 19 water companies with more than 2,000 customers and more than 130 other small water providers. (See Appendix B for a list.) Some water utilities operate within Tucson city limits, and Tucson Water operates both inside and outside city limits. All utilities provide water to customers under rules established by state and federal governments to protect the users and, in some cases, to protect future generations of users. Some laws and regulations protect people from unsafe drinking water, while others are designed to prolong the water supply. Individuals who pump their own water for domestic use are not subject to most of the rules – domestic wells that pump less than 35 gallons per minute are exempted. Those relying on such wells, however, are not protected by regulations to ensure the health and safety of water consumers. Indian tribes generally are not subject to state or federal rules, but often have their own system for managing water and protecting users.

ADWR has authority over some aspects of groundwater pumping within an area designated as the Tucson Active Management Area (TAMA). This includes most of the Pima County portion of the Santa Cruz River watershed. (See Preface, Figure 4, which is a map of TAMA.) ADWR performs overall groundwater supply planning for the area. The agency also approves or denies well drilling permits for all wells except small domestic wells and sets conservation requirements for water providers. ADWR cannot, however, regulate pumping to protect riparian areas nor can the agency coordinate the activities of various users or agencies with water responsibilities. (More information about ADWR's powers and responsibilities is provided later in this chapter.)

The Arizona Department of Environmental Quality (ADEQ) and the U.S. Environmental Protection Agency (EPA), are concerned with the quality of groundwater and surface water. Their mandate is to prevent pollution of

Figure 7-2 The Arizona Legislature has authority in various water management areas. Photo: Arizona Department of Library, Archives and Public Records.

Table 7-1 Agencies responsible for water management in Pima County.

	FEDERAL	STATE	COUNTY-CITY	OTHER
Safe Drinking Water Act	EPA	ADEQ		Water providers may set stricter standards for their companies
Clean Water Act	EPA	ADEQ		
Septic Tank Rules		ADEQ	County Health Department	
Landfills	EPA	ADEQ	County and City each operate landfills	
Pollution, Surface Water	EPA	ADEQ		
Pollution, Groundwater	EPA	ADEQ		
Areawide Water Quality Planning			PAG	
Hazardous Materials	EPA	ADEQ	PCDEQ	
Septic Tanks		ADEQ	PCDH	
Groundwater Allocation		ADWR		
Surface Water Allocation	Bureau of Reclamation for Colorado River Water	ADWR		
Water Rates and Rate Structures		ACC regulates private companies and co-ops, but not cities, or irrigation or improvement districts	Tucson, Oro Valley, Marana for their system	Boards for water companies, co-ops and districts
Floodplain and Stormwater Management	EPA and FEMA	ADEQ	County and City FCDs	

Agencies designated in bold below have the primary responsibility. Others have secondary responsibility and/or implement rules of the primary agency**. EPA -** U.S. Environmental Protection Agency**; ADEQ -** Arizona Department of Environmental Quality**; ADWR -** Arizona Department of Water Resources**; ACC -** Arizona Corporation Commission; **FCD -** Flood Control District; **PCDEQ -** Pima County Department of Environmental Quality**; PAG -** Pima Association of Governments.

water supplies to ensure that consumers get safe drinking water.

The Arizona Corporation Commission (ACC) regulates rates charged by private water companies, but not by irrigation districts or municipal utilities. Its role of protecting the water consumer sometimes conflicts with ADWR's role of requiring water conservation or the use of renewable supplies instead of groundwater. For example, ADWR might require that a utility adopt water-saving strategies. To adopt such strategies, a water provider might need to raise water rates to cover the cost. The ACC, however, has rarely allowed the increased rates. ACC has even prevented rate increases to build treatment facilities to improve water quality. A rate increase is only allowed after a facility is actually in place.

WATER QUALITY REGULATIONS

Tucsonans have experienced occasional water quality problems over the past 100 years. A flowing Santa Cruz River once was used as a water supply, and its quality at times was impaired by cattle and human waste. Shallow wells tended to produce alkali-tainted water. Outhouses contaminated the shallow water table.

Tucson was not unique. Throughout the United States in the nineteenth century water-borne diseases such as cholera, diarrhea, dysentery or typhoid were prevalent. Measures were taken to control water quality problems and laws passed to require that water providers adopt such measures. For example, chlorine was found to be a highly effective disinfectant by the late 1800s, and most major municipal supplies were chlorinated by 1920. A dramatic drop in water-borne diseases in the United States resulted. By the 1950s, however, people began to be concerned about human-made pollutants, especially toxic substances such as DDT. Developing technologies to deal with chemical pollutants took longer than working out solutions to health problems relating to bacteria and viruses. The problem was more complex, with thousands of different pollutants. Recently, concern has focused on parasites found in water supplies, such as cryptosporidium and giardia. These have caused widespread sickness, even death in several cities and are difficult to control by traditional methods.

Various legislative efforts were made to improve water quality. Congress passed the Clean Water Act in 1972 to protect surface waters from pollution. The law initially listed only a small number of pollutants, but more were added to the list as the law was applied over time. The act attempts to maintain water quality by controlling the kinds of wastes that are released to surface waters. In 1974, Congress passed the Safe Drinking Water Act to assure that drinking water supplies were safe. In 1980, Congress passed the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), more commonly known as the Superfund Act. This law is designed primarily to clean up areas that were polluted in the past and to prevent the occurrence of future contamination from hazardous materials. In 1980, the Arizona Legislature passed the Environmental Quality Act which, among other intents and purposes, protects the quality of groundwater. Other significant laws that protect water quality regulate hazardous materials and disposal of wastes. Most of these laws are discussed later in this chapter. Table 7-1 briefly shows which agencies are responsible for various water management matters.

Surface Water Quality

Federal and state laws and regulations, under the umbrella of the federal Clean Water Act, regulate surface water quality. The state and EPA administer portions of the federal program. States have the right to set their own water quality standards using EPA guidelines. These standards are to be reviewed every three years. EPA then issues permits and, if needed, takes enforcement actions based on the standards. EPA, however, also issues National Pollution Elimination Discharge System (NPDES) Permits.

Point Sources

Point sources of pollution are those sources that come from a discreet location such as a pipe. Point source discharge standards and permits are based on the adoption of the best available pollution reduction technology. Point sources are much easier to regulate than non-point sources — pollutants that come from a wide area, with no discreet discharge point. A local example of a point source is the outflow pipe from the Ina Road Water Pollution Control Facility.

The law requires that the level of water quality necessary to protect existing designated uses be maintained and protected. No degrada-

Figure 7-3 The origins of point source pollution are distinct and identifiable; hence a point source also is called an end-of-the-pipe source. Photo Barbara Tellman.

tion of existing water quality is permitted in a navigable water if the existing water quality does not meet applicable water quality standards. Where existing water quality in a navigable water meets or exceeds applicable water quality standards, the existing water quality must be maintained and protected. A procedure exists, however, for the ADEQ director to allow limited degradation in some cases.

NPDES permit conditions and water quality standards are ultimately based on criteria developed by EPA. These criteria are supposed to accurately reflect the latest scientific knowledge regarding such matters as the effects of pollutants on the health and welfare of humans and wildlife; the effects of pollutants on biological communities; and biodiversity for varying types of receiving waters.

An important purpose of regulation is to protect designated uses. An established use is not easily changed to a less protective use. Such a change can be made, however, through the "use attainability analysis" process in which the applicant must prove that the existing protected use does not actually exist in the stream.

Non-point Sources

Non-point source pollution is pollution that comes from several diffuse sources, not through a specific discharge – e.g., grazing. It is usually regulated through Best Management Practices (BMPs), which are guidelines developed through consultation between ADEQ and the affected industry. BMPs are intended to achieve a specific water quality goal, rather than mandating specific prescribed conditions. For example, Arizona has BMPs for grazing. The business or industry then is required to meet performance-based standards.

NPDES Permits.

One section of the law sets requirements on industries and local governments to abate pollution. The EPA issues NPDES permits to entities that discharge to "waters of the United States." (This is defined very broadly.) Permit conditions are set according to federal requirements, but with specific requirements often based on local conditions. The permits are for a specified period of time, but are renewable. Sometimes the conditions are changed when the permit is renewed. An example of an entity with a NPDES permit in Pima County is Pima County Wastewater Management Department.

Stormwater Permits

Stormwater runoff from urban areas is a major non-point source of pollution in watercourses. Arizona, with its dry washes and months without rain, experiences special problems with runoff. Pollutants such as oils settle on roads, and the infrequent rains allow pollutants to accumulate. During summer storms, many streets fill with water that rapidly drains to washes and ultimately to rivers, carrying large amounts of pollutants that have collected on the streets. The daily news often contains warnings to drive carefully during the first major summer rain because of oil slicks on the streets. Also insecticides, cleaning fluids and other domestic pollutants might be present in stormwater, as well as industrial pollutants, although these are more carefully controlled than domestic pollutants.

Pollution from urban stormwater runoff is very difficult to control since it comes from thousands of sources and enters washes and rivers in many different ways. As awareness of stormwater quality problems increased, Congress directed EPA to develop regulations requiring large cities to establish programs to control urban runoff. EPA regulations considered urban population figures to determine which cities needed a NPDES permit. Both Tucson and Pima County fit the criteria for needing a permit. The county submitted a two-part permit application, with the first part submitted in 1991 and the second part in 1993. The city filed a storm water permit application with EPA in 1992 and in 1998. Both city and county permits were approved.

To obtain a NPDES permit, an applicant must address various EPA concerns. Measures must be taken to control such activities as illicit connections and illegal dumping to storm drains and to control runoff of pollutants from municipal landfills, industrial facilities and construction sites. The applicant also must inventory land uses to determine the quantity and quality of discharged water and develop a management plan for stormwater runoff. This plan involves identifying problem areas and working out strategies and practices to reduce the flow of pollutants into bodies of water. As part of the plan, the applicant must describe what already has been done to eliminate pollutants from stormwater runoff as well as what new efforts will be undertaken to further control such pollutants.

Pima County's permit requirements include street sweeping, land development controls, a household hazardous waste program and a stormwater sampling program. The county also advises businesses and construction personnel about stormwater regulations.

The City of Tucson has an ongoing Stormwater Master Plan (TSMP) incorporated into its NPDES permit. The TSMP emphasizes the preservation of naturally vegetated watercourses to improve water quality and urges residents to harvest rainwater. Retaining stormwater on property reduces runoff flowing over streets and paved surfaces and picking up various pollutants. Other aspects of the permit include conducting site inspections of private developments on five acres or more. Also, the city will inspect industrial sites that are required to obtain NPDES permits, to ensure they are in compliance. The city also monitors stormwater quality problems in the community to anticipate and prevent problems before they occur. The city also is emphasizing public education or outreach, to make people aware they have a personal effect on stormwater quality.

TREATMENT PLANT FUNDING

Another section of the Clean Water Act provides financial assistance for constructing municipal wastewater treatment plants. The law has been more successful in controlling biological pollutants than in dealing with toxic materials. During the 1980s, Congress provided funding through EPA to build wastewater treatment systems. Most of Arizona's large treatment plants were built at least partially with federal subsidies which helped pay the costs of growth. In the 1990s, these funding sources dried up as Congress cut back on federal spending. The program changed to a "revolving fund" which provides seed money for loans to communities for wastewater treatment. The loan payments are in turn made available to other communities as loans to continue support for building their wastewater treatment facilities.

Figure 7-4 Rainfall flowing over urban surfaces picks up various constituents and forms urban runoff nonpoint source pollution.

GROUNDWATER QUALITY LAWS

Arizona's Environmental Quality Act is designed to prevent groundwater pollution. Not federally mandated, the act is entirely an Arizona initiative, passed in response to serious groundwater pollution problems. The act called for the creation of ADEQ, to manage water and air quality and solid waste regulation.

The heart of the water quality section of the law is a requirement that anyone who plans water discharges that might reach groundwater must go through the Aquifer Protection Permit (APP) process. This applies to discharges directly to watercourses as well as discharges on dry land overlying a groundwater source. The applicant must show that the discharge will not cause or contribute to a violation of Aquifer Water Quality Standards as defined by regulation. All aquifers are considered to be drinking water aquifers with drinking water standards, unless reclassified for a lesser quality. An aquifer that does not meet drinking water standards for some constituents, but meets the standards for others may have a different level of standard for each constituent. The standard is not necessarily determined at the point of discharge, but may be determined at a point underground and is influenced by existing water quality. If a standard for that groundwater has already been exceeded, the applicant must demonstrate that no further degradation will occur.

Applicants must use Best Available Demonstrated Control Technology (BADCT) to obtain a permit. Certain dischargers, such as agricultural dischargers, which fit into a group sharing common characteristics, do not have to go through the full process. Instead they may be treated as part of the "General Permit" process that already has established rules. Exemptions to the APP requirements include households, stock ponds, mining overburden returned to the excavation site, water transportation systems, community sewer systems, storm water impoundments, water storage facilities and water used for public landscaping (e.g., golf courses).

The law also has a permitting system for recharge and underground storage facilities. ADWR reviews such facilities for water supply concerns and ADEQ reviews the water quality matters. The applicant must meet all APP regulations except BADCT requirements.

Wastewater reuse projects also go through a permitting process. Regulations are stricter when treated wastewater is to be used in areas accessible to the general public (e.g., school yards) than when used in areas that are fenced, with restricted public access (e.g., an industrial site). Edible crop irrigation with effluent is the most strictly regulated.

HAZARDOUS WASTES

EPA has requirements for underground storage tanks, with special emphasis on gasoline tanks. The agency also has a wellhead protection program for discharges in the vicinity of water wells. EPA also regulates hazardous waste sources and landfills and maintains the Superfund or CERCLA, which is designed to clean up hazardous waste sites. The polluter then may be charged for the cleanup. Far more sites have been identified nationally than have been cleaned up under this program. Arizona has 111 official Superfund sites, with few having been cleansed of hazardous materials. A curious feature of the Superfund program is that it exempts oil-based hazardous wastes. Arizona's WQARF (Water Quality Assurance Revolving Fund) helps pay for clean up of polluted sites that do not meet the Superfund definition. Lack of funding has plagued the program.

Wastewater and Septic Systems

If wastewater is released to a surface water source, a NPDES permit is required. ADEQ requires a permit if wastewater is reused, recharged or released into a constructed wetland. County health departments, under ADEQ oversight, administer septic tank permits under state legislative rules.

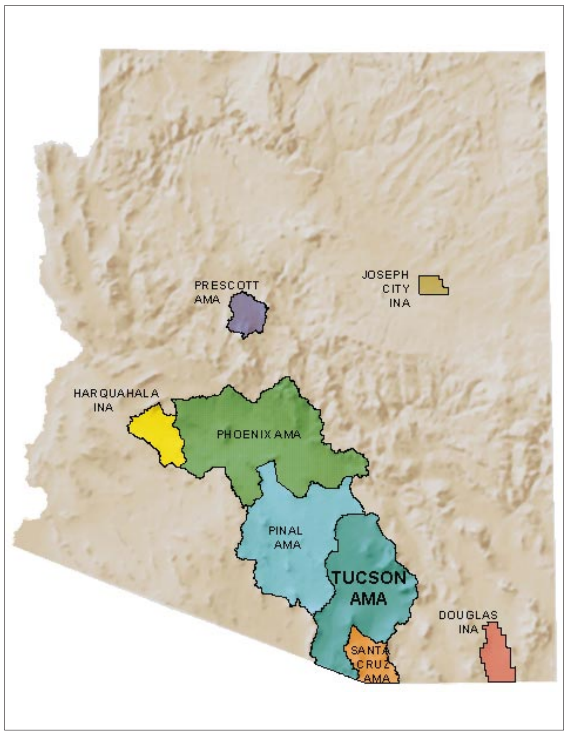
SAFE DRINKING WATER ACT

The federal Safe Drinking Water Act regulates the quality of water provided to consumers by water companies and municipalities. Under this act, EPA regulates public water systems, defined as those that pipe water to at least 25 people or 15 connections for at least 60 days per year. These systems may be owned by homeowner associations (e.g., Winterhaven), investor-owned water companies (e.g., Green Valley Water Company), cities and towns (e.g., Tucson Water), domestic water improvement districts (e.g., Metro Water), irrigation districts serving domestic customers (e.g., Flowing Wells Irrigation District) and others (e.g., The University of Arizona).

The act does not cover smaller services or individual domestic wells. EPA sets basic standards for pollutants of concern and requires water providers to take certain measures to meet those standards. EPA is supposed to identify the potential pollutants in drinking water, study their possible health effects and set standards for the problem pollutants. The list grows as new problems are detected. New regulations adopted in 1998, for example, require water providers to control cryptosporidium, a water-borne parasite that poses a public health threat. The law requires testing at regular intervals and consumer notification if standards are not met. Although numerous violations have been recorded in recent years in the Tucson area, almost all those violations were for technical errors, such as failure to report or monitor. Almost no cases were reported of water quality standards being exceeded.

EPA recognizes that small water providers, unlike large utilities, often are unable to afford certain types of testing and treatment procedures. Variances therefore are allowed based on financial condition and the number of customers served. Smaller companies, however, must still use the best available technology within a certain price range. In addition, funding is available to assist those small companies with the greatest needs. Drinking Water Revolving Funds were created in each state to channel federal money to small water providers. EPA sets requirements for states to follow to maintain eligibility under this program

Figure 7-5 Arizona's Active Management Areas and Irrigation Non-Expansion Areas.



WATER SUPPLY REGULATIONS

Our present system of water law grew out of the intense competition for water among early American miners and settlers. People at that time were competing for surface water, and the laws that developed were intended to protect the rights of those who arrived first from the claims of those who arrived later. The law to determine surface water rights is called the prior appropriation doctrine. By the early 1880s, most of the surface water in the Tucson area was claimed for use.

Competition for groundwater developed much later when increasingly powerful pumps enabled pumpers to draw water from beneath lands owned by others. Groundwater laws were passed in the 1950s to protect existing farmers from being pumped dry by new farms. The laws, however, hardly take note of the fact that some groundwater and surface water are actually hydrologically connected. Pumping that affects surface water rights is therefore legal throughout most areas of the state because under Arizona law, surface water and groundwater are generally considered to be separate.

As more people moved to Arizona, the burgeoning urban areas competed with agriculture for groundwater. In 1980, the Legislature passed the Groundwater Management Act (GMA) which sets goals and policies for the most problem-plagued parts of the state. ADWR, which was established to administer the GMA, is responsible for allocation of both surface water and groundwater.

GROUNDWATER MANAGEMENT ACT

Central to the GMA was the establishment of four Active Management Areas (AMAs) in areas of the state with the greatest groundwater overdraft problems: the Phoenix, Prescott, Pinal and Tucson AMAs. A fifth, the Santa Cruz AMA, was created in 1994 when it was split off from TAMA. Some other areas were designated Irrigation Nonexpansion Areas (INAs). (See Figure 7-5.) In these areas, new pumping for agriculture is limited, but other pumping is not. Most of eastern Pima County is included within TAMA. There are no INAs within Pima County.

Each AMA must develop five successive plans for reaching its goal over the period 1980 to 2025. The first four plans each cover a ten-year period, while the last plan covers the final five years. The AMAs are currently preparing to enter the third management period, which covers the years 2000 to 2010. TAMA issued its draft Third Management Plan in the fall of 1998.

"PAPER" OR "WET" WATER?

"Paper water" is a term coined to distinguish between actual usable water ("wet water") and water that exists only as a calculated figure to satisfy certain requirements. A water budget, for example, may include assumptions about how much water will be recharged in a large area, without considering whether the water is in fact available for recharge or, if recharged, whether it can be recovered in an area where it is needed. The budgeted water therefore is a calculated figure and represents "paper water."

Safe Yield

The management goal designated for all AMAs except the Pinal AMA is that of reaching "safe yield" by the year 2025. Achieving safe yield involves reaching, and thereafter maintaining a long-term balance between the annual amount of groundwater withdrawn and the annual amount of natural and artificial recharge within an AMA. Each AMA has its own criteria for satisfying the requirements. For example, the Phoenix AMA allows 7.5 percent of the annual supply to be mined groundwater. In TAMA, as much as 15 percent can be mined groundwater. The balance must come from renewable supplies — CAP or other surface water. Therefore, even the GMA safe yield requirements allow depletion of groundwater, but over a long period of time. In the Draft Third Management Plan for TAMA, ADWR states that even with use of CAP water and conservation measures, the safe yield goal will not be met.

The ADWR water budget is calculated by estimating water use based on projected population, probable per capita water use, agricultural and industrial use and Indian use. Supply is based on assumptions about CAP use, recharge and effluent use. Estimating up to 45 years into the future is obviously difficult, and projections are revised in succeeding management plans. For example, population estimates for TAMA in the year 2025 have been revised downward, from 1,693,000 people in the Second Management Plan (SMP) to 1,266,500 in the Third Management Plan (TMP). These figures represent official state projections.

Assured Water Supply

New subdivisions are required to demonstrate that they have an "assured water supply" before being built. What counted as an "assured water supply" originally was very broad and included groundwater withdrawals that would lower the water table by as much as 1,000 feet. An assured water supply also could be demonstrated by contracting for CAP water or subcontracting with an entity that had contracts for CAP water, whether the CAP water ever reached the subdivision or not. Assured water supply rules have been revised and somewhat tightened to include the following criteria:

- Sufficient quantity of water is continuously available to satisfy the water demands of the development for 100 years;
- Water source meets water quality standards;
- Proposed use of water is consistent with conservation standards;
- Proposed use is consistent with water management goals; and
- Applicant is financially capable of installing the necessary water distribution and treatment facilities.

The concept of assured water supply does not assure sustainability for more than 100 years, and the requirements can be met in some ways that do not assure sustainability. Participating in a recharge program or contracting for CAP water can be sufficient to meet the requirement.

Municipal Conservation Programs

AMAs establish conservation goals for each municipal water provider or major agricultural or industrial water user. Large municipal water providers are allowed to choose among four programs to regulate their water use. The total gallons per capita per day (gpcd) program is the base program, under which gpcd goals are set for each provider. If goals are not met, a provider can be fined, although provisions allow water use in very dry years to be balanced with use in wet years. Alternative approaches include:

- **Non-Per Capita Conservation Program**, which allows water providers having resources to implement conservation programs as well as access to alternative supplies, to implement specific indoor and outdoor water conservation measures as well as education programs instead of meeting specific gpcd goals. To be accepted into this program, providers must demonstrate that they have reduced groundwater use.

