AN ECONOMIC AND INSTITUTIONAL ASSESSMENT OF GROUNDWATER RECHARGE IN AN ARID ENVIRONMENT: TUCSON BASIN CASE STUDY

By

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DEDICATION

I dedicate this work to those individuals who try to help people to help themselves. Two of those are my parents. I ask Allah (Glorify to Him) to forgive me and my parents.

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ABSTRACT

The City of Tucson, located in a semi-arid region, faces escalating pressure on its groundwater resources associated with rapid urbanization and population growth over the past 50 years. Because of concern that the declining water table will threaten the city's development, bringing water from Colorado River via the Central Arizona Project (CAP) was perceived as the sole solution for Tucson's water problem. As soon as CAP water arrived in Tucson in 1992, its quality provoked a quarrel over its use for potable purposes. A significant outcome of that quarrel was the enactment of the 1995 Consumer Protection Act (CPA). The primary objective of the CPA is to preclude the use of CAP water for drinking purposes at least until year 2000, unless it is treated to achieve the same quality as the groundwater previously supplied. The CPA encourages using CAP water for non-potable purposes and for replenishing Tucson aquifer through recharge.

This study examines the economic and institutional issues involved in utilizing CAP water for recharge and non-potable purposes in the Tucson Basin. The economic assessment focuses on the impact of CAP water recharge on the water table, the resulting pumping cost savings, and the concomitant benefits of saving groundwater and of using CAP water instead of reclaimed water. The institutional assessment focuses on the effectiveness of using CAP water in stabilizing groundwater withdrawal and replenishing Tucson's aquifer.

Four planning scenarios were designed to measure and compare the costs and benefits with and without CAP water recharge. Cost-Benefit Analysis was utilized to

measure recharge costs and benefits and to derive a rough estimate of cost savings from preventing land subsidence. The results indicate that the institutional requirements can be met since one scenario relatively stabilizes groundwater and the two other scenarios will recover it. The economic benefits from reducing pumping cost and saving groundwater are not economically significant. Yet, when combing the use of CAP water for recharge and non-potable purposes, scenario 3 would not only augment the water table, but also demonstrate positive net economic benefits from savings groundwater, decreasing pumping costs and using CAP water instead of reclaimed water.

Chapter 1: Introduction

1.1. Introduction

In the Tucson basin, as in the other areas of central Arizona, the permissiveness of the groundwater law fostered a situation prior to 1980 in which there were virtually no restrictions on groundwater pumping other than the economic restriction imposed by pumping cost. Groundwater overdraft associated with extensive pumping became a public policy issue because of fears that the declining water table would threaten the state's development. For these reasons, on June 11, 1980, Arizona's legislature enacted the Groundwater Management Act (GMA) (A.R.S. 45-401). Arizona became the first state in the nation to adopt a public regulatory approach for managing groundwater resources, rather than continue depending entirely on economic forces to mitigate the groundwater depletion problem.

The primary objective of the GMA is to regulate groundwater usage among the three major groundwater users (municipalities, agriculture and industry) by providing conservation standards and establishing a new water agency. The most significant regulatory approach was the establishment of the right to withdraw groundwater along with regulations to curtail the usage of groundwater by the three classes of users in the Active Management Areas (AMAs). The AMAs include most of Maricopa, Pima, and Pinal counties and the Prescott area in Yavapai county. They are called the Phoenix, Tucson, Pinal and Prescott AMAs respectively (Figure 1.1).