Table 7-2 The draft water budget for the Tucson AMA.

Third Management Plan Scenario: Projected Future Conditions Assuming Third Management Plan Conservation Goals are Achieved by 2010 and Continue through 2025, Tucson Active Management Area

SECTOR	1990	1995	2000	2005	2010	2015	2020	2025
Projected AMA Population	655,000	768,000	838,300	921,000	1,005,300	1,092,200	1,179,200	1,266,500
Projected Irrigation Acres	40,000	36,100	35,320	35,750	33,900	30,400	26,400	21,400
MUNICIPAL SECTOR								
Total Demand	130,100	155,500	171,900	186,300	199,800	216,200	230,000	243,100
Total Supply	130,100	155,500	171,900	186,300	212,100	232,000	249,800	267,100
CAP	0	100	8,500	107,000	108,100	119,500	131,700	143,800
Effluent	6,300	7,700	11,600	23,400	32,900	36,000	37,100	37,700
Groundwater	123,800	147,700	151,800	55,900	58,800	60,700	61,200	61,600
AGRICULTURAL SECTOR								
Total Demand	93,800	98,000	104,700	117,700	107,500	97,000	85,000	70,000
Total Supply	93,800	98,000	104,700	117,700	107,500	97,000	85,000	70,000
CAP	0	0	0	10,400	15,800	15,800	15,800	15,800
Effluent	4,000	1,800	3,000	3,000	3,000	3,000	3,000	3,000
Groundwater	89,800	96,200	101,700	104,300	88,700	78,200	66,200	51,200
INDUSTRIAL SECTOR								
Total Demand	48,800	60,200	71,000	72,100	73,300	73,000	74,200	75,400
Total Supply	48,800	60,200	71,000	72,100	73,300	73,000	74,200	75,400
CAP	0	0	0	0	0	0	0	0
Effluent	800	800	1,300	1,700	2,900	3,600	4,200	4,700
Groundwater	48,000	59,400	69,700	70,400	70,400	69,400	70,000	70,700
Evapotranspiration	3,700	3,700	3,700	3,700	3,700	3,700	3,700	3,700
Total Demand	276,400	317,400	351,300	379,800	384,300	389,900	392,900	392,200
Total Groundwater use	265,300	307,000	326,900	234,300	221,600	212,000	201,100	187,200
(Less) Net natural recharge	60,800	60,800	60,800	60,800	60,800	60,800	60,800	60,800
(Less) Incidental recharge	70,300	82,300	80,800	39,600	35,000	34,400	33,600	32,300
(Less) Cuts to aquifer	0	0	5,100	32,900	35,800	37,700	41,400	45,100
(Less) Extinguished credits	0	0	11,700	8,400	7,900	7,600	0	0
Actual Overdraft	134,200	163,900	168,500	92,600	82,100	71,500	65,300	49,000
(Less) Remediation water	0	0	8,400	7,000	6,500	6,500	6,500	6,500
(Less) Allowable groundwater	0	0	10,000	32,200	34,700	36,200	36,400	36,400
Accounting Overdraft	134,200	163,900	150,100	53,400	40,900	28,800	22,400	6,100

NOTE: all units are acre-feet unless otherwise noted.

Source: Arizona Department of Water Resources, Draft Third Management Plan, Tucson AMA, 1998.

ADWR monitors the implementation and results of these measures.

- **Alternative Conservation Program**, which allows providers with an unusually large and growing amount of non-residential water use (e.g., a major new industrial plant) some flexibility in meeting conservation requirements. After limiting annual groundwater withdrawals, providers must meet gpcd requirements for residential users only, while implementing specific conservation measures for non-residential water users. ADWR monitors achievement of residential water use goals and implementation and results of non-residential conservation measures.
- **Institutional Provider Program**, which allows providers serving primarily non-residential users, including prisons, hospitals, military installations, airparks, and schools, to meet conservation requirements designed specifically for non-residential use. These conservation requirements usually include specific conservation measures for non-residential uses and a maximum residential gpcd rate.

Small water providers, defined by ADWR as serving less than 250 acre-feet of water per year, generally lack the resources to implement conservation programs, and are exempt from meeting specific gpcd requirements. Small providers are required to meet "reasonable conservation requirements," as established by the director of ADWR.

ADWR has no authority to enforce conservation requirements directly on water users or consumers, only on water providers. This causes problems for some water companies. Regulated by the ACC, private water companies have to assume the initial costs of conservation programs since they are unable to charge their customers for the cost of such programs until the program has been proven effective. Also changes in rate structures to encourage conservation have to go through a rate hearing process before the commission. The ACC does not regulate municipally-owned water companies, but such utilities including Tucson Water, Oro Valley Water and Metro Water go through their own public process before changing water rates.

Agricultural Conservation Requirements

The GMA regulates agricultural water use in several ways. First, no new agricultural land can be developed for irrigation within AMAs and INAs. Only lands which were legally irrigated with groundwater in the five years prior to implementation of the GMA in 1980 may continue to be irrigated with groundwater. Such lands received an Irrigation Grandfathered Right. Only holders of the right may withdraw, receive and use groundwater for growing crops on two or more acres of land within an AMA.

Second, farms are given a maximum annual allotment of groundwater to be used for irrigation. The allotment is calculated by multiplying the maximum number of acres irrigated at any time from 1975 through 1979 by an irrigation water duty. The irrigation water duty is calculated from the annual amount of water per acre that is reasonable to apply to produce the crops that were historically grown from 1975 through 1979. This irrigation water duty is reduced over time as increasing water application efficiencies are required.

In order to allow for variations in weather and changing agricultural market conditions, farms are given a flexibility account, allowing them to accumulate credits for the difference between their actual water use and the groundwater allowance, or borrow from the account if their actual groundwater use exceeds their allowance. Accumulated credits can be used in future years, if needed, to meet conservation requirements. There is no limit to the number of flexibility credits that can be accumulated, and farms are allowed to borrow up to 50 percent of their maximum annual groundwater allotment. Annual groundwater allotments were set near the historic peak of irrigated acreage; thus much more groundwater than is needed is legally available to farmers each year. With irrigation efficiencies increasing on farms and significant amounts of farmland out of production, many farms have accumulated large flexibility account balances.

Industrial Water Use

AWDR assigns conservation requirements specific to each category of industrial water use and encourages substitution of renewable water sources for groundwater.

- **Turf-Related Facilities** are given annual water allotments calculated for each facility. Water for golf courses is generally limited to 23.8 acre-feet per hole, or enough water for 5 acres of turf per hole at 4.6 acre feet per acre.
- **Metal Mines** must limit water loss from tailings ponds, recycle water, and reduce water use for dust control.
- **Power Plants** must achieve a specified number of "cycles of concentration" when they

are in full operation. Cycles of concentration is a measure of the degree to which cooling water is recycled. As water is recycled, salt concentrations increase due to evaporation, and fresh water must be added. Maximizing cycles of concentration saves water.

- **Large-Scale Cooling Facilities** must reach specific concentrations of silica or total hardness in the water used for cooling before the water is discharged and new water is used.
- **Sand and Gravel Operations** must recycle wash water and implement two additional conservation measures related to dust control and cleanup activities.
- **Dairies** are given annual water allotments based on assumed water needs. Dairies can alternatively apply to the director of ADWR to be regulated under the Best Management Practices Conservation Program, under which a combination of such practices will be required.

INDIAN WATER RIGHTS

In general, federal environmental laws do not apply to tribal lands. Most tribes have their own environmental and/or wildlife agencies, with regulations often modeled on federal laws. Since tribes control some headwaters of Arizona rivers, actions on tribal lands may significantly affect nontribal areas. Conversely, actions on nontribal lands have affected Indian lands. In some cases, nontribal entities such as mines have been allowed to use tribal lands with fewer environmental restrictions than would apply on nontribal land. Tribes and the U.S. Bureau of Indian Affairs have become more cautious in recent years about agreements that might result in polluted, waters and have more vigorously enforced their laws.

This photo has been removed due to copyright restrictions on the web

Figure 7-6 Tohono O'odham ollas, or clay water jars, from the nineteenth century are reminders of Native Americans' early water rights. Photo: Arizona Historical Society/Tucson.

The settlement of Indian water rights is an issue with broad implications throughout Arizona, not only to the tribes involved but also to non-Indians. Throughout much of U.S. history, Indians, their water rights systematically ignored and violated, have been an aggrieved party. The basis for Indian water rights claims is a U.S. Supreme Court decision (the Winters Decision), which established the principle that when the federal government set aside lands for Indian reservations or to serve other federal purposes, the government also implicitly reserved sufficient water rights to accomplish the purposes for which the reservations were created. These unrecorded and unquantified Indian water rights therefore were established at the time reservations were created, and so generally predate Anglo, non-Indian water rights. Although the Winters Decision was decided in 1908, only recently have Indian water rights gained serious recognition in the courts.

Settling Indian water rights is very important to Arizona. With 21 Indian tribes controlling about 28 percent of the state's land base, tribal water claims are extensive. Some observers argue that total tribal water rights in the state could exceed Arizona's total surface water supplies. With no new sources of water available to allocate to tribes, water to settle Indian claims could come from present water users. The senior priority dates of Indian water rights means such rights have precedent over later water claims, usually belonging to non-Indians. Some CAP water, however, is presently unallocated and is available for use in Indian water rights settlements.

The state of Arizona presently is involved in adjudications of the Gila River and Little Colorado River watersheds to determine the types, amounts, and priority dates of the rights of all water users in the watersheds. First initiated in 1978, the two Arizona adjudications will eventually determine the water rights of most water users in the state, including Indian tribes and the federal government. Seven tribes have filed claims in the Gila watershed, the principal watershed in Arizona incorporating the state's largest population centers, Tucson and Phoenix. The Gila River adjudication is estimated to be the largest lawsuit ever filed in the United States, affecting 60,000 parties, including many in Pima County.

Tohono O'odham Water Rights

Although representatives of state, federal and tribal governments usually negotiate Indian water rights, implications of settlements can greatly affect cities and counties. For example, an understanding of the Tohono O'odham (Papago) water claims is essential when considering Tucson's water future.

Tucson's early growth and development depended upon groundwater found in the Upper Santa Cruz Basin. This aquifer extends beneath the San Xavier District of the Tohono O'odham. As early as 1881, the Tucson Water Company drilled wells east of San Xavier to obtain water. This wellfield developed with the growth of the city, and by the 1970s Tucson pumped approximately 40,000 acre-feet of water annually from wells located just outside the reservation. Having by law to rely on an unresponsive federal government to promote and protect its interests, the tribe was left at a distinct disadvantage.

By 1976, after several court cases that supported and defined Indian water rights, the Tohono O'odham were in a position to claim most of the available water in the Tucson Basin. The implications to non-Indian interests of such a claim were vast, with the possibility that bond ratings would be jeopardized, private loans more difficult to obtain, economic growth halted, and water possibly reallocated from current users to the Tohono O'odham.

In 1975, the federal government, on behalf of the Tohono O'odham, sued the City of Tucson, mining companies and agricultural interests. In brief, the suit claimed the defendants damaged the tribe's water rights by excessive pumping. The tribe had at least two strategies to follow: negotiate a settlement or precede with the suit to its final resolution. In the face of the cost, time and various uncertainties associated with a court case, a consensus developed that a negotiated settlement would be in the best interest of all involved.

Tucson took the suit very seriously as is indicated by an excerpt from an *Arizona Daily Star* editorial at the time: "More than a century of government failure to preserve the Papagos' interests assured the tribe a court victory. And victory for the Papagos could have meant the permanent shutdown of mines and farms and an end to city growth and development." Such dire consequences, however, were unlikely, even with the Indians winning a court case.

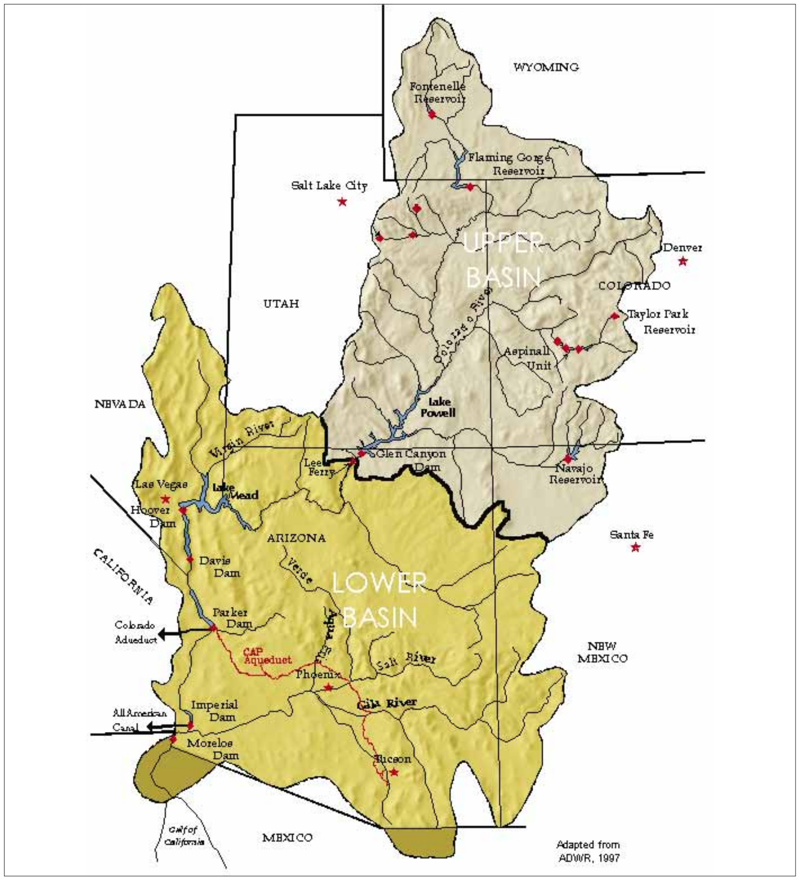
Negotiations took place with the express goal "to develop a fair and reasonable water resources plan which will satisfy the present and future water needs of eastern Pima County," including "a speedy resolution of Papago Indian water right claims." In making the best of a threatening situation, non-Indians used the suit as part of a strategy to benefit their own interests. By claiming that Colorado River water would be needed to negotiate with the Tohono O'odham, non-Indians were building a case for the federal government to complete the CAP canal to Tucson. Whatever settlement was negotiated would need to be financed by federal legislative appropriation.

Southern Arizona Water Rights Settlement Act On October 12, 1982, after agreement was reached by both House and Senate, President Reagan signed into law the Southern Arizona Water Rights Settlement Act (SAWRSA). The act obligated the U.S. Secretary of Interior to deliver 66,000 acre-feet per year to the San Xavier and Schuk Toak districts of the Tohono O'odham Nation. This total is to include 37,800 acre-feet of CAP water and 28,200 acre-feet of wastewater effluent or exchange water, which may be used to exchange for another type of water suitable for agriculture. The tribe has the right to market its negotiated water to users within TAMA or parts of the Upper Santa Cruz Basin not within TAMA. Costs associated with the delivery of CAP water under the sale, exchanges or temporary dispositions are non-reimbursable. The act also established a cooperative fund to pay operations, maintenance and repair charges related to delivery.

A schedule was set for delivering water and developing facilities for its use. Meanwhile a dispute arose among the Tohono O'odham Nation, its San Xavier District, and allottees, individual land owners on the San Xavier District. The dispute was the result of developing opposition to dismissing the U.S. v. Tucson lawsuit and to the terms of the SAWRSA settlement. The dispute spawned two additional lawsuits: Alvarez v. Tucson and Adams v. U.S.

Since about 1990, efforts have been made to negotiate an agreement between the allottees, the nation, the federal government and the major defendants to implement SAWRSA and dismiss the lawsuits. Negotiations are ongoing.

Figure 7-7 The Colorado River Basin.



Meanwhile work which was to be done by the U.S. Bureau of Reclamation to develop the facilities for delivering and using the water on the reservation has been delayed, although construction began in spring of 1999 on a pipeline to take water to the San Xavier District for agricultural purposes. The non-Indian defendants, however, have been more timely in meeting SAWRSA obligations. Tucson and Pima County have contributed effluent, with funding appropriated by the state and non-Indian interests to set up a trust fund. Until U.S. v. Tucson is dismissed, however, SAWRSA is not fully effective. As of yet, no water has been delivered to the Indian people.

CAP AND THE COLORADO RIVER

Arizona's allocation of Colorado River water is determined by the Law of the River, a collection of legislation, compacts, judicial decisions, international treaties and administrative rules that governs water allocation on the river. The Colorado River Compact of 1922 divided the river into two basins: the Upper and Lower Basins, with the river's average annual flow divided equally between the basins. Lees Ferry in northern Arizona marks the boundary between the two basins (See Figure 7-7). According to the compact each basin is to receive 7.5 million acre-feet per year. Arizona is a member of the Lower Basin, along with Nevada and California. A division of the waters of the Lower Basin originally was suggested by Congress in the Boulder Canyon Project Act and upheld in the Arizona vs. California Supreme Court decree in 1964. Arizona was allotted 2.8 million acre-feet of Colorado River water, California was allotted 4.4 million acre-feet, and 300,000 acre-feet was allocated to Nevada. Along with its Lower Basin allocation, Arizona also gets 50,000 acre-feet of Upper Basin water.

Approximately 1.3 million acre-feet of Arizona's allocation of Colorado River water is consumed along the mainstem of the river, mainly for agricultural purposes. This leaves an average of 1.5 million acre-feet per year to be carried to central Arizona via the CAP canal. The canal has a design capacity for delivery of 2.1 million acre-feet per year, which is reduced to approximately 1.9 million acre-feet per year due to the need for routine maintenance. This extra capacity allows Arizona to take water above its annual allocation if a surplus is declared on the river.

CAP deliveries may be interrupted by drought shortages on the river or by the need to repair and maintain the canal. To gain the support of California's delegation for Congressional approval of the CAP, Arizona was forced to agree that, in times of shortage, California's full 4.4 million acre-feet will be delivered before any water will be provided to the CAP. As a result, any shortages in the Lower Basin will be borne first by the CAP. The risk of drought shortage is projected to increase over time. After the year 2025, the probability of shortages affecting CAP water users is anticipated to reach approximately 30 percent. The probability that municipal and industrial users will be affected is approximately 5 percent.

The law assigns the highest priorities for delivery of subcontracted CAP water to Indian and municipal and industrial (M&I) subcontractors. The lowest priority is assigned to non-Indian agriculture. This means if scheduled deliveries must be curtailed in any year, deliveries to non-Indian agricultural subcontractors will be cut first.

The amount of water delivered over the year is set, but the amount delivered each day varies greatly over the year, depending on demand. At times of high demand municipal users get first priority, but only for direct delivery. Municipal recharge projects have a lower priority than agriculture. In March 1997, delivery to recharge sites was halted temporarily to meet demands for direct municipal use and agriculture. This reversal of the priority system that normally places agriculture last may require recharge systems be designed to accept larger amounts of water at times when deliveries are high to compensate for the times when deliveries are cut. Possible changes to this policy are being discussed.

Concerns about CAP outages due to drought or maintenance point to the need for some mechanism to enhance delivery reliability. This could be either storage at the end of the aqueduct (terminal storage) or an operational plan that could involve keeping a certain number of groundwater pumps ready to provide water in case of an emergency. Consideration of terminal storage has been delayed indefinitely as a result of Tucson's decision to suspend direct delivery of CAP water.

The draft Environmental Impact Statement relating to terminal storage estimated that Tucson would experience planned maintenance outages of five to 30 days per year. Emergency outages are projected at zero to three times every 10 years. These emergency outages could last up to two months. An emergency outage lasting 48 to 365 days could happen zero to two times every 50 years. Situated at the end of the canal, Tucson is in the position of having the least reliable CAP water supply. Terminal storage options include a 15,000 acre-foot above-ground reservoir, a 15,000 acre-foot per year underground storage and recovery facility, and installation of redundant features to minimize maintenance outages. Cost of the above-ground reservoir was estimated to be about $100 million. If built as part of the CAP, the costs would be borne by CAP water users in Pima, Maricopa and Pinal counties, with financing by the federal government at a 3.342 percent interest rate over a 50-year period.

CENTRAL ARIZONA WATER CONSERVATION DISTRICT

The Central Arizona Water Conservation District (CAWCD) is a state agency with the primary responsibility of managing the CAP. Voters in Maricopa, Pima and Pinal Counties elect board members generally based on population. The district is concerned with water fees and property taxes for CAP, water allocation, canal operation and maintenance. CAWCD is responsible for repaying CAP reimbursable construction costs to the federal government. The district also works with the Arizona Water Banking Authority and the Central Arizona Groundwater Replenishment District to implement CAP storage and recovery programs.

PROGRAMS TO PROMOTE RECHARGE

Underground Water Storage, Savings, and Replenishment Program

Administered by ADWR, the Underground Water Storage, Savings, and Replenishment Program (UWS) encourages the use and/or storage of renewable supplies, including CAP water. There are two types of facilities allowed under this program: Underground Storage Facilities and Groundwater Savings Facilities.

Underground Storage Facilities (USFs) involve physical recharge of water through injection wells, infiltration basins, or natural watercourses. Water stored at these facilities can be designated for one of several uses: recovery in the same calendar year (annual storage and recovery), long-term recovery using storage credits, or not to be recovered at all. If the water is recovered, it does not have to be recovered in the same place as it was stored. However, recovery rules are designed to prevent recovery of water in areas where groundwater levels are substantially declining.

Groundwater Savings Facilities (GSFs) usually involve farms which agree to use CAP water rather than pumping groundwater. GSFs are referred to as "in-lieu" recharge facilities because CAP water is used in lieu of groundwater, but GSFs do not involve physical recharge. In a typical GSF arrangement, an entity such as a municipal water provider sells CAP water to a farm, usually at a price lower than what the farm would pay to pump groundwater. In return, the state grants credits to municipal providers for the amount of groundwater that otherwise would have been used. The municipal provider can use these credits to offset pumping of groundwater in meeting ADWR conservation rules. A majority of the activity under the UWS program to date in TAMA has been through GSFs.