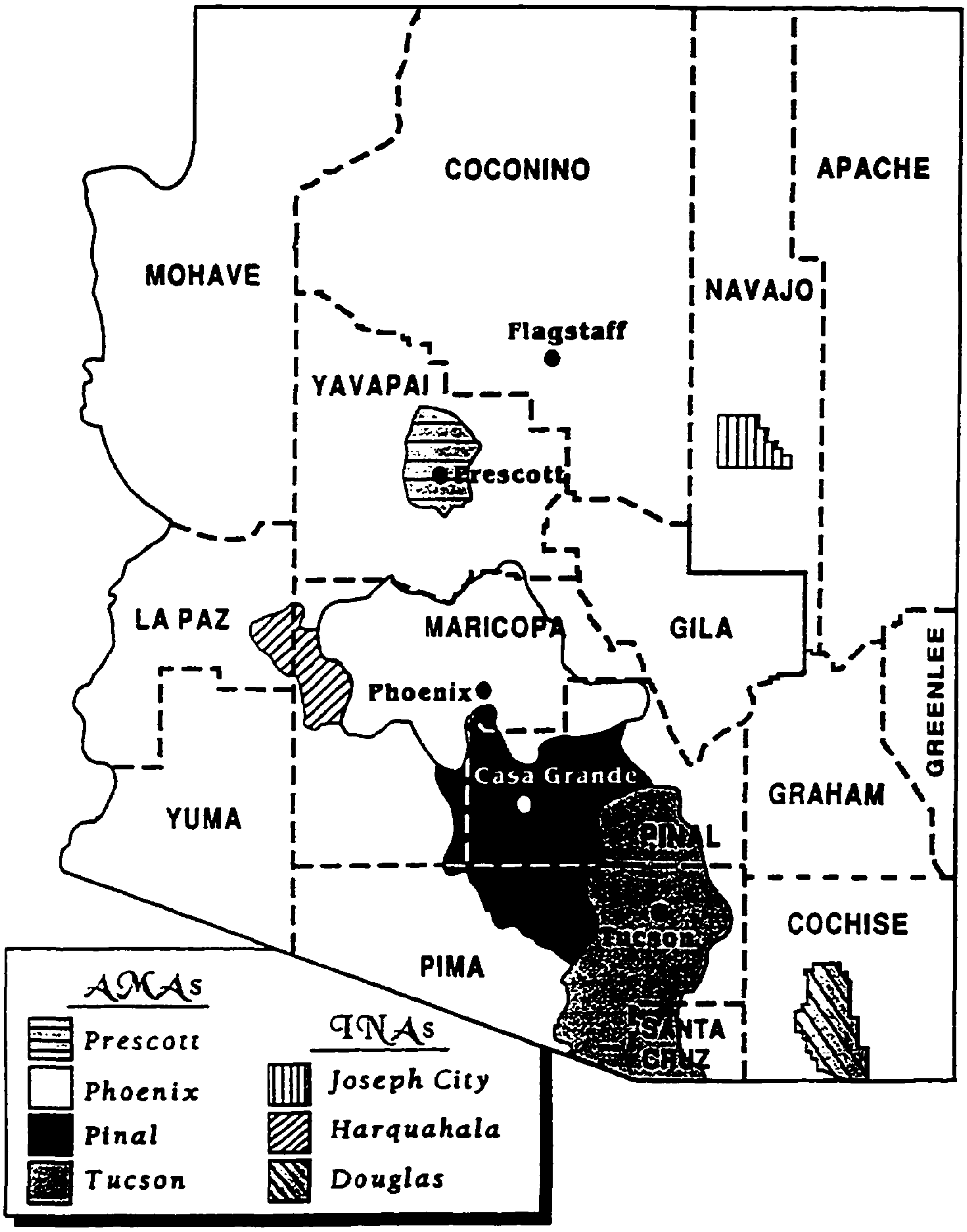

Figure 1.1. AMAs and INAs in Arizona (ADWR, 1994)

1.2. Tucson Active Management Area (Tucson AMA)

The water supply problem is not the same for the Phoenix, Pinal, and Tucson AMAs. While all three AMAs are contending with a groundwater mining issue, the Phoenix AMA has extensive surface water supplies provided by the Salt River Project, therefore, its reliance on groundwater is not as great as in the Pinal or Tucson AMAs.

The Tucson AMA is the most problematic water-deficient area in central Arizona for the following reasons: (1) surface water supplies are now virtually non-existent within its borders, in particular since the Santa Cruz river stopped flowing in the mid-1940s; and (2) the city of Tucson is experiencing rapid urban growth, possibly doubling its urban population over the next two decades.