Arizona Water Banking Authority

Arizona cannot currently directly use all its allotted CAP water and does not expect to directly use the full allotment until the year 2030. Since California claims a right to take unused Colorado River water, Arizona has devised a way of keeping as much of it as possible in the state. The Arizona Legislature created the Arizona Water Banking Authority (AWBA) to acquire unused portions of Arizona's allocation of Colorado River water and put it to use for storage underground or, in other words, to recharge it in central Arizona. AWBA is authorized to store water to meet one of four overall goals: to protect municipal uses from possible drought situations or CAP delivery interruptions; to meet Indian water rights claims; to meet local water management objectives; or to facilitate interstate water banking with California or Nevada. AWBA is funded using property taxes, groundwater withdrawal fees in counties with CAP water (Maricopa, Pinal and Pima counties) and money from the state's general fund.

AWBA does not construct recharge facilities, but uses recharge structures built by other entities, such as Tucson Water or CAWCD. The water flows through the CAP canal to the storage facility, and AWBA pays CAWCD for the water costs. AWBA participating entities then benefit by accruing credits for the water stored and by using the water when needed under certain conditions dictated by state law. Credits earned with money from the general fund are used to benefit cities, towns and water providers along the aqueduct. Water storage credits earned with money from groundwater withdrawal fees are to be used in the AMA where the fees were collected. Credits from the property tax accrue to CAWCD to meet demands of municipal and industrial customers when CAP supplies are interrupted.

AWBA also is allowed to negotiate and enter into interstate water banking agreements with California and Nevada, subject to approval by the director of ADWR and subject to other conditions. Such agreements would allow California and/or Nevada to pay to store unused Colorado River water in Central Arizona. This obviously benefits Arizona as more water is added to our aquifers, but the other two Lower Basin states also would gain from the transaction. In later years, those states can "recover" their stored water under a forbearance agreement, through which Arizona would refrain from taking a portion of its entitlement of Colorado River water equal to the amount of water to be recovered. The state that had banked the water could then recover the banked water directly from the river. In effect, by paying to store unused Colorado River water in Arizona, California or Nevada can earn the right to later divert portions of Arizona's Colorado River allocation from the river.

The AWBA directly recharged approximately 45,000 acre-feet of excess CAP water in 1997 and approximately 70,000 acre-feet in 1998, of which about 12,000 acre-feet was in Pima County at the Central Avra Valley Recharge Project, the Avra Valley Recharge Project and the Pima Mine Road Recharge Project. The bank also accrued 149,000 in water storage

Figure 7-8 Decorative fountains raise an issue beyond supply and demand — the aesthetics of water. Photo: UA Biomedical Communications.

credits for in-lieu "recharge," none of which occurred in Pima County.

Central Arizona Groundwater Replenishment District

In 1993, the Arizona Legislature passed a law that provides an alternative method for subdivisions and water providers to meet the rules requiring a demonstrated 100-year supply of water. Entities that couldn't otherwise demonstrate an adequate physical supply can pay the Central Arizona Groundwater Replenishment District (CAGRD) a fee for the groundwater that the subdivision or water provider is "mining." The CAGRD then takes responsibility for acquiring and recharging water to offset the mined groundwater. Since "replacement" water does not have to be recharged in the same location as the withdrawal, localized groundwater declines may not be prevented by the arrangement. The overall management goal of safe yield, however, is furthered.

Under CAGRD the fees paid are the same (per unit volume) for each of the contributing "members." Members that are water providers pay the fee directly to CAGRD. In the case of certain subdivisions, each lot owner is a member and the individual pays in the form of an assessment on the property tax bill. One of the consequences of this is that the costs associated with an "assured" water supply are not borne directly by developers. This is one factor for the popularity of the CAGRD option. To date, approximately 115 subdivisions and eight water providers have applied for, or obtained, membership in the CAGRD.

Figure 7-9 The Endangered Species Act is concerned with the effects of human activity on the natural environment. Above is the federally protected desert tortoise. Photo: Barbara Tellman.

LAKES AND POOLS

In 1987, the Legislature enacted a law restricting the use of surface water or potable groundwater in artificial lakes and ponds in AMAs. A new lake cannot exceed 12,320 sq. ft. — the size of an Olympic-sized pool — unless filled with wastewater or poor quality groundwater. Lakes built before 1987 are exempted, as are lakes in public parks. The size of residential swimming pools also is limited to Olympic size, although the number of pools is not limited.

WATER TRANSFERS

In the 1970s, Tucson Water began buying farmland in the Avra Valley to obtain water rights in the area. Once the courts determined the arrangement was legal under certain conditions, Tucson considered Avra Valley groundwater an important part of its water supply. In the 1980s, other cities went even farther afield in search of water, to rural areas remote from urban centers. For example, Scottsdale bought land along the Bill Williams River in western Arizona. Some people in rural areas became concerned about losing water supplies and property tax base critical for their survival. In response, the Legislature passed a law limiting new transfers of water from non-AMAs. Because of the law, Tucson is not able to import water from outside the TAMA, such as from the San Pedro River.

FEDERAL ENVIRONMENTAL LAWS

Two federal laws that have some impact on water decisions are described briefly below, although they are not primarily water-related.

Table 7-3 Largest municipal water providers serving Pima County.

LARGEST MUNICIPAL **PROVIDERS**	SERVICE **AREA POP.**	WATER USE **(Acre-feet)**	TOTAL **GPCD**
City of Tucson	621,290	115,860	166
Metro Water District	44,153	9,161	185
Town of Oro Valley	23,416	6,503	248
Flowing Wells Irrig. District	15,000	2,945	175
Community Water Co.	14,261	2,249	141
Avra Water Co-op	6,688	935	125
Lago del Oro Water Company	6,461	1,787	247
Davis-Monthan AFB	6,191	1,969	284
University of Arizona	5,695	1,624	255
Ray Water company	4,617	658	127
Green Valley Water Company	4,390	2,318	471
AZ State Prison Complex	4,097	602	131
Hub Water Company	4,078	1,118	245
Arizona Water Company	3,984	366	82
Marana Municipal Water System	3,467	623	160
Las Quintas Serenas	2,388	345	129
Marana Water Service	1,736	337	173
Farmers Water Company	983	373	339
Forty-Niner Water Company	872	833	853

(1997 data. Figures may differ from Appendix B because they represent different years.)

Source: Arizona Department of Water Resources.

National Environmental Protection Act

The National Environmental Protection Act (NEPA) is intended to ensure that significant projects done by the federal government or that use any federal subsidies do not cause environmental damage in the process. Provisions do not apply to private, nongovernmental projects unless they have a federal component such as a housing development that involves federal loan guarantees.

When an eligible project is planned, an Environmental Assessment (EA) must be conducted. If this assessment does not indicate that environmental problems are anticipated, the public has the right to comment and either approve or request a more detailed Environmental Impact Statement (EIS). Other federal agencies such as U.S. Fish and Wildlife Service must be given the opportunity to comment on matters under their jurisdiction. The public has the right to comment on the EIS and a public hearing must be held. If troublesome issues arise, a mitigation plan is developed.

Endangered Species Act

The purpose of the Endangered Species Act (ESA), passed in 1973, is to conserve the nation's biological heritage consisting of its animal and plant species. The law enlists all federal agencies and departments in an effort to conserve threatened and endangered species and to promote the purposes of the act. As stated in Section 7 of the act, all federal agencies are "to insure that actions authorized, funded, or carried out by them do not jeopardize the continued existence" of an endangered species or "result in the destruction or modification of habitat of such species." Section 9 of the ESA includes prohibitions against "take" which is defined in the act as "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect or attempt to engage in any such conduct."

The ESA also charges the above agencies to identify and designate "critical habitat" for listed species, based upon the best scientific data available. This is to identify and protect habitat essential to the species' survival and recovery. Critical habitat is the specific areas, within or outside the species' geographical range at the time of listing, which contain essential physical or biological features for conserving the species and which may require special management or protection.

When constructing the CAP canal in the Tucson area special precautions were taken to avoid harming various species. An important deer movement area between the Tucson Mountains and the Schuk Toak District of the Tohono O'odham Nation west of Tucson is crossed by the CAP canal. To minimize disruption to deer movement and other wildlife in this unique area and to preserve this corridor, the U.S. Bureau of Reclamation buried parts of the canal under six major washes and purchased 4.25 square miles of deer habitat. The corridor will be managed by Pima County as part of the Tucson Mountain Park system and will be protected from future development.

This area also contains important habitat for the kit fox, the endangered Tumamoc globe-berry plant, and three potential endangered species: the desert tortoise, the Gila monster and the Thornber's fishhook cactus. The corridor will protect about 27,000 Thornber's fishhook cactus. Obviously any construction projects involving the movement and storage of water must proceed especially carefully to anticipate ESA concerns.

Even now, with the CAP system essentially completed, the ESA continues to impact water resource planning. Along with water, the CAP brings fish and other aquatic species from the Colorado River. Some aggressive, non-native fish pose a potential threat to Arizona's native fish species, all of which are listed as endangered or threatened. The concern is that during periods of high precipitation or snowmelt, when normally dry rivers are flowing, the CAP canal might provide a water link allowing non-native fish to reach the headwaters of streams, invading the habitat of native species. Eliminating such hazards can require building expensive fish barriers or other obstacles to non-native fish, resulting in water project delays and additional costs.

REGULATION OF WATER COMPANIES

The 19 largest municipal water providers within the Tucson area are listed in Figure 7-3. (See Appendix B for a list of all water providers in Pima County.) Tucson Water, the largest, serves about 80 percent of the total population. About 12 percent of the population is served by private domestic wells and a large number of very small companies.

Different regulations regarding water rates apply to different types of water providers. Elected officials and the mandate of the electorate control municipal water companies. This can lead to disenfranchisement when the boundaries of the water company and the municipality are different. Also voters within the Tucson city limits who receive water from utilities such as Flowing Wells Irrigation District have the right to vote on Tucson Water issues. Both of these situations prevail in Tucson. Tucson Water's service area extends far beyond city limits, and private water providers operate within city limits. Municipal water companies can approve increased rates, and they may float bond issues, spreading capital costs into future years.

Private water companies and water cooperatives, on the other hand, are regulated by the ACC. Raising or restructuring rates requires ACC approval in a rate hearing. Private companies generally are not allowed to raise rates to recover future costs. For example, if ADWR requires conservation programs, the ACC may refuse a rate increase to cover the costs until after the money has been spent and the program proven to be effective. Similarly, a small water company cannot increase rates to build a new well or a treatment system. Instead, it must build the well or the treatment system, then recover the costs. Also ACC does not allow water companies to recover CAP holding costs. These are costs for CAP water rights not presently being used.

As a result, private water companies and water cooperatives may find themselves in a regulatory bind. ACC's goal is to keep rates low to benefit consumers; the ADWR goal is to conserve water within AMAs; and an ADEQ goal is to ensure safe drinking water quality. A private water company confronting these varied regulatory goals may have problems initiating conservation programs. Without the power to borrow money or float bonds, a small water company's very survival may be threatened when major capital improvements are needed.

The ACC does not regulate irrigation districts, regardless of whether they actually provide irrigation water (e.g., Flowing Wells) or water improvement districts (e.g., Metropolitan Domestic Water Improvement District). These districts are responsible solely to their boards and members. ADWR regulates all water providers regarding water supply (assured water supply and safe yield) and water use issues (conservation), with EPA and ADEQ regulating water quality issues.

REGIONAL WATER QUALITY PLANNING

The Pima Association of Governments (PAG) is responsible for coordinating water quality and transportation planning as well as regional population projections. Each local government entity, regardless of its size, has one vote on PAG decisions. An Environmental Planning Advisory Committee and its Water Quality Subcommittee, which is made up of government staff and local residents, study and make recommendations on such matters as new wastewater treatment facilities, water reclamation and pollution cleanup. PAG votes on their recommendations to determine whether they become policy.

FLOODPLAIN MANAGEMENT

Both Pima County and the City of Tucson are involved in flood control and the development and enforcement of floodplain ordinances. Pima County's flood control district (FCD) is governed by the Board of Supervisors acting in its capacity as Pima County FCD managers. Established by state statute in 1978, county flood control districts work to reduce the risk of flood loss, minimize the impact of floods on human safety, health and welfare, and restore and preserve the natural and beneficial values served by floodplains. Established as political taxing subdivisions of the state, FCDs have the power to levy taxes to support flood-control projects. Their area of jurisdiction may include incorporated and unincorporated areas.

Legislation also allows an incorporated city or town within a county to assume responsibility for its floodplain management. Tucson maintains its own floodplain management program within Pima County. Pima County FCD is mainly concerned with areas outside city limits. Intergovernmental agreements (IGAs) have been signed with the city, however, for the district also to be responsible for waterways within certain incorporated areas. IGAs are likely to be worked out for regional watercourses that have significant flow during 100-year flood events, such as the Rillito Creek and the Santa Cruz River. Pima County therefore maintains the major watercourses in the area, although the city may be responsible for sections of them. Finally, floodplain maps are under the jurisdiction of the Federal Emergency Management Agency (FEMA) which administers the national flood insurance program. Communities that do not comply with FEMA rules are not eligible for federal flood insurance.

POWERS OF COUNTIES AND CITIES

Counties generally have only those powers granted to them by the state, unless they have adopted charter government. Counties are required to look after the "health, safety, and welfare" of their residents. As a result, they maintain health departments, building codes, etc. Counties do not currently have the authority to operate water systems. Pima County has a department of environmental quality which is primarily involved with air quality and hazardous waste. County health departments have some water quality responsibilities related to human health; e.g., they regulate septic tanks. County zoning decisions may be based on the ability of government to provide services such as wastewater treatment. In at least one case a massive rezoning was denied on the basis of an insufficient water supply, the lack of which could have been a serious health problem.

Cities have varied levels of involvement in water management. Some cities (e.g., Tucson) operate water companies, and many cities operate wastewater facilities (e.g., Show Low). Many cities have water conservation programs (e.g., Phoenix).

Cities and counties may assess fees on new development (impact fees) to recover the cost of providing services to the new area. Such services include water and wastewater facilities. Both cities and counties operate under state and federal water quality and quantity laws.

City and County Ordinances

Cities and counties also have their own laws, referred to as ordinances. In general, these ordinances may be stricter than state or federal ones, but may not be less strict. Thus a city cannot opt out of following the Safe Drinking Water Act, but it can decide to meet more stringent standards, such as the tighter THM standard that the City of Tucson has imposed on itself. On occasion, however, the state government has preempted this right.

Water Consumer Protection Act

The Water Consumer Protection Act (WCPA), a ballot proposition passed by City of Tucson voters in 1995, (See page 139) had three major goals:

- prohibit Tucson Water from directly delivering CAP water unless the salt content was substantially reduced;

• prohibit delivery of water from polluted sources, including treated TARP water (See page 66) ; and
• compel the city to offset groundwater withdrawals with recharge, including recharge of CAP water.

Other goals included:
• encourage the city to trade and sell its CAP allotment;
• avoid recharge in areas of known landfills; and
• prevent disinfection byproducts such as THMs from being introduced into the aquifer through treatment and direct injection recharge. The WCPA did not deal specifically with corrosivity.

In 1997, Proposition 201 was on the ballot but failed to pass. It would have repealed many of the provisions of the WCPA, substituting less restrictive goals.

Tucson Xeriscape Ordinance

This ordinance applies to new multifamily, commercial and industrial developments. Its goal is to conserve water by applying xeriscape principles. These principles include using drought-tolerant plants, maintaining limited grass areas and applying mulch and soil improvements. Landscaped areas must be designed to take advantage of storm water run-off, and water-conserving irrigation systems are required.

City and County Plumbing Codes

Both city and county require that water-efficient fixtures be used in all new residential and commercial construction. Toilets must be ultra-low flush (i.e., 1.6 gallons per flush or less) and faucets must not exceed 2.5 gallons per minute. The code also applies to replacement of old fixtures. Requirements also are established for evaporative coolers, air conditioners, decorative fountains and waterfalls.

Water Waste Ordinance

Since 1984 it has been illegal for people within the City of Tucson to let water flow off their property onto public areas or other property. A "water cop" can fine individuals, property managers and landscape contractors who are guilty of this infraction. Tampering with water meters also is illegal.

Golf Course Water Use

Tucson and Pima County have ordinances requiring the use of CAP or effluent for new golf courses where feasible. (See Chapter 5 for more information.)

Emergency Water Conservation

Upon declaring a water emergency because of problems with water supply, the Tucson City Council may prohibit or restrict non-essential uses of water. Examples of restricted activities are outdoor irrigation except areas using reclaimed water, washing of sidewalks, outdoor water-based play, automatic water service in restaurants, misting systems, filling swimming pools and spas, and washing of vehicles except at facilities with recirculation systems. Exceptions can be allowed for reasons of public health, safety or economic hardship.

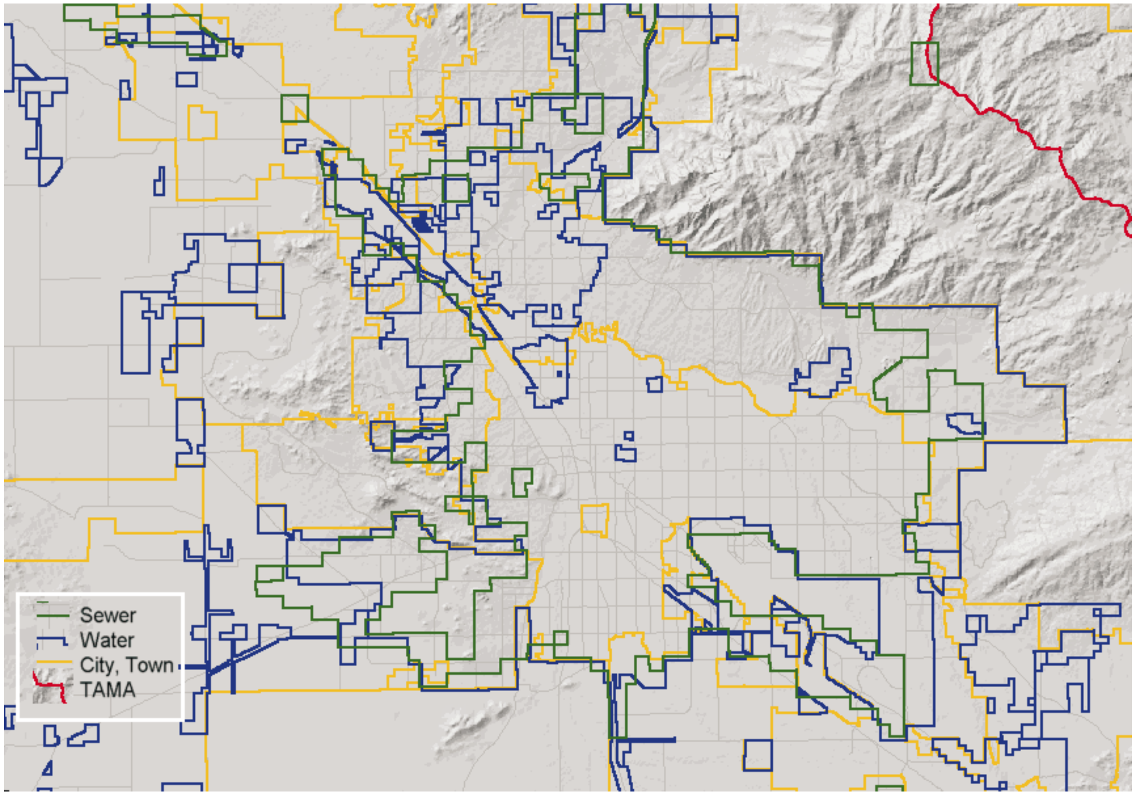
MANAGING WATER AND WASTEWATER

Tucson operates the largest water system in the area, serving about 600,000 persons an average of about 97 million gallons of water daily. The city serves customers both inside and outside city limits. Since Tucson Water is managed by the Tucson City Council, people who are not city residents have little say on city water decisions, even though they receive city water. Approximately 16 other water providers serve another 155,000 customers in the area. The remaining 81,000 water users are served by very small water companies or have their own wells. Some of these water companies are within the city limits of Tucson, Oro Valley or Marana. The cities do not regulate the activities of these water providers and cannot require their compliance in such activities as water conservation programs.

Water providers that are not municipal water departments, on the other hand, have little or no say in certain city decisions that affect them, such as rezonings and conservation ordinances. ACC regulates rates and some procedures of private water companies, but not municipal utilities or irrigation districts. ADWR can require all three types of water utilities to implement conservation measures and meet sustainability goals but has no jurisdiction over water users themselves. At times, ACC and ADWR rules conflict.

Pima County handles most wastewater in the region, with treatment plants at Roger Road and Ina Road, next to the Santa Cruz River. Pima County also runs several small treatment plants outside the metropolitan area.

Figure 7-10 Jurisdictional boundaries.



Sources: Pima County Technical Services, Arizona Department of Water Resources.

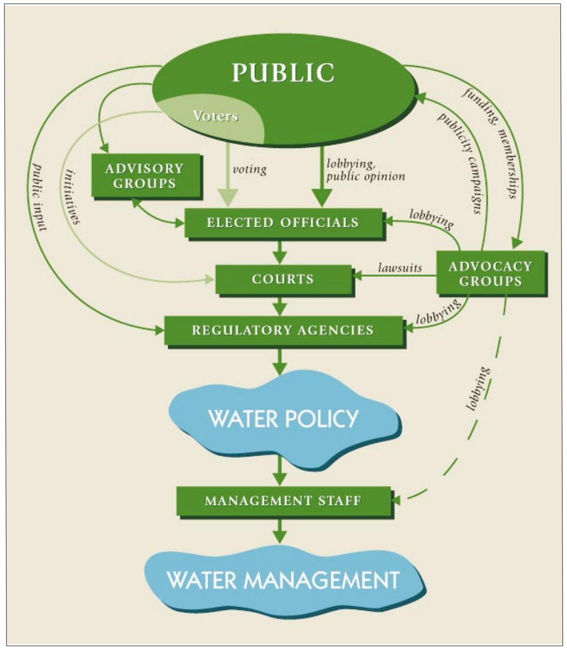
Because of an intergovernmental agreement between Tucson and Pima County, Tucson has rights to most of the effluent that comes from wastewater treatment facilities throughout Pima County. A few neighborhoods have their own treatment facilities, and some people have septic tanks or other kinds of individual treatment systems. Some subdivisions with golf courses, such as El Conquistador, use treated water from their local community for watering the golf course.

COORDINATING WATER MANAGEMENT

Despite, or perhaps because of the many laws and rules, no one agency has legal authority to coordinate water use area-wide. This is to the detriment of efficient water management. TAMA and the Pima Association of Governments (PAG), however, address some basin-wide issues that were previously discussed. The following further characterizes water management in the Tucson area:

- No agency has the authority to require water users to take a particular kind of water, such as effluent or CAP water. Some people believe mines and farms should use lower quality water and leave the groundwater for drinking purposes. But the type of water that businesses and water companies use is generally determined by the market place or historical accident. In other words, they generally use the cheapest water source, which often is groundwater. Also, individuals have the right to pump groundwater for their own domestic use, and over 24,000 private wells exist in the Tucson area. The only limiting factors are well spacing regulations and the cost of drilling and operating a well.
- No agency can mandate that all categories of water users shall contribute to help pay for solutions to water problems. For example, no agency can require businesses that use groundwater to pay a fee to support CAP activities in an effort to prevent the water table from declining. While some local taxes and pumping fees are charged, the funds do not help pay Tucson Water's cost of using CAP water.
- No agency can require individuals to conserve water. ADWR can set per capita goals that water providers must meet, but those providers in turn have no authority to require water savings of their customers. The City of Tucson could pass an ordinance limiting water use, but it would not apply to people living outside city limits and probably not even to customers of other water providers within city limits.

Figure 7-11 Generalized model of municipal water policy.



• Elected officials often make land use decisions without worrying about long-term water supplies. Rezonings within established water service areas certified for assured supply may proceed, although new developments outside such areas must go through the approval process. In 1999, a rezoning for the Canoa Ranch near Green Valley was denied partly because of water supply issues. This, however, was the exception, and other reasons existed for opposition to this rezoning.

BASIN-WIDE WATER MANAGEMENT

Local water management is characterized by a complex web of overlapping, and occasionally conflicting political and geographical jurisdictions. Overlapping jurisdictions in the Tucson area are shown in Figure 7-10. Figure 7-11 provides a generalized model of municipal water policy management. Though attention tends to be focused on elected officials, many other "players" are involved. The public, particularly the voting public, has the ultimate say in most policy matters and has several avenues for influencing water policy (rules, laws and guidelines) and water management (implementation of policy).

Coordinated and comprehensive basin-wide management has been advocated at various times. Such "watershed management" has several obvious advantages, and a few more subtle disadvantages. The most compelling reason cited for watershed management is the ability to treat water resources as part of an integrated system. In its most optimistic implementation, decisions such as land use, transportation and population growth all would be evaluated in terms of their basin-wide impact on water resources.

Critics of the existing situation note the difficulty in establishing long-term plans when so many of the critical decisions are split among different agencies and groups. Moreover the responsibility to meet long-term demands is often unevenly distributed. For example, while developers are required to demonstrate a 100-year assured water supply, they are not required to consider the basin-wide impacts of their development. This raises some thorny hydrologic issues as well as concerns about relative inequity. In another example, some have complained that the costs of renewable supplies like CAP water have been disproportionately borne by Tucson Water customers.

The expectation is that stronger basin-wide management would reduce disparities and promote true sustainability. Promoters also note that a watershed management authority could reduce some of the political and economic inefficiencies inherent in the current situation.

The splintered nature of local water management can be counted as both a cost and a benefit. The inefficiency that results from multiple jurisdictions also can provide some measure of control against a single entity having too much authority. A watershed authority could make it easier to implement ecologically sound policies, but it also could be an efficient mechanism for mischief.

Some people have argued that the Tucson region should have a government agency with powers to buy and sell water throughout the region and to determine who uses which kinds of water. There could still be private water companies under the larger umbrella agency. The Tucson City Council vetoed establishing an agency with some of these powers when it voted against establishing the Santa Cruz Valley Water District in 1993. This agency would have had some of the responsibilities of the Central Arizona Groundwater Replenishment District for this area.

Benefits of area-wide management include reserving the highest quality water for municipal use while lower quality water would be used for industry and agriculture. Also the costs of augmenting the supply could be distributed more fairly throughout the region. The managers could either be elected directly by the voters or appointed by the county and cities in the region. One argument against this approach is that the managers would have enormous power. If they were appointed, with one vote per city (like PAG), Tucson city residents would be unfairly under-represented. If they were elected, it might be difficult to adequately educate voters about the qualifications of these managers with highly technical responsibilities. People who generally support less government are opposed to increasing government power over water. A change in state law would be required to create such an agency as well as approval of local governments and the voters. For this agency to acquire private water companies a company would either have to be willing or be acquired through condemnation. This approach, while having some benefits, has generally not been considered politically feasible.

TUCSON WATER OPERATIONAL OPTIONS

Some people have argued that private water companies should provide all water service in the area, and that Tucson (or any government) should not be in the water business. They argue that Tucson Water should privatize its operations because this would distance a professional service from political decision-making. They point out that Tucson Electric Power provides power very effectively as a stockholder-owner corporation and that Tucson Water could do the same. If it were a private water company, the ACC would oversee water rates, not local politicians. Opponents argue that customers are better protected by officials they elect directly and that a profit-making company would probably have to charge higher rates. They also argue that if the company had to go through costly rate hearings, they would have to charge more for water.

Others note that water is fundamentally different from electricity, natural gas and other utilities in ways that argue for public ownership. Water has public health, aesthetic, and environmental aspects that the others lack. The public may be willing to pay more for water supplies that are purer or sustainable, or to subsidize certain public uses or water. Thus, the private sector may not be the best provider.

Another option is to leave Tucson Water under city control, but have a private management company operate the facilities, rather than city employees. The City Council would continue to set policy, but would contract for services as it does with its public transit system. The benefits are that the council would be less involved in operational details, leaving that to outside professional management which would provide the services as contracted. Such a major transition, however, could create problems in water service, without necessarily improving it.

Another option is for Pima County to become the regional water provider, at least for the water service area now served by Tucson Water, as it is now the primary regional wastewater provider. This would require a change in state law to enable the county to take on this new charge. The principal advantage would be the enfranchising of Tucson Water customers outside city limits. This has generally been considered politically infeasible as Tucson likely would be unwilling to give up this power.

Still another option is one that was pursued for years by Tucson Water; i.e., establish Tucson Water as the only municipal water provider in the region. During the 1960s and 1970s, the city acquired numerous small water companies with the goal of providing unified water management both inside and outside city limits. Officials believed that one consolidated water system could better distribute water and costs fairly among customers, perform more effective water conservation programs and assure adequate water for fire protection in all areas. All companies were acquired through voluntary purchases. One drawback of this system is that it would serve a greater number of people who, because they live outside city limits, cannot vote on water matters that affect them.

ENFRANCHISING NON-RESIDENTS

Because the voting public has such an important influence on water decision making, having the right to vote on water matters is important. Only Tucson city residents, however, may vote for City Council and mayor or cast ballots in water bond elections, water initiatives and referendums affecting Tucson Water. Many people who live outside city limits object to this disenfranchisement. Meanwhile city residents who do not receive water from the city have the right to vote on Tucson Water matters.

If the city continues to be the major municipal water provider in the area, is there some way to enfranchise non-residents? Various bills to deal with this issue have been introduced in the Legislature. The most recent one would give ACC responsibility for approval of water rates for people outside city limits. Opponents point out that water rates could be very different inside and outside the city, with rates outside probably increasing to cover the cost of going through rate hearings. Current state law forbids a municipality from charging substantially more to customers outside its limits; modest rate differences must be based on higher costs to deliver the water.

Most people would not consider it fair or legal for non-residents to vote for city officials since most decisions made by those officials are unrelated to water matters; e.g., decisions that impact city taxes and services. Should all water customers vote on water bond issues, since water bonds are repaid not by taxes but by water service revenues? Should they be able to vote on water initiatives and referenda? An argument can be made for these rights, but a change in state law probably would be required to enable a city to have an election outside city limits.

AFTERWORD

There was a whole folklore of water. People said a man had to make a dipperful go as far as it would. You boiled sweet corn, say. Instead of throwing the water out, you washed the dishes in it. Then you washed your hands in it a few times. Then you strained it through a cloth into the radiator of your car, and if your car should break down you didn't just leave the water to evaporate in its gullet, but drained it out to water the sweet peas. *Wallace Stegner,* Wolf Willow, A History, a Story, and a Memory of the Last Plains Frontier.

As the above quote shows, the best water managers in the West have relied on imagination and creativity to get the most out of a drop of water. Some may argue, however, that the quote describes a far simpler time than the present. Today, we use vast amounts of water for purposes frontiersmen never dreamed; we've become a bit more particular about water quality, too.

In fact, if you have read the first seven chapters of this report and aren't confused by now, then you haven't been paying attention. Tucson's water situation is a fiendishly complex, multi-dimensional conundrum. Each piece of the puzzle is linked to others, some in obvious ways, some in ways that are far more subtle.

This complexity comes from the innate nature of the resource, as well as the relationships among various factors. For instance, as a physical resource, water involves disciplines ranging from chemistry and microbiology to civil engineering and hydrogeology. In a larger context, water resources are often tied to issues like population growth, property rights and quality of life.

While individual aspects of a particular water issue may be well understood by the research community, the interactions are often poorly understood. This is true within the physical sciences, but is particularly acute when the interactions involve physical sciences, social sciences and the humanities.

To further complicate matters, only a limited community consensus exists on what we are trying to accomplish. We all want a reliable, bountiful, sustainable water supply. We demand that it be safe, palatable, and environmentally benign. And we want it provided to our homes, businesses and parks at the lowest possible cost.

We also want fairness, or equity, as each of us defines it. Here is where the consensus starts to break down. For some, equity means traditional uses of water are favored. Others demand economic equity — those who benefit, pay. In practice, this might mean that those continuing to pump groundwater should subsidize those who switch to renewable supplies. Some want political equity — those who are affected, should decide. This would require new political mechanisms whereby all water users could vote on the candidates and initiatives that determine their water future. And still others are concerned with inter-generational equity. They don't want today's consumption decisions to limit the options and quality of life of future Tucsonans.

We also would like less political strife over water. This can tempt us to put off difficult decisions, perhaps by calling for yet another study. Groundwater overdraft is the sort of problem that is easy to ignore. A declining water table is out of sight and out of mind. There is no perceived sense of urgency, no hard deadlines by which we absolutely must act. And so inaction becomes a tempting course.

As tempting and politically expedient as it may be, inaction is itself a form of decision-making, but one rarely based on sound analysis or the expressed preferences of citizens. There are other compelling reasons to act sooner rather than later. Options may diminish over time, or grow more expensive. Political costs often rise over time, too.

The decisions we make, or avoid making in the next few years are likely to have important, lasting consequences. Assuming we act, who should decide on our course? Are technocrats or self-appointed water experts best suited to make the hard decisions? Not likely. The former tend to have deep but narrow knowledge; the latter may offer appealingly simplistic but unproven solutions.

The authors of this report also decline to make recommendations, for two reasons. First, some of the most informed water researchers are among the least certain of how to proceed. (We get confused at times, too.) Second, and more importantly, physical and social scientists simply have no basis for making policy decisions. These water resource issues aren't about right and wrong decisions. They are about values and priorities, expressed as choices with social consequences.

Does that mean voters must directly decide details of our water strategy, as they have been asked to do recently through initiatives? Is it fair or reasonable to expect a busy, preoccupied electorate to become informed on the nuances of groundwater hydrology and the finer aspects of alternative water purification systems? Clearly not. Rather, it is up to the technocrats to describe possible courses of action, and their respective costs and tradeoffs. Voters must express their beliefs, values, and preferences with respect to water. Then our elected officials must do the heavy lifting of turning this information into sound, long-term water policy.

How then can the reader help make decisions about Tucson's water future? Part of the process is examining your personal goals and values and then considering what options will best achieve your objectives. No single "magic bullet" is available to assure a long-term, high-quality water supply. Most choices have both benefits and drawbacks.

BALANCING THE BUDGET

We invite you, the reader, to work through a series of options in order to shape your recommendations to decision makers. We begin by restating the overdraft problem, and determining how important achieving a sustainable water supply is to you.

A simplified water balance was presented in bar chart form in the Preface (See page vi). This shows that in 1997, water demand in the TAMA totaled some 345,400 acre-feet. Renewable supplies, consisting of natural groundwater replenishment, CAP water, and effluent totaled only 194,500 acre-feet, leaving a water deficit of 150,900 acre-feet of mined groundwater.

A somewhat more detailed water budget is depicted on the adjoining page. This information is graphically depicted as an "octopus" on the following page. The top section of the water budget lists all water sources that contribute to the aquifer, including natural, incidental, and direct recharge. Gains to the aquifer also include underground flow into our aquifer from the Santa Cruz AMA to the south. The center section of this water budget tallies losses from the aquifer, which are mainly groundwater pumping for municipal, industrial, and agricultural uses. Other losses from the aquifer include underground flow from our aquifer into the Pinal AMA to the north, and evapotranspiration from shallow groundwater.

The bottom portion of the budget represents direct uses of effluent and CAP water, which are renewable supplies. While these uses do not directly affect the aquifer balance, there may be indirect impacts. For example, if CAP water was not available to irrigate some agricultural land, groundwater might be used instead. On the other hand, effluent not used to irrigate a golf course might be left in the riverbed, where much of it would become incidental recharge to the aquifer.

The bottom line of this water budget is the same as in the bar chart in the introduction — we are pumping far more groundwater than is being replaced in the aquifer. This situation is not sustainable in the long run. The only options for approaching or attaining sustainability are making full use of our CAP allocation, severely limiting current and future water demand, or some combination of the two.

TO SUSTAIN OR NOT TO SUSTAIN

How important is a sustainable water supply to you? Sustainability is not an all-or-nothing concept. When using our water supply, we have a range of choices, including the following:

- Try to balance water supply and water demand to guarantee water availability indefinitely;
- Try to prolong the life of the water supply over a shorter term, say 50 or 100 years;

"Wet Water" Budget*

For Tucson Active Management Area, 1997 data (in acre-feet)

GAINS TO AQUIFER		
GROUNDWATER INFLOW FROM SANTA CRUZ AMA		**8,700**
RECHARGE		
Natural	Mountain	38,900
	Streambed	37,700
	subtotal	76,600
Incidental	Municipal	56,900
	Industrial	5,300
	Agricultural	26,500
	subtotal	88,700
Direct	CAP	7,800
	Effluent	3,200
	subtotal	11,000
Total recharge		**176,300**
Total of all gains to aquifer		**185,000**
LOSSES FROM AQUIFER		
GROUNDWATER OUTFLOW TO PINAL AMA		**-24,500**
GROUNDWATER PUMPING		
Municipal		-145,300
Industrial		-57,700
Agricultural		-104,700
Total groundwater pumping		**-307,700**
EVAPOTRANSPIRATION (from shallow groundwater)		**-3,700**
Total of all losses from aquifer		**-335,900**
AQUIFER BALANCE		
Total of gains and losses (overdraft)		**-150,900**

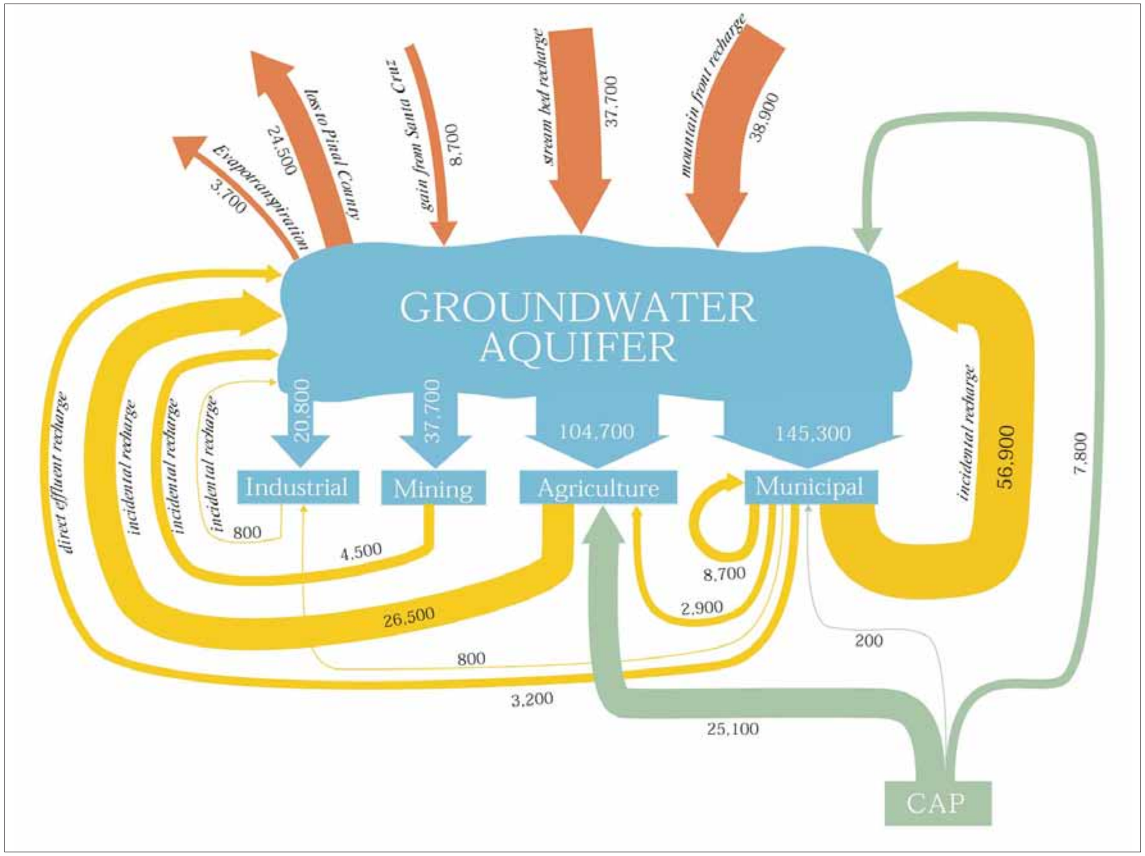
DIRECT USE OF RENEWABLE SUPPLIES**	
EFFLUENT (Direct Use)	
Municipal	8,700
Industrial	800
Agricultural	2,900
Total direct effluent use	**12,400**
CAP (Direct Use)	
Municipal	200
Agricultural	25,100
Total direct CAP water use	**25,300**
Total of direct use of CAP water & effluent	**37,700**

NOTES ON WATER BUDGET CALCULATIONS

* This budget uses data from ADWR, but differs from ADWR's "paper water" budgets by considering only the physical use and movement of water. Direct recharge is counted as a gain to the aquifer in the year recharge occurs, not when recharge credits are used. Irrigation with CAP is counted as direct CAP use, not groundwater or *in lieu* "recharge."

** These uses may indirectly benefit the aquifer by serving as a substitute for groundwater that would have been pumped. Incidental recharge from these uses is already included in the "Gains to the Aquifer" section.

Water budget flow chart. (1997 data)



Sources: Arizona Department of Water Resources, Water Resources Research Center.

- Plan to deplete some parts of the aquifer (Avra Valley, for example) while protecting the central city from subsidence; or
- Use as much water as we want for as long as it lasts.

Current state law directs us to aim towards prolonging the supply into the future, but does not require complete sustainability. This is because "Safe yield" allows a certain amount of groundwater mining.

People who support sustainability or prolonging the life of the water supply are mainly concerned about:

- Avoiding subsidence;
- Assuring an affordable water supply for future generations;
- Assuring water quality for future generations;
- Complying with requirements of state law;
- Preserving the desert from "urban sprawl" or "overdevelopment."

People who don't support sustainability usually feel that:

- The present is more important than the distant future;
- New technologies may be developed over time to solve the problem;
- The problem is too far off to be a concern;
- Information about water supplies and water quality is incomplete or not credible;
- Their family may not be here when the problems arise;

Do you recognize your views in either list? Or do you identify with some statements from both lists? How much do you value a sustainable water supply? What kind of limitations are you willing to impose on others? What sacrifices are you willing to make?

WATER BUDGET SCENARIOS

Conventional wisdom is that most people in the community support either a sustainable supply or at least prolonging our supply. But there are many divergent views as how best to approach this goal. To balance supply and demand we can control water use and/or increase the supply. We can control water use by limiting the number of people using water and/or limiting the amount each person uses. We can also transfer water use from one sector to another (e.g., reduce agricultural activities to save water for other uses). Water supplies can be increased by capturing more rainwater and snow

Supply & Demand Scenarios*

Based upon Approximate Current Levels of Demand by Sector, in Acre-Feet

	Demand (% of current)				Groundwater Pumping					
	Muni.	**Indus.**	**Ag.**	**Supply**	**Muni.**	**Indus.**	**Ag.**	**Total**	**CAP**	**Balance†**
Current levels	100	100	100	Groundwater for all sectors	150,000	50,000	125,000	325,000	0	-180,000
	100	100	100	Groundwater for municipal, CAP for others	150,000	0	0	150,000	175,000	-5,000
	100	100	100	CAP for municipal, groundwater for others	0	50,000	125,000	175,000	150,000	-30,000
2X Municipal	200	100	100	Groundwater for all sectors	300,000	50,000	125,000	475,000	0	-273,000
	200	100	100	Groundwater for municipal, CAP for others	300,000	0	0	300,000	175,000	-98,000
	200	100	100	CAP for municipal, groundwater for others	0	50,000	125,000	175,000	300,000	+27,000
2 Mun. ½ Ag. & Ind.	200	50	50	Groundwater for all sectors	300,000	25,000	62,500	387,500	0	-201,000
	200	50	50	Groundwater for municipal, CAP for others	300,000	0	0	300,000	87,500	-113,000
	200	50	50	CAP for municipal, groundwater for others	0	25,000	62,500	87,500	300,000	+99,000
	200	50	50	Half groundwater, half CAP for all sectors	150,000	12,500	31,300	193,800	193,800	-7,000
2 Mun., Ag. & Ind.	200	200	200	Groundwater for all sectors	300,000	100,000	250,000	650,000	0	-417,000
	200	200	200	Groundwater for municipal, CAP for others	300,000	0	0	300,000	350,000	-67,000
	200	200	200	CAP for municipal, groundwater for others	0	100,000	250,000	350,000	300,000	-117,000
	200	200	200	Half groundwater, half CAP for all sectors	150,000	50,000	125,000	325,000	325,000	-92,000

* This table represents a range of supply and demand scenarios for general illustration; it should not be used to make specific future projections. Simplified assumptions (e.g. all groundwater or all CAP for a sector) have been made to clarify the relationships between supply, demand and the aquifer balance.