Examining water supply and utilization in the Tucson AMA provides a good example of the growing pressure on water resources associated with rapid urbanization and economic growth in an arid environment. Also, Tucson has experienced dramatic changes in the policies that affect and the institutions that govern its water use over the last four decades. Such analyses can be extended and applied to cases in other countries facing similar water crises. In coming to an understanding of the present water situation in the Tucson AMA, it is important to review briefly groundwater use and water policies in a historical perspective.

1.3. Background

1.3.1. Historic Use of Groundwater in the Tucson AMA

In the Tucson basin, in which the city of Tucson is located, the development of groundwater supplies began at about the turn of this century. At that time, irrigation came from erratic flows of the Santa Cruz River as shown in Figure 1.2. Irrigated acreage was able to expand by the use of primitive pumps installed in shallow wells. The annual groundwater pumpage in the Tucson basin increased from 7,000 acre-feet (af) in 1915 to 38,000 af in 1930 (AWC,1975). With increased irrigation, large-scale pumping of groundwater came into general use, which causes the flow rates of Santa Cruz River to decline. The groundwater pumpage in the Tucson basin, increased from 38,000 af in 1930 to 106,000 af in 1945. In addition, water pumpage in Avra Valley which started in 1935 at 1,000 af, increased to 23,000 af in 1945 (AWC, 1975).

In the economic boom following World War II, the irrigated acreage in the Tucson basin steadily increased. This growth resulted in a dramatic increase in water pumpage in the Tucson basin from 106,000 af in 1945 to 240,000 af in 1970, and in Avra Valley from 23,000 af in 1945 to 157,000 af in 1970 (AWC, 1975). Water users in the Tucson basin continue to depend on groundwater to support nearly all economic activity, despite the availability of Central Arizona Project (CAP) water and treated effluent. Total water use in the Tucson AMA is currently about 300,000 af per year. Roughly 90 percent of the total water supply is groundwater (ADWR-SAMA, 1996).