† This number represents the approximate "wet water" loss or gain to the regional aquifer. The value is calculated as: (net natural recharge [76,600]) - (groundwater outflow [24,500]) - (evapotranspiration [3,700]) - (groundwater pumping) + (incidental recharge) + (groundwater inflow [8,700]). Incidental recharge is itself calculated as 38% of municipal demand (multi-year average), 20% of agricultural demand, and 12% of industrial demand. This balance does not consider factors such as long-term storage through recharge, or changes in incidental recharge rates.

melt, importing and using water from elsewhere and accepting wastewater as a supply for more uses.

Here is where you bring it all together, combining the factual information gleaned from the first seven chapters with your values and preferences, to generate tentative choices. The final step is to see what the consequences of those choices are, and how your choices interact with each other. To do that, we use water budget scenarios.

The table on the preceding page shows ten illustrative water supply and demand scenarios. The left side of the table shows municipal, industrial and agricultural demand expressed as percentages of current demand. The "supply" column describes who pumps groundwater and who uses CAP water under each scenario. (Note that use of effluent has little effect on the water budget bottom line, because nearly all effluent not re-used is directly or incidentally recharged.) These assumptions about water demand levels and supply allocations on the left side of the table are used to estimate resulting groundwater pumping by sector, CAP usage, and aquifer balance, as shown on the right side of the table.

The first three scenarios hold demand at current levels. The first scenario shows that if everyone uses pumped groundwater, we have a large deficit in the aquifer. The second scenario suggests that if all growth were halted and groundwater were reserved solely for municipal uses, the aquifer would be nearly in balance. The next three scenarios correspond to an eventual doubling of municipal demand, as population grows. Here, reserving groundwater for municipal uses does not bring the aquifer close to balance. By contrast, using CAP water for all municipal uses actually produces a surplus in the aquifer.

The third set of scenarios combines municipal growth with a halving of industrial and agricultural demand. Note that serving a 50-50 blend of groundwater and CAP water to all sectors nearly balances the aquifer. The final set of scenarios corresponds to a doubling of water demand in all sectors. This could occur, for example, if population growth continued unabated, mining expanded, and tribal water allocations were used to expand irrigated agriculture on reservation lands. In such a situation, there is not sufficient CAP water available to bring the aquifer close to balance.

Those of you with Internet access are now invited to try your hand at water budgeting by making your own assumptions. An interactive version of this budget is on the Web at:

http://ag.arizona.edu/AZWATER/

Use it to construct a scenario that reflects your values, preferences and sense of fairness. Try out a number of options. For example, you may want to limit water use by controlling population, or by requiring more conservation; or you may want to lessen long-term salinity problems by using less CAP water.

See how close your preferred options come to balancing supply and demand. Remember that if you make some changes, other figures will be affected. For example, if you eliminate agriculture and replace it with naturally vegetated park land, the water savings will be greater than if you replace it with golf courses. If you use more effluent, you will have less incidental recharge. To get close to water sustainability, you will have to make hard choices. When push comes to shove, where are you willing to compromise?

Appendix A

WATER TERMS

Acre-foot (a.f.) - The amount of water needed to cover an acre of land one foot deep, equal to 325,851 gallons.

Algae - Aquatic one- or multi-celled plants without true stems, roots and leaves but containing chlorophyll. Algae may produce taste and odor problems.

Alluvium - Debris from erosion, consisting of some mixture of clay particles, sand, pebbles, and larger rocks. Usually a good porous storage medium for groundwater.

Artesian well - A well in which water rises to the surface without pumping from a permeable geological formation that is overlain by an impermeable formation. No artesian wells remain in the Tucson area.

Artificial recharge - The deliberate act of adding water to a groundwater aquifer by means of a recharge project. Artificial recharge can be accomplished via injection wells, spreading basins, or in-stream projects. See also incidental recharge, natural recharge, recharge.

Aquifer - One or more geologic formations containing enough saturated porous and permeable material to transmit water at a rate sufficient to feed a spring or for economic extraction by a well. Combination of two Latin words, *aqua* or water, and *ferre*, to bring; literally, something that brings water.

Assured Water Supply - A technical term used in the Groundwater Management Act defined as a supply of water theoretically sufficient to meet the needs of a new development or customers of a municipal water supplier for 100 years. The methods for determining this are spelled out in AACR12-15-701.

Augmentation - Supplementing the water supply by such means as importing water from another basin or storing water.

Base flow - Streamflow derived from groundwater seepage into the stream; water that flows on the surface independent of precipitation.

Basin - See Groundwater basin.

Ccf (hundred cubic feet) - a unit of water used by some municipal water providers for metering and billing purposes. 1 Ccf = 748 gallons.

Central Arizona Project (CAP) - A facility consisting of canals, pumping stations and pipelines used to transport water from the Colorado River at Lake Havasu to Central Arizona and ultimately to Tucson.

CERCLA - The Comprehensive Environmental Response, Compensation and Liability Act, commonly known as Superfund, which regulates disposal and cleanup of hazardous materials.

Chloramine - A chemical used to disinfect and innoculate water supplies. Formed by combining chlorine and ammonia, chloramine is generally more stable but less potent than chlorine.

Chlorine - A chemical commonly used to disinfect water. It is highly effective against algae, bacteria and viruses, but not protozoa.

Coliform bacteria - a common type of bacteria found in soil and water and which grows in the intestines of warm-blooded animals. They are generally not harmful, but high levels may indicate the presence of other harmful bacteria or viruses.

Cone of depression - A drop in the water table around a well or wells which have been pumping groundwater. Depending on the rate of pumping and aquifer characteristics a cone of depression can be shallow and extend only a few feet or it can extent for several miles. Since water flows downhill underground, a cone of depression pulls water from the surrounding area into it, thus affecting the nearby water table.

Constructed wetland - A manmade wetland, usually designed to utilize wastewater and often involving a wildlife habitat component.

Consumptive use - A use that makes water unavailable for other uses, usually by permanently removing it from local surface or groundwater storage as the result of evaporation and/or transpiration. Does not include evaporative losses from bodies of water. Compare with non-consumptive use.

Corrosivity - A measure of the ability of water to corrode pipes. Corrosion occurs when metal is exposed to conditions which cause the breakdown of the metal through an exchange of ions. If corrosion is severe enough, the pipes may break entirely. EPA has no standards for corrosivity.

Desalinization - A process of removing salts and other dissolved minerals from water.

Disinfection byproducts - Compounds formed from the interaction of treatment chemicals with materials (usually organic) in the water.

Distribution system - An interconnected grid of water mains, valves, storage reservoirs and pressure boosting or reducing facilities.

Downgradient - The direction water flows by force of gravity.

Drawdown - A lowering of the groundwater level or the piezometric pressure caused by pumping, measured as the difference between the original groundwater level and the level after a period of pumping.

Effluent - Water that has been collected in a sewer for subsequent treatment (ADWR definition). The term is also commonly used to refer to water discharged from a treatment plant.

Evapotranspiration - The amount of water transpired through pores and evaporated by vegetation.

Electrodialysis - a membrane filtration process that uses an electric charge rather than water pressure to force dissolved solids through the membrane pores. Used by Buckeye, AZ.

Filtration - The process of passing water through materials with very small holes (pores) to strain out particles. Filtration can remove microorganisms including algae, bacteria and protozoa, but not viruses.

Flexibility Account - A paper account in which farmers can accumulate credits for unused portions of their groundwater allotments for use in meeting conservation requirements in the future.

Floodplain - The area near a watercourse inundated during floods. The 100-year floodplain is the area that is expected to be inundated by a flood of a magnitude that has a one-in-a-hundred probability of occurrig in any year.

GPCD (Gallons per capita per day) - The amount of water used on average by an individual each day. Total gpcd is calculated by dividing total water use in the area, including industrial and commercial uses, by the number of users. Residential gpcd is the number resulting from only considering domestic water use.

Gradient, hydraulic - The change of pressure per unit distance from one point to another in an aquifer. When an area is said to be "downgradient" it is at a lower level and water will flow in that direction.

Groundwater - Subsurface water body in the zone of saturation, or more commonly, available groundwater is defined as: That portion of the water beneath the surface of the earth that can be collected with wells, tunnels, or drainage galleries, or that flows naturally to the earth's surface via seeps or springs.

Groundwater basin - An area enclosing a relatively distinct hydrologic body or related bodies of groundwater.

Groundwater savings facility (GSF) - A facility, usually a farm, which agrees to use a renewable water supply such as CAP water instead of groundwater under the UWS program. Entities with extra renewable supplies, such as municipal water providers, sell CAP water to the farms and in return get a credit for groundwater saved, which can be used to offset future groundwater pumping.

Hardness- A water quality parameter that indicates the level of alkaline salts, principally calcium, magnesium, and iron, and expressed as equivalent calcium carbonate ($CaCO_3$). Hard water is commonly recognized by the increased quantities of soap, detergent or shampoo necessary to raise a lather.

Hydraulic gradient - see gradient, hydraulic.

In-lieu recharge - A term used by ADWR to describe the process of using a renewable supply instead of pumping groundwater at a Groundwater Savings Facility. No water is actually recharged.

Impact fee - A fee charged to developers to cover part or all of the costs of providing services, such as sewers, water connections, and roads. Such a fee is allowed but not required under state law.

Incidental recharge - Water incidentally added to a groundwater aquifer due to human activities, such as excess irrigation water applied to fields or water discharged as waste after a use. See also recharge, artificial recharge, natural recharge.

Infiltration - The process of water entering the soil or streambed surface.

Injection well - An artificial structure (usually an existing well) used to recharge the water table by forcing water down the well.

Irrigation district - A political entity created to secure and distribute water supplies. Most irrigation districts provide water for irrigation on farms, but some which originated for agricultural purposes now primarily serve municipal customers.

mg/l - Milligrams per liter - Roughly equivalent to parts per million (see below).

Microfiltration (uf) - a form of filtration using a membrane with larger pores than nanofiltration. It is highly effective in removing pathogens, including parasites such as giardia, but does not remove salts. Because it has large pores, UF does not leave a saline concentrate, although filters must be backwashed to keep the pores open.

Mineral content - See Total dissolved solids.

Mountain front recharge - Natural recharge that occurs at the base of the mountains because of rainfall or snow melt at higher elevations.

Municipal water use - All non-irrigation uses of water supplied by a city, town, private water company or irrigation district. Generally includes domestic, commercial, public and some industrial uses.

Nanofiltration (NF) - A form of filtration using membranes with larger pores than reverse osmosis. NF removes most salts, pathogens and organics. Like RO the process requires pretreatment of water with chemicals or a sand-based system. NF has not been used commercially on a large scale for drinking water.

Natural recharge - Natural replenishment of an aquifer generally from snowmelt and storm runoff. See also recharge, artificial recharge, incidental recharge.

Ozone - A highly reactive form of oxygen (O_3) used to disinfect water.

Non-consumptive use - A water use that leaves the water available for other potential uses, usually after it has been collected in a sewage system. Most indoor uses are largely non-consumptive. Compare with consumptive use.

Parts per million (ppm) and parts per billion (ppb)- A measures of the concentration of materials in a liquid, often used to describe the degree of contamination of water. One ppm indicates that for each one millions units of water there is one unit of the contaminant, One ppb indicates that for each one billion units of water there is one unit of the contaminant. 1 ppm is approximately equal to 1 mg/L.

Permeability - A measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient.

pH - A measure of the relative acidity of water. Below 7 is increasingly acid, 7 is neutral and above 7 is increasingly alkaline.

Potable water - Water that is suitable for drinking, from a Latin word meaning "drink."

Primary treatment - Initial treatment given to sewage, usually removal of solids and possibly some disinfection.

Private water utility - A water provider that is owned by individuals or a corporation and sells water to customers.

Protozoa - Microscopic animals that occur as single cells. Some can cause disease in humans. They are not destroyed by disinfection, but can be destroyed by filtration.

Public utility - A water or power provider owned by a government such as a city or town.

Recharge - Augmentation of the groundwater by the addition of water. See natural recharge, artificial recharge, incidental recharge.

Reclaimed water - Tertiary-treated water available for use on turf or other facilities.

Reservoir - A facility for storing water until it is to be used. A reservoir may be open or covered.

Reverse osmosis - A process whereby water is forced through membranes that contain holes so small that even salts cannot pass through them. It removes microorganisms, organic chemicals and inorganic chemicals, producing very pure water.

Runoff - Drainage or flood discharge which leaves an area as surface flow or as pipeline flow, having reached a channel or pipeline by either surface or sub-surface routes.

Safe yield - 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 within a designated area.

Secondary treatment - The most common level of treatment of sewage, involving removal of solids, use of bacterial action for purification, and the addition of disinfectants.

Service area - The area served by a municipal water provider, within which it may hold a monopoly.

Sewage - Water that has been used by individuals or businesses and needs treatment.

Sewer - A pipeline used to transport sewage to a treatment facility.

Sludge - Solids left over from the wastewater treatment process.

Sodium - A mineral which occurs naturally in most water.

Soft water - Water with relatively low concentrations of certain dissolved minerals, principally calcium, magnesium, and iron. Water from which these minerals have been mostly removed, usually through an ion exchange process.

Soil-aquifer treatment - A method of treating water by letting it seep through soil and other materials to mitigate pollution.

Subsidence - Downward movement of the land surface associated with groundwater pumping, especially where such pumping exceeds safe yield and the water table has dropped. Uneven rates of subsidence over an area can lead to differential subsidence, which can cause lateral movement of the land surface, and cracks and fissures to appear. This is more likely to occur in areas where the aquifer varies in thickness, such as near the edges of groundwater basins. Subsidence is an essentially irreversible process, not greatly ameliorated by later raising the water table.

Subsurface water - All water below the land surface, including soil moisture, capillary fringe water in the vadose zone, and groundwater.

Superfund - A commonly used name for the federal Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).

Surface water - Water that flows on the surface in streams.

Terminal storage - A facility for storage of water near the end of a pipeline or canal. A facility to be used in times of water shortage in the CAP system (due, for example, to damage to the canal), that would supply water during a period of system repair or while wells are being reactivated.

Trichloroethylene (TCE) - A compound used most often for degreasing metal parts during manufacturing. Found as a pollutant in some Tucson-area groundwater, suspected of causing certain serious diseases.

Trihalomethanes (THMs) - Disinfection byproducts arising from the combination of chlorine with organic matter in the water.

Tertiary treatment - Post-secondary treatment of water designed to improve the quality of the water to the point where it can be put to a particular beneficial use.

Total dissolved solids (TDS) - A measure of the minerals dissolved in water. Up to 500 ppm is considered satisfactory and above that level increasingly unsuitable for domestic use. Tucson-area groundwater generally has TDS levels between 200 and 600 ppm; CAP water has TDS of about 700 ppm.

Transmissibility - The flow capacity of an aquifer measured in volume per unit time per unit width. Equal to the product of permeability times the saturated thickness of the aquifer.

Transmission line - A pipeline for transporting water.

Treated wastewater - The treated water that comes from a sewage treatment plant.

Treatment plant - A facility using various physical and chemical processes for treating water or wastewater. Treatment can include disinfection, filtration, adjusting the pH, adding corrosion inhibitors, and improving taste and odor.

Turbidity - The reduction of transparency in water due to the presence of suspended particles, or a cloudy appearance in the water. Increased turbidity raises the risk of water-borne pathogens growing and reproducing. Turbid water is therefore more difficult to disinfect.

Underground storage facility (USF) - A facility for artificial recharge of water supplies into an aquifer.

Underground Water Storage, Savings, and Replenishment Program (UWS) - A program administered by the ADWR to encourage the storage and/or use of renewable supplies. Rules governing permitting and operation of Underground Storage Facilities and Groundwater Savings Facilities are described under this program.

Vadose zone - The unsaturated zone lying between the earth's surface and groundwater table.

Volatile organic compounds (VOCs) - Solvents used as degreasers or cleaning agents. They evaporate easily producing odors typical of gasoline, kerosene, lighter fluid or dry cleaning fluid. Some may be cancer-causing.

Water main - A large pipeline which transports water to smaller distribution lines which take water to homes and businesses.

Water table - The upper boundary of a free groundwater body, at atmospheric pressure.

Wellfield - A group of wells in a particular geographic area, usually operated by one entity.

Wetlands - An area that always has water at or near the surface. A natural wetland receives its water from a groundwater source and is also called a "cienega". A constructed, or artificial, wetland usually receives its water from some wastewater source, either agricultural, industrial or municipal.

ACRONYMS

ACC - Arizona Corporation Commission

ADEQ - Arizona Department of Environmental Quality

ADWR - Arizona Department of Water Resources

AMA - Active Management Area

APP - Aquifer Protection Permit

AVID - Avra Valley Irrigation District

AWBA - Arizona Water Banking Authority

AWS - Assured Water Supply

BADCT - Best Available Demonstrated Control Technology

BMP - Best Management Practice

CAP - Central Arizona Project

CAGRD - Central Arizona Groundwater Replenishment District

CAVSARP - Central Avra Valley Storage and Recovery Project

CAWCD - Central Arizona Water Conservation District

CMID - Cortaro Marana Irrigation District

DES - Arizona Department of Economic Security

DDT - Dichloro-Diphenyl-Trichloroethane

EA - Environmental Assessment

EIS - Environmental Impact Statement

EPA - U.S. Environmental Protection Agency

ED - Electrodialysis

ESA - Endangered Species Act

FCD - Flood Control District

FEMA - Federal Emergency Management Agency

FICO - Farmers Investment Company

GMA - Arizona Groundwater Management Act of 1980

GPCD - Gallons Per Capita per Day

GPM - Gallons Per Minute

GSF - Groundwater Savings Facility

INA - Irrigation Non-Expansion Area

MF - Microfiltration

NF - Nanofiltration

NPDES - Non Point Discharge Elimination System

PAG - Pima Association of Governments

PCE - Perchloroethylene

PCHD - Pima County Health Department

PDEQ - Pima County Department of Environmental Quality

RO - Reverse Osmosis

SAT - Soil-Aquifer Treatment

SAWRSA - Southern Arizona Water Rights Settlement Act

TARP - Tucson Airport Remediation Project

TAMA - Tucson Active Management Area

TCE - Trichloroethylene

TDS - Total Dissolved Solids

THM - Trihalomethane

TSMP - Tucson Stormwater Management Plan

USF - Underground Storage Facility

USGS - United States Geological Survey

UWS - Underground Water Storage, Savings, and Replenishment Program

VOCs - Volatile Organic Compounds

Water CASA - Water Conservation Alliance of Southern Arizona

WCPA - Water Consumer Protection Act

WRRC - Water Resources Research Center

Appendix B
SUPPLEMENTARY INFORMATION

CONTENTS

WATER PROVIDERS IN PIMA COUNTY

Following is a list of water providers in Pima County registered with the Environmental Protection Agency in 1998. Note that some are schools or businesses providing water only during certain hours. If some of the following population numbers do not agree with those in the text, its because they may represent different years.

Water System	Population Served
A-A RV Campground	100
ADOC-Correction Training	3700
ADOT Canoa R/A	1375
Ajo Domestic Water Improvement	2190
Amity Circle Tree Ranch	150
Amphitheater School District	10,615
Arivaca Townsite Water Co	240
ASARCO Silver Bell Unit	930
Avra Water Coop, Inc	3,300
AZ Parks Board-Catalina St	400
AZ Portland Cement-plant	160
AZ Water Co-Ajo	2,000
Bermuda Gardens Trailer	93
Breakers Water Park	533
C & N Water Co	32
Cactus Country Tr Haven	250
Mt. Lemmon Camps	850
Campbell Estates	300
Canada Hills Water Co	5,012
Canyon Ranch	485
Carol Anne Dr Homeowners	52
Casa Motel & Camping	30
Casitas De Castilian	200
Catalina Country Mobile	130
Caterpillar Water	65
Colonial Mobile & Trailer	150
Community Water - Green Valley	12,320
Continental School	250
Coronado Forest Drive In	40
Cortaro Acres Home	30
Cortaro Water Users Assn	1,920
Cyprus Sierrita Corp	760
Decker Community Water Co	29
Deep Well Cooperative	40
Del Lago Water Co	990
Desert Hills School	107
Desert Shores MHP	405
Desert Water Well Coop S	45
Desert Willows MHP	320
Diamond Grove Mobile HE	208
Dome Well Association	27
DYTR-Catalina Mountain	450
E & T Water Co	800
Elkhorn Ranch	50
Emery Park Mobile Home Pk	240
Evergreen Cemetery	35
Exxon Corporation	200
Far Horizons East	1,500
Far Horizons Mobile Home	290
Farmers Water	2,389
Federal Corr Institute	750
Flowing Wells Irrigation District	16,160
Foothills Mobile Homes	95
Forty-Niners Water Company	790
Francesca Water Company	100
Fred's Arena Bar & Steak	40
Green Valley Water Company	8,125
Greenfields School	250
Gringo Pass Trailer Park	55
Halcyon Acres	400
Halfway Station MHP	64
High Chaparral Water Coop	35
Hohokam Mobile Home Park	60
Homeowners Coop	45
Hub Water Co	4,040
Hughes Missile Systems Co	4,000
IBM	3,100
I M Water Co Inc	340
King's Trailer Lodge	45
Kino Mobile Home Park	110
Kitt Peak National Observatory	300
La Casita Water Co	25
La Cholla Air Park Ed Pr	200
Lago Del Oro Water Co	4,500
Lakewood Estates Water C	750
Las Quintas Serenas WC	1,169
Manor Trailer CC	170
Marana Water Service Inc	1,715
Mesaland Water Co-op	350
MDWID - Metropolitan Domestic Water Improvement District	36,250
Midvale Farms Water Company	200
Mirabell Water Coop	210
Mission Palms Apartments	900
Mr G's Diner	50
Mt Lemmon Water Co	600

Water System	Population Served
North La Cholla MHP	100
Oracle Villa Apartments	822
Orchard Valley MHP	80
Organ Pipe NM-Headquarters	412
Pacific Fruit Express	50
Palm Vista Estates MHP	400
Pantano Water Coop	98
Pima County Parks	9,142
Pima Cnty Dot Avra Valle	106
Pima Ramada Mobile Home Park	35
Pita Water	38
Quail Creek Water	180
Quail Valley Tennis Club	40
Rabies Control Center	20
Rainbow Tavern	51
Raindance Water Coop	60
Rancho De La Osa	40
Rancho Del Conejo Water	522
Rancho Los Amigos MHP	200
Rancho Sierrita Well Assc	102
Rancho Tierra Blanca	40
Rancho Vistoso Water Co	4,300
Ranchwood Mobile Park	200
Ray Water Co Lansing Str	2,880
Regina Cleri Center	25
Rillito Water Users Assoc	200
Rincon Country East Rv re	920
Rincon Mesa Landowner's	65
Rincon Ranch Estates Water Co	905
Rincon Water Co	50
Rio Vista Mobile Home Pa	2000
Riverside Apts	10
Saguaro National Park	420
Saguaro Water Company	35
Sahuarita Heights Mobile	110
Sahuarita Sch, Dist 3,	1,800
Sahuarita Village Water	135
Sahurita Park Pcpr	40
Salpointe High School1	288
Samalayucca Improvement	150
Sandario Water Co	555
Santa Catalina Mission Church	100
Sasabe Border Water Co	68
Shae Water Company	28
Sierra Court Trailer Park	100
Sierra Tucson	100
Sierrita Foothills	50
Sierrita Mountain Water	80
Siete Casas Joint Venture	60
Silver Cholla Park	200
Sleepy Hollow MHP	1,110
Solana & Sombra MHP	200
Soldier Camp Permittees	50
Sopori Elementary School	300
Southern Pines Baptist Church	100
Spanish Trail Water Co	770
St Joseph's Hospital	1,400
Su Casa MHP	100
Summit Water Company	33
Summit Water Coop	78
Tanque Verde Guest Ranch	40
Terminal Stations	500
The Lazy Bone RV Resort	300
Thim Utility Company	828
Thunderhead Ranch	93
Town & Country MHP	640
Town of Oro Valley Water	10,850
Tra-tel Tucson RV Park	50
Tucson Electric Power Co	550
Tucson General Hospital	500
Tucson Meadows MHP	650
Tucson Medical Center	2,500
Tucson Racquet Club	400
Tucson Rock	40
Tucson Rock and Sand	40
Tucson Water Dept	55,3040
University of Arizona	1,5950
Universal Ranch Store	8
USAF-Davis Monthan AFB	8,900
United States Forest Service	950
Vail School	110
Val Verde Inc	45
Valle Verde Del Norte	300
Veterans Medical Center	900
Via Verde West MHP	100
Villa Capri Trailer Park	420
Vision Quest Annex	30
Vista Del Norte TP	750
Voyager Water Company	2,500
Webb's Steak House	60
Wells Fargo Well Assoc	80
White Stallion Guest Ran	45
Wildflower Water Co-op	84
Winter Haven Ranch	125
Winterhaven Water & Dev	765
Wycliffe Mountain Vista	26
Zimmerman Enterprises	200

Source: U.S. Environmental Protection Agency Web Site: www.epa.gov

EFFLUENT USE ALTERNATIVES

Following is a list of effluent projects and potential alternatives as of January 1999, compiled by the Regional Effluent Planning Partnership.

What happens to effluent today?

1. Santa Cruz River discharge. This represents the existing conditions and incidental recharge.
2. City of Tucson Reclaimed Water System. Direct use of tertiary effluent.
3. Agricultural irrigation. The reuse of treated secondary effluent for the irrigation of non-food agriculture.

ALTERNATIVES — IN PROGRESS

1. Santa Cruz River Managed Underground Storage Facility (Roger Road to Ina Road). Acquiring credits for existing discharge which is recharging the aquifer.
2. Santa Cruz River Managed Underground Storage Facility (Ina Road to Red Rock). Acquiring credits for existing discharge which is recharging the aquifer.
3. Rillito/Swan Effluent Wetland Recharge. This project involves additional treatment and constructed recharge.
4. Kino Effluent Wetland Recharge. This project combines the direct reuse of reclaimed water for turf irrigation with a constructed recharge operation.
5. Marana High Plains Effluent Recharge Project. Constructed recharge and vegetation enhancement.
6. Atturbury Wash Project. Wetlands treatment and dry well recharge at Lincoln Regional Park in the west tributary of Atturbury Wash.
7. Lower Santa Cruz Replenishment Project located north of Avra Valley Road. Direct recharge using basins and streambed.

FUTURE/PROPOSED ALTERNATIVES

1. Santa Cruz River Managed Underground Storage Facility, 100 percent credit accrual for SAWRSA effluent. Managed recharge Roger Road to Red Rock.
2. Wastewater reclamation in Oro Valley and Metro Water service areas. This project would include a wastewater reclamation facility and effluent lines to existing and planned golf courses or, possibly, to recharge basins.
3. Effluent Reuse in Green Valley. The project would involve the use of effluent for golf course turf irrigation and agricultural irrigation.
4. Avra Valley Wetlands Treatment and Effluent Recharge Project. Wetlands treatment and basin recharge.
5. Marana Santa Cruz River Park and Recharge Project. This project provides for a combination of facilities including constructed and managed recharge facilities and turf areas for irrigation reuse. Located at Cortaro Farms Road and the Santa Cruz River.
6. Tangerine Road Wastewater Pollution Control Facility.
7. Pascua Yaqui Golf Course and Pascua Yaqui Recharge Projects.
8. Harrison-Pantano water reclamation facility. Reclamation facility that will provide effluent suitable for reuse, recharge or discharge to Pantano Wash.
9. Kolb/Bilby water Reclamation Facility. Reclamation facility that will provide effluent suitable for reuse, recharge or discharge to a nearby watercourse. The proposed site is in the vicinity of Kolb and Bilby Road.
10. Santa Cruz River downtown enhancement.

RATE STRUCTURE FOR TUCSON WATER

Tucson Water's charges (as of summer 1999) for delivery of potable water are comprised of four basic components: Minimum Charge, Usage Charge, Isolated Area Service Charge, and CAP Charge. Each of the components and its specific rate schedules is discussed in the following section. Tucson Water bills its customers on a monthly basis; all charges shown are monthly charges.

Minimum Charge

The minimum charge for all metered accounts is based upon the meter size and is levied whether or not any water is used. The charge includes a 3 Ccf minimum usage allowance for all customer classes except for sub-metered mobile home parks which receive a minimum usage allowance based on the number of occupied units. The monthly minimum charges are as follows:

Service Charge	Meter Size (inches)	Service Charge ($)
	0.75	$ 5.30
	1.00	$ 6.40
	1.50	$ 9.50
	2.00	$ 14.00
	2.50	$ 20.00
	3.00	$ 25.00
	4.00	$ 42.00
	6.00	$ 82.00
	8.00	$ 123.00
	10.00	$ 185.00
	12.00	$ 305.00

Usage Charge

The usage charge for all metered accounts is based upon the actual water utilized by the customer between monthly meter readings in excess of the minimum water use allowance. Charges for non-residential customers are further divided between winter and summer rate schedules. Winter rates are applicable to water usage from November through April. Summer rates are applicable to water usage from May through October.

For customers in the Multifamily, Submetered Mobile Home Park, Commercial, and Industrial customer classes, a two-tiered summer surcharge is charged for water usage above the customer's average monthly water usage for the previous winter rate period (November - April). Tier 1 is charged on all water used during the month which exceeds the customer's monthly winter average usage. Tier 2 is an additional charge on all water used during the month which exceeds 150 percent of the customer's monthly winter average usage. All charges identified below are based upon water use in units of Ccf (100 cubic feet). One Ccf equals 748 gallons.

Customer Class/Charge	Amount (Ccf)	Winter ($/Ccf)	Summer ($/Ccf)
Residential - single family	0 - 3	0.00	0.00
	4 - 15	1.62	1.62
	16 - 30	2.61	2.61
	over 30	3.29	3.29
Duplex-Triplex	0 - 3	0.00	0.00
	4 - 20	1.62	1.62
	21 - 35	2.61	2.61
	over 35	3.29	3.29
Multi-family	0 - 3	0.00	0.00
	over 3	1.35	1.35
	summer surcharge - tier 1		0.95
	summer surcharge - tier 2		0.25
	maximum charge per Ccf		2.55
Submetered mobile home parks	0 - 3	0.00	0.00
	over 3	1.35	1.35
	summer surcharge - tier 1		0.95
	summer surcharge - tier 2		0.25
	maximum charge per Ccf		2.55
Commercial	0 - 3	0.00	0.00
	over 3	1.40	1.40
	summer surcharge - tier 1		0.95
	summer surcharge - tier 2		0.25
	maximum charge per Ccf		2.60
Industrial	0 - 3	0.00	0.00
	over 3	1.21	1.21
	summer surcharge - tier 1		0.95
	summer surcharge - tier 2		0.25
	maximum charge per Ccf		2.41
Construction	0 - 3	0.00	0.00
	over 3	1.89	1.89

Isolated Area Service Charge

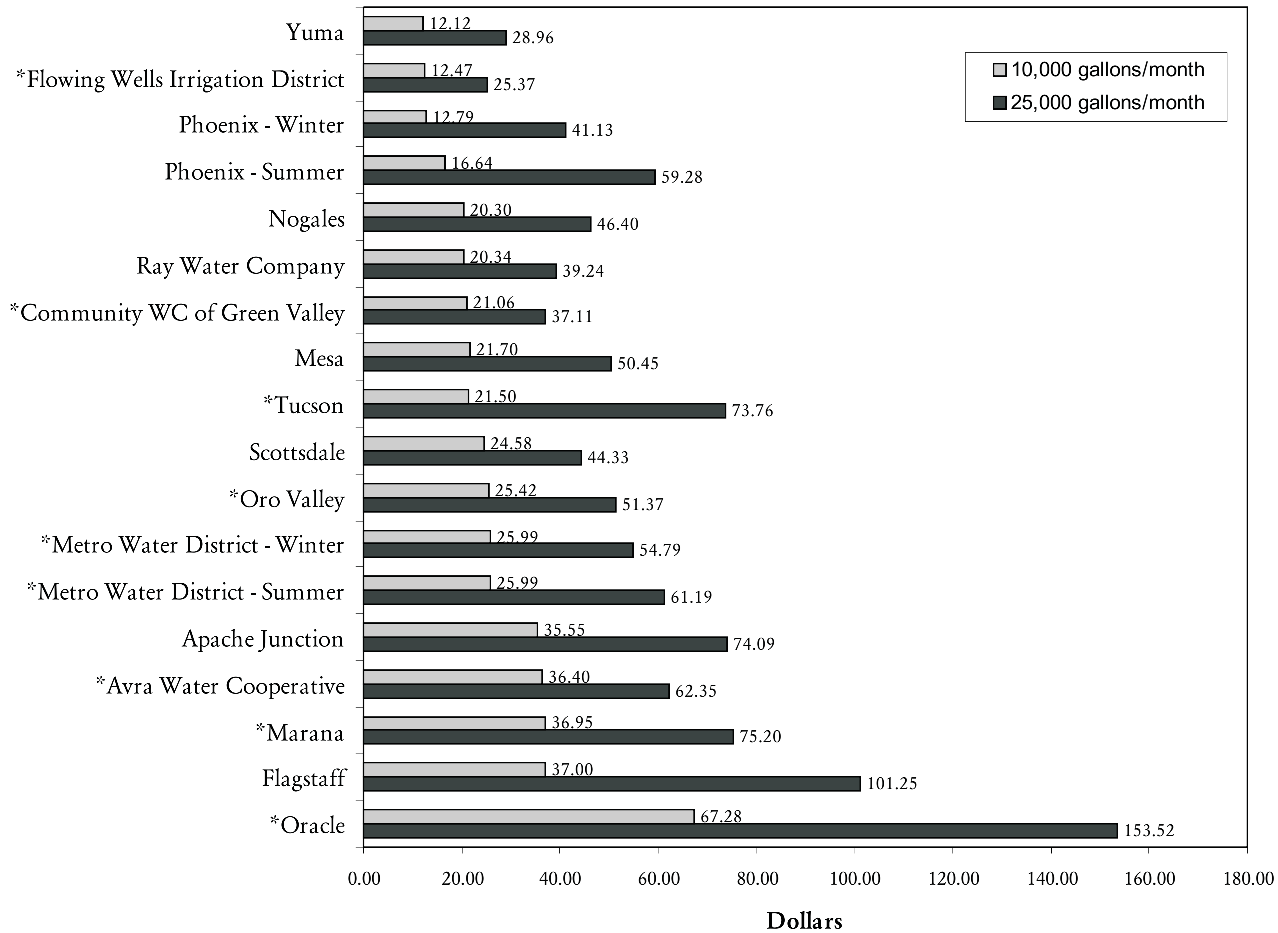
For water customers who are located in water delivery areas that are isolated and not connected to Tucson Water's central service area, an isolated area service charge is applied to each Ccf of monthly water usage to cover the higher costs of providing water to these isolated areas. The rates are $0.35/Ccf.

CAP Charge

All Tucson Water customers are charged a CAP fee applied to each Ccf of monthly water usage. This charge contributes to covering costs associated with the Central Arizona Project. The rates are $0.02/Ccf.

Source: Tucson Water Web Site: http://www.ci.tucson.az.us/water/tsnwtr/rates/rate99.htm

WATER BILLS FOR SELECTED ARIZONA WATER PROVIDERS



Monthly base charge plus commodity charges. Excludes taxes, surcharges, sewerage charges, etc.
* Denotes Tucson area water providers.

NATIONAL PRIMARY DRINKING WATER STANDARDS

National Primary Drinking Water Regulations (NPDWRs or primary standards) are legally enforceable standards that apply to public water systems. Primary standards protect drinking water quality by limiting the levels of specific contaminants that can adversely affect public health and are known or anticipated to occur in public water systems.

	MCLG[1] (MG/L)[4]	MCL[2] OR TT[3] (MG/L)[4]	POTENTIAL HEALTH EFFECTS	SOURCES OF CONTAMINANTS
INORGANIC CHEMICALS				
Antimony	0.006	0.006	Increase in blood cholesterol; decrease in blood glucose	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder
Arsenic	none[5]	0.05	Skin damage; circulatory system problems; increased risk of cancer	Discharge from semiconductor manufacturing; petroleum refining; wood preservatives; animal feed additives; herbicides; erosion of natural deposits
Asbestos	7 million (fiber >10 micrometers) fibers per Liter	7 MFL	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits
Barium	2	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium	0.004	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries
Cadmium	0.005	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints
Chromium (total)	0.1	0.1	Some people who use water containing chromium well in excess of the MCL over many years could experience allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits
Copper	1.3	Action Level=1.3; TT[6]	Short term exposure: Gastrointestinal distress. Long term exposure: Liver or kidney damage. Those with Wilson's Disease should consult their personal doctor if their water systems exceed the copper action level.	Corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preservatives
Cyanide (as free cyanide)	0.2	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories

	MCLG[1] (MG/L)[4]	MCL[2] OR TT[3] (MG/L)[4]	POTENTIAL HEALTH EFFECTS	SOURCES OF CONTAMINANTS
Fluoride	4.0	4.0	Bone disease (pain and tenderness of the bones); Children may get mottled teeth.	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories
Lead	zero Action Level=0.015	TT[6]	Infants and children: Delays in physical or mental development. Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits
Inorganic Mercury	0.002	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and cropland
Nitrate (measured as Nitrogen)	10	10	"Blue baby syndrome" in infants under six months - life threatening without immediate medical attention. Symptoms: Infant looks blue and has shortness of breath.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits
Nitrite (measured as Nitrogen)	1	1	"Blue baby syndrome" in infants under six months - life threatening without immediate medical attention. Symptoms: Infant looks blue and has shortness of breath.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits
Selenium	0.05	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines;
Thallium	0.0005	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and pharmaceutical companies
ORGANIC CHEMICALS				
Acrylamide	zero	TT[7]	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/wastewater treatment
Alachlor	zero	0.002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops
Atrazine	0.003	0.003	Cardiovascular system problems; reproductive difficulties	Runoff from herbicide used on row crops
Benzene	zero	0.005	Anemia; decrease in blood platelets; increased risk of from cancer	Discharge from factories; leaching gas storage tanks and landfills
Benzo(a)pyrene	zero	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines

	MCLG[1] (MG/L)[4]	MCL[2] OR TT[3] (MG/L)[4]	POTENTIAL HEALTH EFFECTS	SOURCES OF CONTAMINANTS
Carbofuran	0.04	0.04	Problems with blood or nervous system;	Leaching of soil fumigant used on rice and alfalfa reproductive difficulties.
Carbon tetrachloride	zero	.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities
Chlordane	zero	0.002	Liver or nervous; increased risk of cancer	Residue of banned industrial other industrial termiticide
Chlorobenzene	0.1	0.1	Liver or kidney problems	Discharge from chemical and agricultural chemical factories
2,4-D	0.07	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops
Dalapon	0.2	0.2	Minor kidney changes	Runoff from herbicide used on rights of way
1,2-Dibromo-3-chloropropane	zero	0.0002	Reproductive difficulties;	Runoff/leaching from (DBCP) soil fumigant used increased risk of cancer on soybeans, cotton, pineapples, and orchards
o-Dichlorobenzene	0.60.6		Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories
p-Dichlorobenzene	0.075	0.075	Anemia; liver, kidney or spleen damage; changes in blood	Discharge from industrial chemical factories
1,2-Dichloroethane	zero	0.005	Increased risk of cancer	Discharge from industrial chemical factories
1-1-Dichloroethylene	0.007	0.007	Liver problems	Discharge from industrial chemical factories
cis-1, 2-Dichloroethylene	0.07	0.07	Liver problems	Discharge from industrial chemical factories
trans-1,2-Dichloroethylene0.1	0.1		Liver problems	Discharge from industrial chemical factories
Dichloromethane	zero	0.005	Liver problems; cancer	Discharge from increased risk of pharmaceutical and chemical factories
1-2-Dichloropropanezero	0.005		Increased risk of cancer	Discharge from industrial chemical factories
Di(2-ethylhexyl)adipate	0.40.4		General toxic effects or reproductive	Leaching from PVC plumbing systems; discharge difficulties
from chemical factories				
Di(2-ethylhexyl)phthalate zero	0.006		Reproductive difficulties; liver problems; increased risk of cancer	Discharge from rubber and chemical factories
Dinoseb	0.007	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables

	MCLG[1] (MG/L)[4]	MCL[2] OR TT[3] (MG/L)[4]	POTENTIAL HEALTH EFFECTS	SOURCES OF CONTAMINANTS
Dioxin (2,3,7,8-TCDD)	zero	0.00000003	Reproductive difficulties; increased risk of cancer	Emissions from waste incineration and other combustion; discharge from chemical factories
Diquat	0.02	0.02	Cataracts	Runoff from herbicide use
Endothall	0.1	0.1	Stomach and intestinal problems	Runoff from herbicide use
Endrin	0.002	0.002	Nervous system effects	Residue of banned insecticide
Epichlorohydrin	zero	TT[7]	Stomach problems; reproductive difficulties; increased risk of cancer	Discharge from industrial chemical factories; added to water during treatment process
Ethylbenzene	0.7	0.7	Liver or kidney problems	Discharge from petroleum refineries
Ethelyne dibromide	zero	0.00005	Stomach problems; reproductive difficulties; increased risk of cancer	Discharge from petroleum refineries
Glyphosate	0.7	0.7	Kidney problems; reproductive difficulties	Runoff from herbicide use
Heptachlor	zero	0.0004	Liver damage; increased risk of cancer	Residue of banned termiticide
Heptachlor epoxide	zero	0.0002	Liver damage; increased risk of cancer	Breakdown of hepatachlor
Hexachlorobenzene	zero	0.001	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories
Hexachlorocyclopentadiene	0.05	0.05	Kidney or stomach problems	Discharge from chemical factories
Lindane	0.0002	0.0002	Liver or kidney problems	Runoff/leaching from insecticide used on cattle, lumber, gardens
Methoxychlor	0.04	0.04	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock
Oxamyl (Vydate)	0.2	0.2	Slight nervous system effects	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes
Polychlorinated biphenyls zero (PCBs)	0.0005	S	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	Runoff from landfills; discharge of waste chemical
Pentachlorophenol	zero	0.001	Liver or kidney problems; increased risk of cancer	Discharge from woodpreserving factories
Picloram	0.5	0.5	Liver problems	Herbicide runoff
Simazine	0.004	0.004	Problems with blood	Herbicide runoff

	MCLG[1] (MG/L)[4]	MCL[2] OR TT[3] (MG/L)[4]	POTENTIAL HEALTH EFFECTS	SOURCES OF CONTAMINANTS
Styrene	0.1	0.1	Liver, kidney, and circulatory problems	Discharge from rubber and plastic factories; leaching from landfills
Tetrachloroethylene	zero	0.005	Liver problems; increased risk of cancer	Leaching from PVC pipes; discharge from factories and dry cleaners
Toluene	1	1	Nervous system, kidney, or liver problems	Discharge from petroleum factories
Total Trihalomethanes (TTHMs)	none[5]	0.10	Liver, kidney or central nervous	Byproduct of drinking water disinfection system problems; increased risk of cancer
Toxaphene	zero	0.003	Kidney, liver, or thyroid problems; increased risk of cancer	Runoff/leaching from insecticide used on cotton and cattle
2,4,5-TP (Silvex)	0.05	0.05	Liver problems	Residue of banned herbicide
1,2,4-Trichlorobenzene	0.07	0.07	Changes in adrenal glands	Discharge from textile finishing factories
1,1,1-Trichloroethane	0.2	0.20	Liver, nervous system, or circulatory problems	Discharge from metal degreasing sites and other factories
1,1,2-Trichloroethane	0.003	0.005	Liver, kidney, or immune system problems	Discharge from industrial chemical factories
Trichloroethylene	zero	0.005	Liver problems; increased risk of cancer	Discharge from petroleum refineries
Vinyl chloride	zero	0.002	Increased risk of cancer	Leaching from PVC pipes; discharge from plastic factories
Xylenes (total)	10	10	Nervous system damage	Discharge from petroleum factories; discharge from chemical factories
Beta particles and photon	none[5] per year	4 millirems	Increased risk of cancer	Decay of natural and man-made deposits
Gross alpha particle activity	none[5]	15 picocuries per Liter (pCi/L)		Increased risk of cancer Erosion of natural deposits
Radium 226 and Radium 228	none[5]	5 pCi/L		Increased risk of cancer Erosion of natural deposits
MICROORGANISMS				
Giardia lamblia	zero	TT[8]	Giardiasis, a gastroenteric disease	Human and animal fecal waste

	MCLG[1] (MG/L)[4]	MCL[2] OR TT[3] (MG/L)[4]	POTENTIAL HEALTH EFFECTS	SOURCES OF CONTAMINANTS
Heterotrophic plate count	N/A	TT[8]	HPC has no health effects, but can indicate how effective treatment is at controlling microorganisms.	
Legionella	zero	TT[8]	Legionnaire's Disease, commonly known as pneumonia	Found naturally in water; multiplies in heating systems
Total Coliforms (including fecal coliform and E. Coli)	zero	5.0%[9]		Used as an indicator that other potentially harmful bacteria may be present[10] Human and animal fecal waste
Turbidity	N/A	TT[8]	Turbidity has no health effects but can interfere with disinfection and provide a medium for microbial growth. It may indicate the presence of microbes.	Soil runoff
Viruses (enteric)	zero	TT[8]	Gastroenteric disease	Human and animal fecal waste

National Secondary Drinking Water Regulations

National Secondary Drinking Water Regulations (NSDWRs or secondary standards) are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. EPA recommends secondary standards to water systems but does not require systems to comply. However, states may choose to adopt them as enforceable standards.