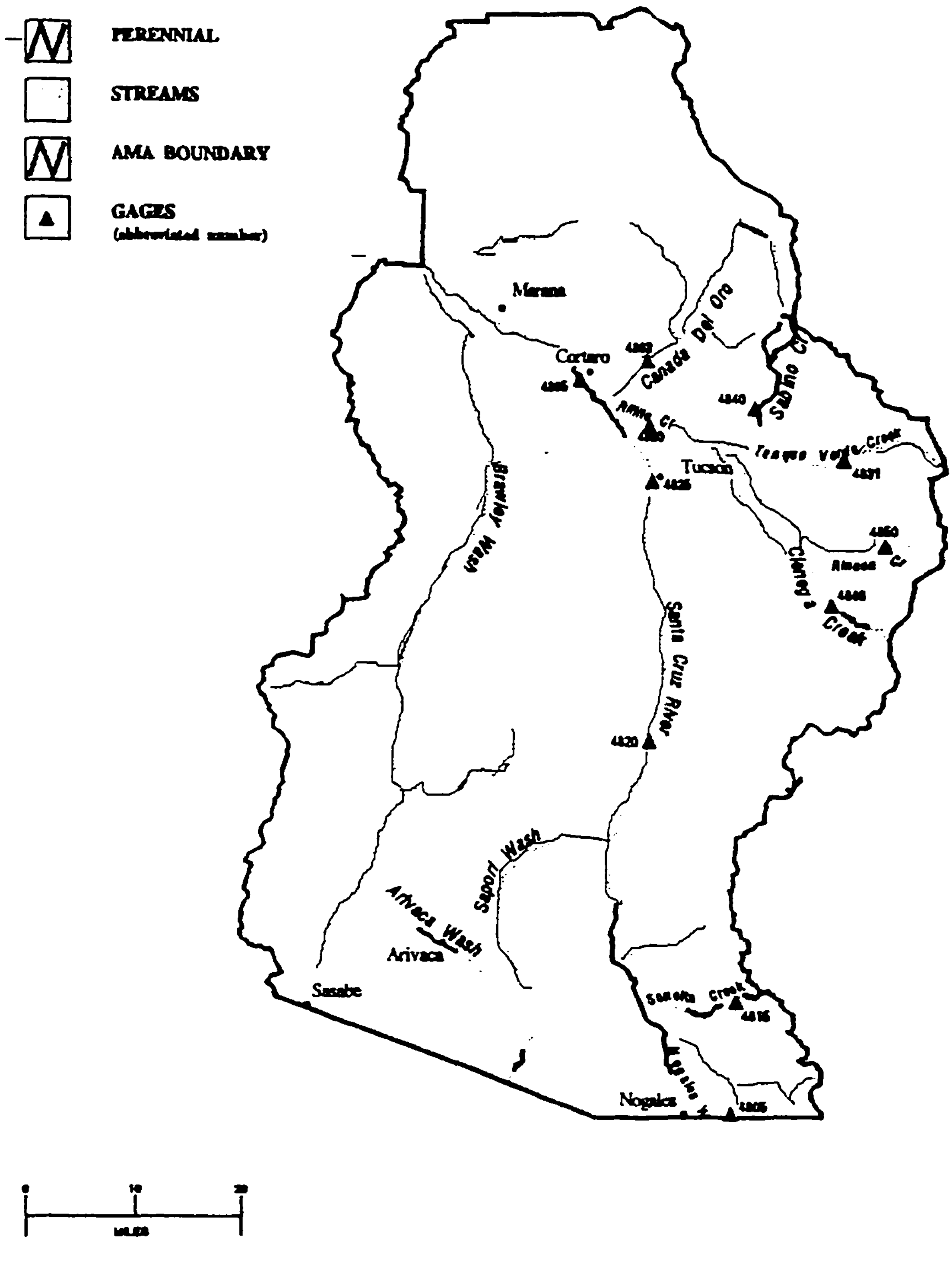

Figure 1.2. Perennial stream Reaches and Gaging Stations (ADWR,1994)

1.3.2. A Brief History of Arizona Water Policy

The Tucson AMA, with its location in a semi-arid region, faces escalating pressure on its groundwater resources associated with rapid urbanization and population growth. Since the city of Tucson is the second largest metropolitan area in the state, its groundwater overdraft has been a growing concern among city planners, industrialists, mining companies and farm managers over the past 50 years.

Yet, even though this concern has been expressed at the state level by the passing of several pieces of legislation regulating groundwater usage, Arizona water policy for the most part has been directed at obtaining imported supplies. Until the 1960s and the early 1970s, the problem of groundwater overdraft in central Arizona was deemed by the state's institutions as simply a water shortage problem that could only be solved by bringing in more water via CAP. Therefore, there were no strong, sound laws to curtail groundwater withdrawal until 1980, when decision makers in the state were persuaded to give high priority to policies for relieving the persistent overuse of groundwater in central Arizona through enactment of the GMA. An additional motivation for passing the GMA was the federal government threat to cut off funding for the CAP.

1.3.3. The Groundwater Management Act

With the passage of the GMA in 1980, water conservation became an official state policy. The immediate effect was the formation of the Arizona Department of Water Resources (ADWR). The Act created four Active Management Areas (AMAs) and three Irrigation Non-expansion Areas (INAs), as shown in Figure 1.1. These areas were the ones most in need of immediate, comprehensive groundwater management. The law mandated that groundwater overdraft must cease by 2025 in the major populated areas of the state, including the Tucson AMA.

The GMA provides the ADWR with three principal management tools for achieving the safe-yield goal: (1) conservation methods; (2) the assured water supply program; and (3) an augmentation program to increase water supply.

The conservation policy requires all water users to meet progressive conservation measures designed to achieve the safe-yield goal by 2025. This goal requires that groundwater withdrawals must be balanced with natural, incidental and artificial recharge. The first step in this policy is to enforce the efficient use of groundwater by all water users. Municipal sectors are required to reduce per-capita water use over time. Industrial sectors are required to use the most recent, efficient water use technology.