Contaminant	Secondary Standard	Contaminant	Secondary Standard
Aluminum	0.05 to 0.2 mg/L	Iron	0.3 mg/L
Chloride	250 mg/L	Manganese	0.05 mg/L
Color	15 (color units)	Odor	3 threshold odor number
Copper	1.0 mg/L	PH	6.5-8.5
Corrosivity	noncorrosive	Silver	0.10 mg/L
Fluoride	2.0 mg/L	Sulfate	250 mg/L
Foaming Agents	0.5 mg/L	Total Dissolved Solids	500 mg/L
		Zinc	5 mg/L

NOTES

1 Maximum Contaminant Level Goal (MCLG) - The maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health effect of persons would occur, and which allows for an adequate margin of safety. MCLGs are non-enforceable public health goals.

2 Maximum Contaminant Level (MCL) - The maximum permissible level of a contaminant in water which is delivered to any user of a public water system. MCLs are enforceable standards. The margins of safety in MCLGs ensure that exceeding the MCL slightly does not pose significant risk to public health.

3 Treatment Technique - An enforceable procedure or level of technical performance which public water systems must follow to ensure control of a contaminant.

4 Units are in milligrams per Liter (mg/L) unless otherwise noted.

5 MCLGs were not established before the 1986 Amendments to the Safe Drinking Water Act. Therefore, there is no MCLG for this contaminant.

6 Lead and copper are regulated in a Treatment Technique which requires systems to take tap water samples at sites with lead pipes or copper pipes that have lead solder and/or are served by lead service lines. The action level, which triggers water systems into taking treatment steps if exceeded in more than 10% of tap water samples, for copper is 1.3 mg/L, and for lead is 0.015mg/L.

7 Each water system must certify, in writing, to the state (using third-party or manufacturer's certification) that when acrylamide and epichlorohydrin are used in drinking water systems, the combination (or product) of dose and monomer level does not exceed the levels specified, as follows: Acrylamide = 0.05% dosed at 1 mg/L (or equivalent)* Epichlorohydrin = 0.01% dosed at 20 mg/L (or equivalent).

8 The Surface Water Treatment Rule requires systems using surface water or groundwater under the direct influence of surface water to (1) disinfect their water, and (2) filter their water to meet criteria for avoiding filtration so that the following contaminants are controlled at the following levels: * Giardia lamblia: 99.9% killed/inactivated Viruses: 99.99% killed/inactivated; * Legionella: No limit, but EPA believes that if Giardia and viruses are inactivated, Legionella will also be controlled; * Turbidity: At no time can turbidity (cloudiness of water) go above 5 nephelolometric turbidity units (NTU); systems that filter must ensure that the turbidity goes no higher than 1 NTU (0.5 NTU for conventional or direct filtration) in at least 95% of the daily samples for any two consecutive months; * HPC: NO more than 500 bacterial colonies per milliliter.

9 No more than 5.0% samples total coliform-positive in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive). Every sample that has total coliforms must be analyzed for fecal coliforms. There cannot be any fecal coliforms.

10 Fecal coliform and E. coli are bacteria whose presence indicates that the water may be contaminated with human animal wastes. Microbes in these wastes can cause diarrhea, cramps, nausea, headaches, or other symptoms.

Source: Environmental Protection Agency Web Site: www.epa.gov

1999 WATER RATE SCHEDULE FOR THE CENTRAL ARIZONA PROJECT

Cost Component	**1999**	**2000**	**2001**	**2002**	**2003**
Municipal/Industrial Charges (1)	$48/af	$54/af	$54/af	$54/af	$54/af
Agricultural Charges (2)	2/af	2/af	2/af	2/af	2/af
Water Delivery Costs:					
Fixed OM&R (3)	31/af	Determined Annually			
Pumping Energy (4)	38/af	Determined Annually			
Total 1999 Delivery Costs	$69/af				
Delivery Rates	**1999**	**2000**	**2001**	**2002**	**2003**
Municipal and Industrial (A)	$69/af	$70/af	$72/af	$73/af	$75/af
Agricultural					
Pool 1 (200,000 af) (B)	32/af	33/af	34/af	35/af	36/af
Pool 2 (200,000 af) (C)	22/af	23/af	24/af	25/af	26/af
Pool 3 (5,D)	45/af	Determined Annually			
M&I Incentive Recharge (6,E)	43/af				
Federal (F)	69/af	70/af	72/af	73/af	75/af
AWBA (G)	43/af				
Miscellaneous Uses (7, H)	43/af	Determined Annually			

Notes:
1. Paid on full allocation regardless of water deliveries, not included in delivery rates.
2. Paid on actual deliveries and included in delivery rates.
3. $43.5 million fixed OM&R costs ÷ 1,416,000 af of projected deliveries = $31/af. This amount is collected on all ordered water whether delivered or not.
4. $53.6 million pumping energy costs ÷ 1,416,000 af of projected deliveries = $38/af. This amount is collected only for water actually delivered.
5. Rate is pumping energy component plus $5 contribution to fixed OM&R plus the $2 agriculture capital charge.
6. Rate is pumping energy component plus $5 contribution towards fixed OM&R. See reverse side for rules regarding eligibility for and use of M&I incentive recharge water.
7. Rate is pumping energy component plus $5 contribution towards fixed OM&R.

A. M&I – The delivery rate for M&I subcontractors. For M&I users who are not subcontractors, we add the capital charge and create an Excess M&I contractor rate for "as available" water.
B. Pool 1 – All agricultural entities who originally signed a subcontract.
C. Pool 2 – Those agricultural entities that waived their subcontract rights in two-party agreements with CAWCD; CAWCD waived the agricultural take-or-pay requirements. Excluded those agricultural entities that relinquished their subcontracts to others for the benefit of their district, i.e., Harquahala Valley Irrigation District, Roosevelt Water Conservation District, and HoHoKam Irrigation District.
D. Pool 3 – An agricultural customer who meets basic qualifications including those who want more than their allocated share of Pool 1 and Pool 2 water.
E. M&I Incentive Recharge – A special program offered to M&I subcontractors only. They must have valid Arizona Department of Water Resources permits and must gain recharge/storage credits from this activity. The Board has approved this program through 1999. CAP may participate with some agricultural entities in a limited fashion.
F. Federal – For federal purposes (Indians, USBR construction water, etc.)
G. AWBA – Water purchases by the Arizona Water Banking Authority. It is available for scheduling after all other schedules have been filled.
H. Miscellaneous Uses– Water for recreational and fish and wildlife purposes.

CAP WATER SUBCONTRACT AMOUNTS IN THE TUCSON AMA

Entity	**Allocation (acre-feet)**
City of Tucson	138,920
San Xavier District of Tohono O'odham Nation	27,000
State Land Department	14,000
Schuk Toak District of Tohono O'odham Nation	10,800
Metropolitan Domestic Water Improvement District	8,858
Flowing Wells Irrigation District	4,354
Spanish Trail Water Company	3,037
Town of Oro Valley	2,294
Green Valley Water Company	1,900
Midvale Farms	1,500
Community Water Company of Green Valley	1,337
Vail Water Company	786
Pascua Yaqui Tribe	500
Town of Marana	47

THE WATER CONSUMER PROTECTION ACT

THE PURPOSE OF THIS ARTICLE IS TO RESTORE FIRST CLASS DRINKING WATER TO THE PEOPLE OF TUCSON AND REPLENISH TUCSON'S GROUNDWATER SUPPLY BY AMENDING CHAPTER 27 OF THE TUCSON CODE AND ADDING A NEW ARTICLE VI PROVIDING FOR THE USE OF WATER RESOURCES.

Section 1. Chapter 27 of title Tucson code is amended by adding Artic1e VI to read:

ARTICLE VI
WATER CONSUMER PROTECTION ACT

SECTION 27-90. METHOD

1. THE CITY OF TUCSON SHALL USE ONLY GROUNDWATER FROM UNPOLLUTED SOURCES AS ITS POTABLE WATER SUPPLY FOR A FIVE YEAR INTERIM PERIOD BEGINNING ON THE EFFECTIVE DATE OF THIS ARTICLE, EXCEPT AS SPECIFICALLY PROVIDED IN SECTION 27-91.

2. THE CITY OF TUCSON SHALL TAKE THE NECESSARY ACTIONS TO ENSURE THAT IT IS IN TOTAL COMPLIANCE WITH ITS EXISTING CONTRACT FOR CENTRAL ARIZONA PROTECT (CAP) WATER.

3. FOR FIVE YEARS FROM THE EFFECTIVE DATE OF THIS ARTICLE, CAP WATER DELIVERED TO THE CITY OF TUCSON SHALL BE USED ONLY FOR ONE OR MORE OF THE FOLLOWING PURPOSES;

(a) FOR SELLING OR EXCHANGING WATER UNDER THE TERMS OF THE CITY'S EXISTING CAP SUBCONTRACT.

(b) TO PRESERVE TUCSON'S GROUNDWATER FOR DOMESTIC USE BY REPLACING GROUNDWATER WHICH WOULD OTHERWISE HAVE BEEN WITHDRAWN FOR USES OTHER THAN AS POTABLE WATER SUCH AS AGRICULTURE, MING AND OTHER INDUSTRY.

(c) TO PREVENT LAND SUBSIDENCE AND AUGMENT TUCSON'S GROUNDWATER SUPPLY BY BASIN AND STREAM BED RECHARGE.

(d) TO REPLACE OTHER WATER SUPPLIES CURRENTLY BEING EMPLOYED FOR INDUSTRIAL AND LANDSCAPE IRRIGATION USE INCLUDING PARKS, GOLF COURSES AND SCHOOLS.

(e) FOR DIRECT WELL INJECTION IF IT IS TREATED AS DESCRIBED IN SECTION 27-91 AND IS FREE FROM DISINFECTION BYPRODUCTS.

SECTION 27-91. EXCEPTION

NOT WITHSTANDING ANY OTHER PROVISION OF THIS ARTICLE, CAP WATER MAY BE DIRECTLY DELIVERED AS A POTABLE WATER SUPPLY ONLY IF IT IS TREATED IN A MANNER SUFFICIENT TO ENSURE THAT THE QUALITY OF THE DELIVERED WATER IS EQUAL TO OR BETTER IN SALINITY, HARDNESS AND DISSOLVED ORGANIC MATERIAL THAN THE QUALITY OF THE GROUNDWATER BEING DELIVERED FROM TUCSON'S AVRA VALLEY WELL FIELD ON THE EFFECTIVE DATE OF THIS ARTICLE.

SECTION 27-92 RECHARGE.

1. THE CITY OF TUCSON SHALL NOT RECHARGE WATER IN ANY AREA THAT CONTAINS OR IS ADVERSELY EFFECTED BY TOXIC LANDFILLS.

2. TO PREVENT LAND SUBSIDENCE WITHIN THE CITY OF TUCSON'S CENTRAL WELL FIELD, ALL GROUNDWATER WITHDRAWALS SHALL BE COMPLETELY REPLENISHED, AS MEASURED OVER ANY FIVE YEAR PERIOD, USING RECHARGE INCLUDING RECHARGE OF CAP WATER AS PROVIDED IN SECTION 27-90. 3.(e).

SECTION 27-93.
DEFINITIONS

IN THIS ARTICLE, UNLESS THE CONTEXT OTHERWISE REQUIRES:

1. "POLLUTION" MEANS THE PRESENCE OF AN AMOUNT OF ANY SUBSTANCE IN GROUNDWATER WHICH EXCEEDS ANY STANDARD PRESCRIBED BY THE LAWS OF THE STATE OF ARIZONA OR THE UNITED STATES FOR POTABLE WATER.

2. "DISINFECTION BYPRODUCTS" ARE THE CHEMICAL COMPOUNDS FORMED WHEN CHLORINE, OZONE OR CHLORAMINES ARE USED TO DISINFECT WATER CONTAINING DISSOLVED ORGANIC MATERIAL.

Section 2.

FIVE YEARS AFTER THE EFFECTIVE DATE OF THIS ORDINANCE, THE MAYOR AND COUNCIL OF THE CITY OF TUCSON MAY, UPON A MAJORITY VOTE, SUBMIT TO THE REGISTERED VOTERS OF THE CITY FOR APPROVAL AT A CITY OF TUCSON GENERAL ELECTION APROPOS AL TO REPEAL OR MODIFY ARTICLE VI OF CHAPTER 27 OF THE TUCSON CODE AS ADDED BY THIS ORDINANCE.

Section 3 SEVERABILITY

IF A PROVISION OF THIS ORDINANCE OR ITS APPLICATION TO ANY PERSON OR CIRCUMSTANCE IS HELD INVALID, THE INVALIDITY DOES NOT AFFECT OTHER PROVISIONS OR APPLICATIONS OF THE ORDINANCE THAT CAN BE GIVEN EFFECT WITHOUT THE INVALID PROVISION OR APPLICATION, AND TO THIS END THE PROVISIONS OF THIS ORDINANCE ARE SEVERABLE

Appendix C
Additional Information

GENERAL INFORMATION

An overview of water issues in the Sonoran Desert is found in Nancy Laney's *Desert Waters: From Ancient Aquifers to Modern Demands* published by the Arizona Sonora Desert Museum in 1998. A general introduction to water issues in Arizona can be found in *Ensuring Arizona's Water Quantity and Quality Into the 21st Century*, a background report prepared by the University of Arizona for the Seventy-first Arizona Town Hall, October 26-29, 1997. *A Water Issues Primer for the Tucson Active Management Area* published by the Southern Arizona Water Resources Association (SAWARA) in 1983 is a helpful, although somewhat outdated general introduction to the basics of water in the Tucson area. SAWARA has published a series of informative newsletters on a variety of Tucson area water topics, including recharge, CAP, constructed wetlands, water supplies and wastewater. These are available on a Web site. SAWARA also has a video presenting an overview of Tucson's water situation.

Where to Get Free (or Almost Free) Information about Water in Arizona (1998 edition) is a directory of sources of water information, including Web sites. *Where to Find Water Expertise at Arizona Universities* (1998 edition) is a directory of sources of water information at Arizona state universities. Both are by Barbara Tellman and are available free from the Water Resources Research Center (WRRC), The University of Arizona and are in searchable format at the WRRC Web site. This Web site also contains water information as well as links to water agencies.

Chapter 2: LOOKING TO THE PAST TO UNDERSTAND THE PRESENT

Much of the information about the history of Tucson Water came from Lynn Baker, unofficial Tucson Water historian. Much of the information about the history of wastewater in Pima County came from John Schladweiler, unofficial Pima County Wastewater Management Department historian. A valuable source of information about the history of water development and technology in Pima County is a 1986 Master's thesis (University of Arizona) by Doug Kupel titled *Diversity Through Adversity: Tucson Basin Water Control Since 1854*. C.L. Sonnichsen's *Tucson: The Life and Times of an American City*, published by the University of Oklahoma Press in 1982, is a detailed history of Tucson. The history of the Santa Cruz River is discussed in *Arizona's Changing Rivers: How People Have Impacted the Rivers* by Barbara Tellman, Richard Yarde and Mary Wallace, published by the WRRC, The University of Arizona in 1997. More detailed information is available in *Arizona Stream Navigability Study for the Santa Cruz River*, a report by SFC Engineering and others for the Arizona State Land Department in 1996. The history of the Central Arizona Project was documented by Rich Johnson in *The Central Arizona Project*, published by the University of Arizona Press in 1977. The history of opposition to the CAP was documented by Frank Welsh in *How to Create a Water Crisis*, published by Johnson Books (Boulder) in 1985.

Chapter 3: IN SEARCH OF ADEQUATE WATER SUPPLIES

General information about groundwater is available in a booklet from the American Institute of Professional Geologists titled *Ground Water Issues and Answers*, available from the Arizona Geological Survey office in Tucson. Edward Davidson's Geohydrology and Water Resources of the Tucson Basin, Arizona (USGS Water Supply Paper; 1939-E, 1973) has a description of the basics of local geohydrology.

Numerous government documents are available, some of which are listed below. Most of the local government documents and consultant reports done for local government are available in the Tucson Public Library's government reference section in the downtown library.

Tucson Water's Planning and Technical Services Division provides periodic reports on the aquifer and withdrawals, titled *Annual Groundwater Withdrawal and Use Report.* Tucson Water also provides an annual report, *Annual Static Water Level Basic Data Report: Tucson Basin and Avra Valley, Pima County, Arizona*. Tucson Water published a useful booklet in 1998, *Status of the Aquifer*, in conjunction with the U.S. Geological Survey and the Arizona Department of Water Resources. An example of a consultant's report with useful information is by Mark Cross, *Hydrogeologic Constraints on Continued Groundwater Withdrawals by the City of Tucson.* (Errol L. Montgomery and Associates, Inc. 1998). Tucson Water also produces long-term planning documents such as *Tucson Water Resources Plan: 1990 to 2100.*

(Produced by CH2M Hill for Tucson Water. July 3, 1989). and *Tucson Water 50-Year Operating Plan: Planning Assessment Report*. (Malcolm Pirnie, Inc. February 1994).

CAP, General

An overview of the CAP is available in the Arizona Department of Water Resources' Governor's Central Arizona Project Advisory Committee's report (prepared with assistance of the Central Arizona Water Conservation District and the U.S. Bureau of Reclamation), *Description of the Central Arizona Project*. (April 1993). The Central Arizona Water Conservation District has several brochures, maps and informative materials about CAP. The fall-winter 1993 WRRC. *Arroyo*, "Long-Awaited CAP Water Delivers Troubled Water to State" also provides information. Analysis of the possibility of extending the CAP canal to the Green Valley area can be found in Malcolm Pirnie, Inc., in association with Errol Montgomery and Associates, Inc., *Sahuarita-Green Valley Area Central Arizona Project Water Use Feasibility Analysis and Delivery System Optimization Study*, prepared for Arizona Department of Water Resources, TAMA, September 1998.

WEB SITES WITH WATER INFORMATION

Arizona Department of Environmental Quality — www.adeq.state.az.us
Arizona Department of Water Resources — www.adwr.state.az.us
Arizona Geological Survey — www.azgs.state.az.us
Arizona Water Banking Authority — www.awba.state.az.us
Central Arizona Project and Central Arizona Groundwater Replenishment District — www.cap.az.us
Cooperative Extension, The University of Arizona — ag.arizona.edu/extension
Department of Hydrology and Water Resources, The University of Arizona — www.hwr.arizona.edu
Metropolitan Domestic Water Improvement District — www.metrowater.com/
Oro Valley Water Utility — www.ci.oro-valley.az.us/dpw/water_utility_.htm
Pima County Department of Environmental Quality — www.deq.co.pima.az.us
Pima County Flood Control District — sss.dot.co.pima.az.us/flood
Southern Arizona Water Resources Association — www.scottnet.com/sawara/
Tucson Regional Water Council — www.azstarnet.com/~trwc/
Tucson Water — www.ci.tucson.az.us/water
U.S. Bureau of Reclamation — www.usbr.gov
U.S. Environmental Protection Agency — www.epa.gov
U.S. Geological Survey — www.daztcn.wr.usgs.gov/
Water Resources Research Center, The University of Arizona — ag.arizona.edu/AZWATER/
WaterWiser - www.waterwiser.org

Recharge

A discussion of issues related to recharge in the Tucson area and an assessment of current and potential projects using CAP water can be found in the *Regional Recharge Plan,* written by the Institutional Policy and Advisory Group as part of the Regional Recharge Planning Process coordinated by the Tucson AMA of the Arizona Department of Water Resources (Institutional Policy and Advisory Group, 1998). This planning process began with the technical and background work completed by the Regional Recharge Committee, *Technical Report*, Arizona Department of Water Resources Tucson Active Management Area, September 1996.