The GMA makes available three primary methods to reduce agricultural water use: (1) assigning a water duty, which is the "reasonable" amount of water needed to grow an acre of a crop; (2) setting up a withdrawal fee per acre-foot for agricultural water users; and (3) after the year 2006, ADWR can begin to retire farm land in order to reduce water consumption.

The other two management tools are the assured water supply program (AWS) and the augmentation program. The AWS program requires that water providers must demonstrate a sufficient water supply to meet the needs of projected growth and development for the next 100 years. The augmentation program seeks to develop additional water supplies via artificial groundwater recharge, importation of water, and water storage.

1.3.4. Water Policy Implementation

The GMA mandated that the Tucson AMA achieve safe-yield status by 2025. One of the primary policy mechanisms that was adopted in the effort to achieve this goal was the gradual reduction of groundwater withdrawal through the use of CAP water. This policy appears clearly in the *Second Management Plan (SMP)* of the Tucson AMA Office and *Tucson Water Resources Plan (TWRP)* of the Tucson Water Department (TWD). Their major aim was to use 204,000 af of CAP water by 1995.

As soon as CAP water arrived Tucson in October 1992, delivery was initiated to over one-half of TWD's service area for municipal purposes. However, serious problems began to appear when the chemical properties of the CAP water interacted with the unique physical configuration and the microbiology of the aging municipal distribution system. It deteriorated the water pipes and made water rusty and smell bad. The consequences were that one-half of the CAP service area was returned to groundwater in the fall of the 1993. Later, in January 1995, a new policy was adopted to keep all customers on groundwater until a better quality CAP water could be provided. Finally, in November, 1995 the Consumer Protection Act (better known as Proposition 200) was passed, which emphasizes the utilization of groundwater for drinking purposes and CAP water for replenishing the Tucson aquifer through recharge.

The primary objective of the Consumer Protection Act (CPA) is to preclude the use of CAP water for potable purposes unless it is treated to the same quality as Avra Valley groundwater for hardness, salinity and dissolved organic material. To attain this quality requires advanced treatment, which is expensive and has never been applied on this scale. The CPA prohibited the use of CAP water for potable purposes for at least five years. However, the Act encourages the use of CAP water through (1) sale or exchange with agriculture, mines and other industries; (2) recharge basins and in stream beds of the Tucson AMA; and (3) replenishment of the Central Well-field (CWF) due to the declining of the groundwater table in this area.

Further, since 65 percent of the TWD's current withdrawals occur from the CWF area, the CPA required that about 300,000 acre-feet to be replenished in the CWF area over a five-year period after which the CPA may be referred back for the second time to the voters by the Tucson city government[1]. The first referral of the CPA was on November 4, 1997. The proposed amendments were intended to give TWD more flexibility in managing its water resources than is currently provided in the CPA. The major points of the amendment were (1) to eliminate the limitation on the use of CAP water as drinking water only if it met the quality of the water being delivered from Tucson's Avra Valley well field; and (2) to eliminate the CPA requirement that the City replenish its groundwater withdrawals using recharge, including recharge of treated CAP water, as measured over any five year period. Whatever the drawbacks of this

[1] By the end of 1997, there was no artificial recharge in the CWF. The CPA does not provide for an implementation period for TWD to come into compliance.

amendment, it was defeated by 58 percent of the vote. Therefore, the CPA will be effective until November, 2001.

1.4. The Statement of the Problem

Given the pressure of the Safe-Yield Goal (SY) of the GMA, TWD has undertaken several significant planning activities in anticipation of receiving CAP water and providing for its maximum beneficial use. As part of these planning activities, TWD began developing a management plan in 1987. This plan recommended taking maximum advantage of CAP water for both direct use and recharge early in 1995. Recognizing the potential of artificial recharge in helping to achieve SY, TWD initiated the Tucson Recharge Feasibility Assessment (TRFA) (CH2M-Hill, 1988). The TRFA indicated that the most promising alternative for recharging CAP water is to inject it into the Tucson basin aquifer using existing wells. However, the CPA in 1995 eliminated this option and mandated only basin and streambed recharge.

Even though CPA recommended several alternatives to utilize CAP water, the recharge alternative has gained priority over other alternatives due to the fact that artificial recharge offers a number of benefits. One of the major benefits of recharge is the prevention of further decline in the groundwater level, thereby reducing the threat of land subsidence and saving energy costs that result from pumping at greater depths. Other benefits of the recharge alternative were popularized because (1) recharging CAP water is thought to be an inexpensive means of filtration that would eliminate the need for chemical treatment; (2) there is no distribution system to deliver CAP water to local farms and the mining industry; and (3) the construction cost of the delivery system from the CAP canal to farms and mines is too expensive. The validity of these arguments has not been investigated or compared with the estimated costs of recharge, therefore, these issues are not examined in this dissertation.

The technical aspects of artificial recharge in the Tucson AMA have been extensively investigated for the last two decades (CH2M-Hill, 1988). The early work focused more on hydrogeological and technical feasibility. More recent studies have focused on the economic and financial aspects of artificial recharge (Malcolm Pirnie, 1996). One of the most recent studies is the evaluation of CAP water recharging within the Tucson AMA, conducted by TWD in March of 1996. It evaluated recharge in terms of its ability to meet CPA requirements, financial feasibility and regulatory and operational criteria set by the Tucson City Council (TWD,1996)

Neither the recent studies nor the old ones, however, fully examined the economic aspects of groundwater recharge within the Tucson AMA. The economic aspects of the previous studies focused primarily on the cost of the recharge system, and very little, if any, definitive work appears to have measured the value of the benefits from artificial recharge.

1.5. Research Objective

The principal objective of this dissertation is to assess the economic and the institutional aspects of the proposed recharge schemes in the Tucson basin. The aim of the economic assessment is to test the hypothesis that the economic benefits realized from reduced pumping lifts and saved groundwater exceed their costs. These benefits are attributable to the net decrease in groundwater overdraft, because when groundwater is recharged with CAP water, it tends to raise water levels and, hence, reduce pumping lifts. The purpose of the institutional assessment is to examines how effective the use of CAP water through recharge would be in terms of qualifying TWD to meet the SY and CPA provisions.

These assessments would be conducted by: (1) developing four scenarios with and without CAP water recharge, (2) estimating the costs and benefits of each scenario, (3) developing a cash flow and estimating net present value for each of them, (4) performing a sensitivity analysis on selected economic parameters, and (5) conducting a costs and benefits comparison among the four scenarios. Finally the hypothesis that recharge is cost effective is tested by comparing the costs and benefits of the recharge scenarios with the costs and benefits without recharge over the planning period from 1998 to 2025.

1.6. Study Area

The general focus of this dissertation is the assessment of the economic and the institutional benefits of CAP water recharge in the Tucson AMA. However, since TWD is the major water supplier in the Tucson AMA and serves about 78 percent of the Tucson AMA population, and further, since 65 percent of TWD's groundwater supply comes from CWF, the particular focus of this dissertation is to assess the economic and institutional benefits of groundwater recharge in the CWF.

The approximate boundaries of the CWF area (sometimes called the Interior Wellfield) locate it south of the Rillito, west of Saguaro National Parks (East)[2], north of Tucson International Airport and east of Tucson Mountain Park (Figure 1.3). It encompasses nearly 200 squares miles (127,849 acres). Groundwater levels beneath the central area range from 100 to 400 feet below land surface and are dropping at an average rate of 3.5 to 4 feet per year (Malcolm Pirnie, 1994). The average natural recharge rate is 16,750 acre-feet per year (af/yr). The average specific yield of the aquifer is 12 percent (Hanson, 1994). The specific yield is the ratio of the volume of water which rock or soil, after being saturated, yields by gravity relative to the volume of the rock and soil.

Population in the CWF area was estimated to be 496,083 in 1994. The TWD is the largest provider in the CWF area, serving 90 to 92 percent of the population. Since 60 to 70 percent of total current water demand is supplied through the pumping of groundwater from the CWF, this study assumes that without recharging of CAP water, 65 percent of projected water demand would have to come from the CWF.