A series of biennial symposia on recharge have been held over the years and contain much useful information. Copies of the proceedings for past years are available from WRRC. Another conference document is *Proceedings of the Symposium on Effluent Use Management,* edited by Kenneth D. Schmidt and Mary G. Wallace (AWRA 29th Annual Conference August 29 - September 2, 1993).

Some other sources of information on recharge methods and recharge policy in the Tucson area include:

CH2M Hill. *Rillito Recharge Project: An Evaluation of Recharge Techniques*. Prepared for the Arizona Department of Water Resources in Cooperation With Tucson Water and Pima County Flood Control District, July 1992. Tucson water issued a series of reports on *City of Tucson Sweetwater Underground Storage and Recovery Facility* in 1991 and 1994. These are just a few of the many government documents on related topics.

Some theses and dissertations have provided useful information. A complete list of those from the University of Arizona's Hydrology and Water Resources Department is available on the Web site. Keith, S.J., *Stream Channel Recharge in the Tucson Basin and Its Implications for Groundwater Management*. The University of Arizona, Department of Hydrology and Water Resources. M.S. Thesis, 1980.

An analysis of the impacts of the Water Consumer Protection Act can be found in a paper by L.G. Wilson, W.G. Matlock and K.L. Jacobs, *Hydrologic Uncertainties and Policy Implications: The Water Consumer Protection Act of Tucson, Arizona, USA*. Hydrogeology Journal. Vol. 6, pp. 3-14. 1998.

Subsidence

A good general introduction to subsidence is in Steven Slaff's *Land Subsidence and Earth Fissures In Arizona* published by the Arizona Geological Survey, Down-to-Earth Series 3 in 1993. Another general introduction can be found in the *Arroyo* published by the WRRC in Summer 1992 titled "Land Subsidence, Earth Fissures Are Changing Arizona's Landscape."

The following more technical studies were published by the U.S.G.S.:

Anderson, S.R. *Potential for Aquifer Compaction, Land Subsidence, and Earth Fissures in the Tucson Basin, Pima County, Arizona*. U.S. Geological Survey Hydrologic Investigations Atlas HA-713. 1988.

Hanson, R.T. *Aquifer-System Compaction, Tucson Basin and Avra Valley, Arizona*: U.S. Geological Survey Water Resources Investigations Report 88-4172. 1989.

Hanson, R.T., S.R. Anderson and D.R. Pool. *Simulation of Ground-Water Flow and Potential Land Subsidence, Avra Valley, Arizona*. U.S. Geological Survey. Water Resource Investigations Report. 1990.

Hanson, R.T. and J.F. Benedict. *Simulation of Ground-Water Flow and Potential Land Subsidence, Upper Santa Cruz Basin, Arizona*. U.S. Geological Survey. Water Resources Investigations Report 93-4196. 1994.

Frisch-Gleason, Robin, Steven Slaff and Richard A.Trapp. *Bibliography of Subsidence and Earth Fissures Within Arizona.* Arizona Geological Survey Open File Report 95-8. June 1995.

Hoffman, John P., Donald R. Pool, A.D. Konieczki and Michael C. Carpenter. *Investigation of the Causes of Sinks in the San Xavier District, Tohono O'odham Nation, Pima County, Arizona*. U.S. Geological Survey, Open File Report 97-19. 1997.

Schumann, Herbert H. and S.R. Anderson. *Land Subsidence Measurements and Aquifer-Compaction Monitoring in Tucson Basin and Avra Valley, Arizona.* U.S. Geological Survey. Water Resources Investigations Report 88-4167. December 1998.

Effluent

The Winter 1997 issue of SAWARA's Waterwords, *Wastewater, A Growing Resource?* and the Summer 1990 issue, *Special Issue on Effluent As A Water Supply* provide much valuable information.

Information on the supply-related aspects of effluent can be found in:

Galyean, Kenneth C. *Infiltration of Wastewater Effluent in the Santa Cruz River Channel, Pima County, Arizona*. Water Resources Investigations Reports; 96-4021, 1996.

Pima County Wastewater Management Department's *Tucson Water. Regional Effluent Utilization Plan. Phase A: Preliminary Regional Effluent Utilization Study*. Malcolm Pirnie, Inc. February 1991 and a final report in 1995.

Grey Wilson and others studied the water quality impacts of effluent recharge in *Water Quality Changes During Soil Aquifer Treatment of Tertiary Effluent*. Water Resources Research, Vol. 67, No. 3, pp. 371-376. 1995.

Alternative Supplies

Information about alternative water supply and conservation strategies can be found in several issues of *Arroyo*, a periodical series published by the WRRC, The University of Arizona. The spring 1992 issue, "Weather Modification, a Water Resource Strategy to be Researched, Tested Before Tried," the August, 1998 issue, "Managing Watersheds to Improve Land and Water".

Chapter 4: COPING WITH FLOODWATER

An historical, if somewhat dated summary of flooding issues and information in Pima County can be found in *Flooding and Erosion Hazards in Tucson*, published by Southwest Environmental Service in 1980. This is out of print, but available in libraries. Two issues of WRRC's *Arroyo* dealt with general urban wash and flooding issues. "Often Neglected, Urban Washes Now Seen as Attractive Resource" (June 1991) and "Flood Hazards, a Concern in Desert Areas of Arizona" (June l990).

Numerous reports from the Pima County Flood Control District and the City of Tucson deal with specific flood-related issues. There are reports for each major watercourse in connection with proposed projects. *Flood Control Concept Report for the Lower Santa Cruz River*, for example, by the Pima County Department of Transportation and Flood Control District (July 1987) looks at alternative flood control measures in the Marana area. There are also reports for the non-structural flood control projects, such as the Cienega Creek Preserve. Reports dealing with streambed recharge projects are also available from the same sources. FEMA floodplain maps may be viewed at the flood control districts.

Floodwater and Recharge

Guzman, A.G., L.G. Wilson, S.P. Neuman and M.D. Osborn. *Simulating Effect of Channel Changes on Stream Infiltration*. Journal of Hydraulic Engineering. American Society of Civil Engineers, Vol. 115, No. 12, pp. 1631-1645. 1989.

The Regional Recharge Committee issued an informative Technical Report printed by the Arizona Department of Water Resources Tucson Active Management Area in September 1996.

Chapter 5: THE MANY USES OF WATER

Water Use

Much of the information on water use comes from the Arizona Department of Water Resources' Tucson Active Management Area Draft Third Management Plan 2000-2010 (1998) and from the first and second management plans. Also see the Arizona Department of Water Resources' Tucson Active Management Area 1996 report, *State of the AMA.*

Water Conservation

Every major water provider in the area has information for its customers on water conservation techniques. Water CASA and SAWARA also provide such information.

General studies of water conservation include B. Dziegielewski's *Evaluating Urban Water Conservation Programs: A Procedures Manual*, prepared for California Urban Water Agencies by Planning and Management Consultants, Ltd. February 1992.

A study of the impact of water rates on conservation is in Ari Michelsen and others' *Effectiveness of Residential Water Conservation Price and Nonprice Programs* published by the Research Foundation of the American Water Works Association, Denver, 1998.

Residential lawns in Tucson were studied by David Mouat and Michael Parton, Assessing the Impact of Tucson Peak Water Demand Reduction Effort on Residential Lawn Use, 1976-79. Office of Arid Lands, University of Arizona, December 1979.

Martin Karpiscak and others discussed conservation in *Residential Water Conservation: Casa del Agua*. Water Resources Bulletin. Vol. 26. No. 6, December 1990. pp. 939-948.

Residential Water Demand: A Micro Analysis Using Survey Data. by Gary Woodard and Todd Rasmussen, (Hydrology and Water Resources in Arizona and the Southwest, 14, 1984) examines factors that influence conservation.

Other surveys of municipal water use include: and in Tucson Water's *Results from the Fall 1992 Residential Household Survey*. (Draft.1995) and Craft, Marti, "Draft Summary of Landscape Survey Results, for ADWR, TAMA, unpublished.

Water Harvesting, Xeriscape and Reuse

Harvesting Rainwater for Landscape Use, by Patricia Waterfall (University of Arizona Cooperative Extension and the Tucson Active Management Area. Sept. 1998) provides practical, how-to information for homeowners. Pima County Cooperative Extension has a variety of pamphlets dealing with xeriscaping and low water use plants. See their Web site. The Summer 1993 issue of WRRC's *Arroyo* " Home Use of Graywater, Rainwater Conserves Water and May Save Money" provides a good overview. The water quality aspects are discussed in Charles Gerba and others' *Water Quality Study of Graywater Treatment Systems* (Water Resources Bulletin. Vol. 31, No. 1, pp.109-116). An examination of large scale reuse can be found in numerous reports prepared for Tucson Water. One example is *Tucson Metropolitan Wastewater Reuse Assessment Update*. (Malcolm Pirnie, Inc. August 1994).

Riparian Water Use

Information about water use for local riparian and wetlands came from the City of Tucson Multiple Benefit Project and Pima County Flood Control District. Both agencies have brochures for the public describing various planned and completed projects. Riparian preservation and restoration issues were described in two issues of the *Arroyo*. The City of Tucson also has information on the Sweetwater Wetland. The December 1988 issue of *Arroyo* "Flow of Rivers and Streams Provides Rich Benefits, Raises Varied Concerns" and the Spring, 1993 issue "Managing the Flow to Better Use, Preserve Arizona's Rivers" discuss water for riparian areas. Information about the legal aspects of effluent use in riparian areas came from Barbara Tellman's *Arizona's Effluent Dominated Riparian Areas: Issues and Opportunities.* (WRRC, Issue Paper No. 12, 1992).

Agriculture

Studies concerning agriculture include Paul Wilson's *An Economic Assessment of Central Arizona Project Agriculture*, Department of Agricultural and Resource Economics, University of Arizona, A Report Submitted to the Office of the Governor and the Arizona Department of Water Resources, 1992; Arizona Academy, Tenth Arizona Town Hall, Do Agricultural Problems Threaten Arizona's Total Economy? April, 1967. Some statistical information on agriculture can be found in Arizona Agricultural Statistics Service. Arizona Agricultural Statistics. USDA, Phoenix.

Some theses and dissertations on Arizona agriculture include Esher, Joseph C., *The Economic Sustainability of Central Arizona Project Agriculture*. M.S. Thesis, Department of Agricultural and Resource Economics, 1994. Peacock, Bruce, *Complying With the Arizona Groundwater Management Act: Policy Implications,* PhD Dissertation, Department of Agricultural and Resource Economics, University of Arizona. 1994; and Mark Evans, *An Assessment of the Impact of the Arizona Groundwater Management Act in the Phoenix Active Management Area.* M.S. Thesis. Department of Agricultural and Resource Economics.

Metal Mining

Some useful information on metal mining in the Tucson area can be found in Southwest Groundwater Consultants, Inc., *Conservation and CAP Use Potential of Tucson AMA Mines,* Prepared for Arizona Department of Water Resources, TAMA, 1997. Pima Association of Governments, *Groundwater Monitoring in the Tucson Copper Mining District - Detailed Upper Santa Cruz Basin Mines Task Force Area Recommendations*, July 1983. Arizona Department of Mines and Mineral Resources, *Arizona's Mining Update*, 1998.

Chapter 6: ENSURING SAFE DRINKING WATER

Information about water quality in Arizona is available from the EPA Web site. ADEQ also has a Web site with Arizona information. ADEQ's biennial reports (published in even-numbered years) on water quality in Arizona contain valuable information about surface and groundwater quality, including contamination sites of special concern. See Arizona Department of Environmental Quality. *Arizona Water Quality Assessment 1996.* The USGS is collecting a large amount of water quality information under its NAWQA Project (National Water Quality Assessment) some of which is available from the Tucson office. Pima County, City of Tucson, Dames and Moore. A summary of the TCE cleanup project is in *TARP In-Channel Recharge Pilot Proposal, Abbreviated Report* (Pima County, City of Tucson and Dames and Moore. January 1997).

Water Quality

Some general introductions to water quality issues can be found in several issues of the WRRC

Arroyo by Joe Gelt. These include"Water Quality, a Complex Issue" (Summer 1987), "Nonpoint Source Pollution: Unfinished Business on the Water Quality Agenda" (April 1990), "Constructed Wetlands: Using Human Ingenuity, Natural Processes to Treat Water, Build Habitat," (March, 1997) and "Microbes Increasingly Viewed as Water Quality Threat" (March, 1998).

The Pima Association of Governments has published a series of reports on regional water quality matters. Topics include *A Regional Plan for Water, Sewerage and Solid Waste Management*; *An Assessment of Groundwater Quality Near the Sahuarita Landfills, Sahuarita, Arizona; Phase I Report. Final, Avra Valley Recharge Project Stable Isotope Study Year-End Progress Report Fiscal Year 1996-1997; CAP Water Salinity Impacts on Water Resources of the Tucson Basin; Central Avra Valley Storage and Recovery Project Pilot Phase and Expanded Pilot Phase Stable Isotope Study; Fiscal Year 1997-1998 Progress Report; Groundwater Monitoring in the Tucson Copper Mining District - Detailed Upper Santa Cruz Basin Mines Task Force Area Recommendations; Landfills Along the Santa Cruz River in Tucson and Avra Valley; Arizona and the Water Quality State of the Region Report.*

Public attitudes toward CAP water were surveyed by Gary Woodard and other in *Impacts of Changes in Water Quality and Consumer Responses in Tucson, Arizona*. (WRRC 1993). Malcolm Pirnie Environmental Engineers looked at another similar community's experience with a change in water source in *Investigation of Potable Water Complaints in Dickinson, Texas* (Malcolm Pirnie, Inc., Special Study Report, May, 1986).

Water Treatment

Dames and Moore produced a series of papers for Tucson Water on CAP Use Study for Quality Water in 1994 and 1995.

Corrosivity

A study was done for Tucson Water by M. McGuire and others, *Review of Corrosion-Related Water Quality Problems in the City of Tucson* (McGuire Environmental Consultants 30 September, 1993).

More general discussions of corrosivity are by R. Lane, *Control of Scale and Corrosion in Building Water Systems* (McGraw Hill, New York, 1993) and I. Wagner, *Internal Corrosion in Domestic Drinking-Water Installations*. Aqua, 41(4), 219-223, 1992. The effects of corrosion on steel were studied by R.J. Pisigan and J. Singley, *Effects of Water Quality Parameters on the Corrosion of Galvanized Steel* (Journal American Water Works Association, 76-82, November, 1985).

Disinfection and Disinfection Byproducts

These are just a few of many studies of disinfection treatment methods and disinfection byproducts. White, G., *The Handbook of Chlorination*, Van Nostrand Reinhold Company, New York; McGuire, M., S. Reiber, R. Sierka, J. Singley, and C. Steelink, *Disinfectants for Drinking Water Treatment– A White Paper* (Prepared for Tucson Water by Central Arizona Project Water Quality Expert Panel), 25 April, 1995.

Disinfection byproducts are discussed in R.J. Bull's *Toxicology of Drinking Water Disinfection*, (Washington State University, Pullman, WA); G. Cline and J. Russell's *An Evaluation of Treatment Strategies for the Control of Disinfection By-Products: Water Quality vs. Cost* and W.H. Glaze's *Reaction Products of Ozone: A Review*. Environmental Health Perspectives, 69, 151-157, 1986. A great deal of information on this subject is available from the EPA Web site.

Salinity

Studies of salinity in the Colorado River include the Colorado River Basin Salinity Control Forum's *Water Quality Standards for Salinity, Colorado River System, 1993*; the U.S. Department of the Interior's *Quality of Water - Colorado River Basin* (Progress Report No. 18, 1997); and T.G. Miller and others *The Salty Colorado*, The Conservation Foundation, Washington D.C., 1986.

The impacts of salinity are examined in Garrett, Charles K. *Long Range Salinity Impacts in the Tucson Basin* (Prepared for Tucson Water. December 1992); Kleinman, A. and F. Brown, *Colorado River Salinity: Economic Impacts on Agricultural, Municipal and Industrial Users* (U.S. Department of Interior, Denver, 1980); Lohman, L., et al., *Estimating the Economic Impacts of Salinity of the Colorado River* (prepared for the U.S. Bureau of Reclamation. Final Report, 1988); R. d'Arge and L. Eubanks, *Municipal and Industrial Consequences of Salinity in the Colorado River Service Area of California, Salinity Management Options for the Colorado River,* 1978; G.C. Ragan and others, *Improved Estimates of Economic Damages from Residential Use of Mineralized Water* (Completion Report No. 183 Colorado Water Resources Research Institute, Colorado State University, August, 1993); Black and Veatch Consulting Engineers, *Economic Effects of Mineral Content in Municipal Water Supplies* (Research and Development Progress Report No. 260, U.S. Department of Interior, Office of Saline Water, 1967); the California Department of Water Resources, *Consumer Costs of Water Quality in Domestic Water Use – Lompoc Area*, Los Angeles, 1978; and Farnham, D., *Water Quality: Its Effects on Ornamental Plants* (Leaflet 2995), University of California Cooperative Extension, 1985.

Treating water to reduce salinity is discussed in Thompson, M., M.R. Wiesner, G. P. Westerhoff and M. P. Robinson, *Manual on Membrane Processes for Drinking Water Treatment,* Malcolm Pirnie Technical Publication, November, 1991 and in M.S. McGuire and others *Membrane Processing of Surface and Ground Waters for Human Consumption* (by Central Arizona Project Water Quality Expert Panel), 16 January, 1995.

Taste

The following are just a few of many studies of taste in water. Bruvold, W., H. Ongerth and R. Dillehay, *Consumer Assessment of Mineral Taste in Domestic Water.* Journal American Water Works Association, 575-580, November, 1969 and Bruvold, W., and J. Daniels, *Standards for Mineral Content in Drinking Water.* Journal AWWA, February, 1990.

Home water treatment alternatives are discussed in WRRC *Arroyo*, "Consumers Increasingly Use Bottled Water, Home Water Treatment Systems to Avoid Direct Tap Water" (March 1996) and a pamphlet by SAWARA and the League of Women Voters, *Home Water Treatment* . Information on this subject is also available from the Arizona Water Quality Association (602) 947-9850.

Chapter 7: ROLES OF CITIZENS AND GOVERNMENT IN WATER POLICY

William E. Martin, Helen Ingram and others described the development of Tucson's water policies and problems in *Saving Water In A Desert City*, published in Washington, D.C. by Resources for the Future in 1984. A more recent analysis can be found in an article by Wilson, L.G., W.G. Matlock and K.L. Jacobs, *Hydrologic Uncertainties and Policy Implications: The Water Consumer Protection Act of Tucson, Arizona, USA*. (Hydrogeology Journal. Vol. 6, pp. 3-14. 1998). A summary of the City of Tucson's current water policies can be found in the City of Tucson's Mayor and Council Water Policies. Resolution No. 17929. Adopted January 26, 1998. For information about views of the Citizens Alliance for Water Security, email them at caws@techstar-online.com. Philip C. Metzger analyzed Tucson's water management in *To Master A Thirsty Future: An Analysis of Water Management Efforts in Tucson, Arizona*. (A Case Study Report from the Water Resources Program, The Conservation Foundation, May 1984.)

Ensuring Arizona's Water Quantity and Quality into the 21st Century contains a summary of laws pertaining to water quantity and water quality. This background report prepared by The University of Arizona for the 1997 Arizona Town Hall is available from the Arizona Town Hall office in Phoenix.

Discussions of the Groundwater Management Act and its implementation are discussed in "ADWR Developing Second Management Plan" (WRRC *Arroyo* Spring, 1987) and "The Groundwater Management Act: Saving Water and Developing Water Policy" (WRRC *Arroyo* Spring 1988). "Debate, Discussion Mark Ten-Year Anniversary of Arizona's Groundwater Management Act" (WRRC *Arroyo* October 1990); Robert J. Glennon's *Because That's Where the Water Is': Retiring Current Water Uses to Achieve the Safe-Yield Objective of the Arizona Groundwater Management Act*. Arizona Law Review 33:89 1991; State of Arizona Office of the Auditor General, Performance Audit of Arizona Department of Water Resources, Report No. 99-8, April 1999.

General information about the Colorado River Compact is in WRRC's August 1997 *Arroyo*, "Sharing Colorado River Water: History, Public Policy and the Colorado River Compact."

Some problems confronting small water systems are discussed in "Arizona's Small Water Systems Confront Questions, Uncertainties" (WRRC. *Arroyo.* October, 1991).

Regional water management is examined in "Regional Water Supply Agency, A New Arizona Water Policy Concept" (WRRC Arroyo, April, 1991).

Information about the Arizona Water Banking Authority is available from the AWBA Web site. The Central Arizona Water Conservation District (Central Arizona Project) and Central Arizona Groundwater Replenishment District also have a Web site with current information.

A thorough discussion of Indian water rights issues can be found in *Indian Water Rights: Negotiating the Future* published in 1983 by Elizabeth Checchio and Bonnie Colby, available from the Department of Agricultural Economics, The University of Arizona. A shorter explanation can be found in "Settlement of Indian Water Rights, a Priority Issue" (December 1989 WRRC *Arroyo*).

STATUTES DEALING WITH WATER

Water Quantity

ARS (Arizona Revised Statutes) Title 45: Chapter 1 deals with surface water laws; Chapter 2 contains the Groundwater Code, including laws dealing with water rights, transportation of groundwater, wells and artificial recharge; Chapter 3 contains provisions for underground water storage; Chapter 8 contains flood control statutes and the remaining chapters deal with dams, irrigation districts and other matters.

Water Quality

The federal Clean Water Act is contained in 33 USC (United States Code) Chapter 26. This includes laws controlling NPDES permits, wastewater treatment discharges, and related activities.

43 USC contains the Safe Drinking Water Act. The National Environmental Policy Act of 1969 is in 42 U.S.C.4321-4347. CERCLA (or Superfund) is contained in 42 USC - 9601 et seq.

Information about EPA regulations and water quality standards is available from the EPA Web site www.epa.gov. This site also has a list of water providers in Pima County.

ARS Title 49 deals with environmental management, including water quality matters, with emphasis on groundwater protection. The Arizona Administrative Code, Title 18 Chapters 9 and 11 contains specific regulations under the statutes.

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