[2] There are two Saguaro National Parks (East and West)

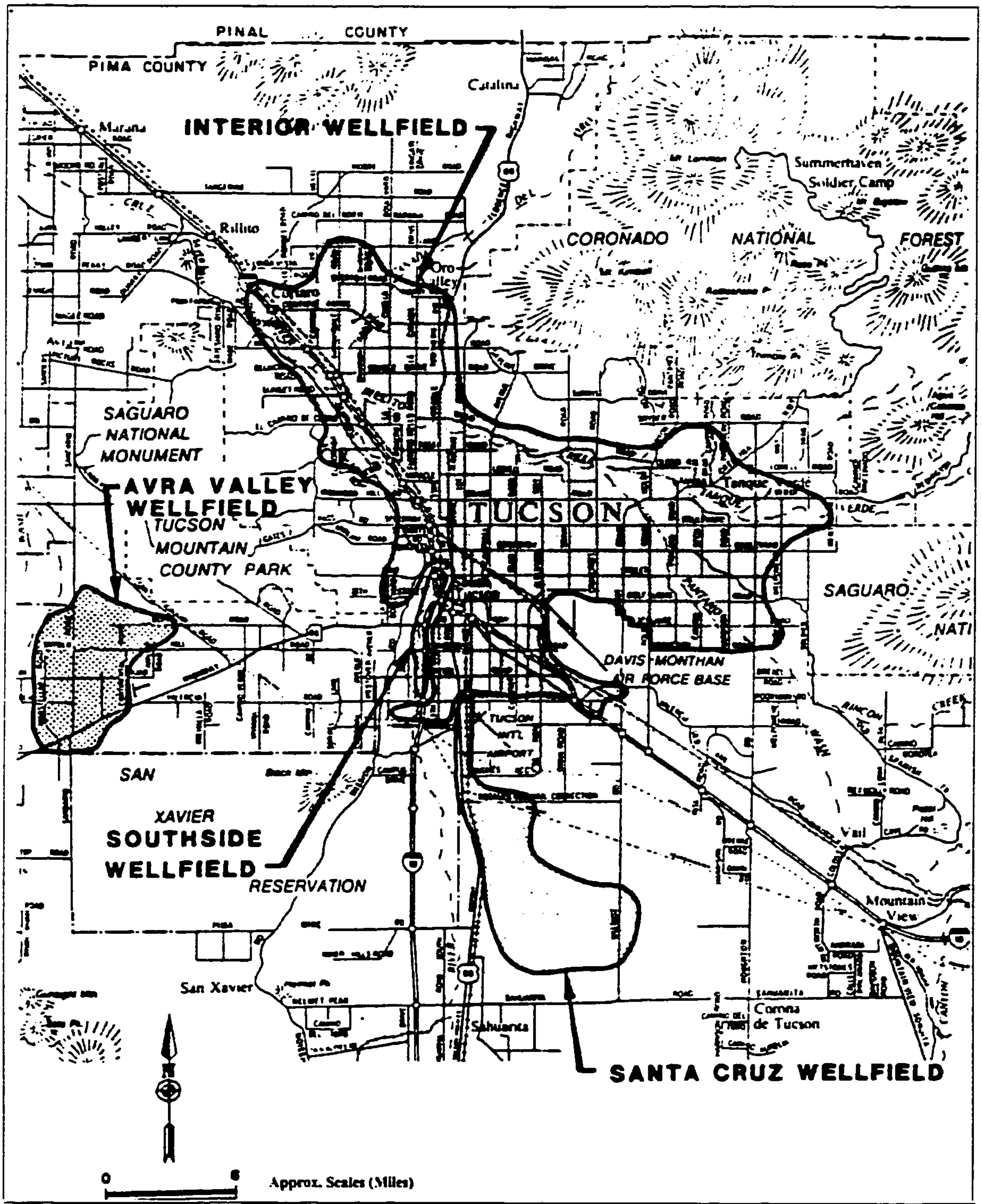

Figure 1.3. Tucson Central Wellfield (Interior Wellfield) (Malcolm Pirnie, 1994)

1.7. Plan of Study

This dissertation is organized into nine chapters. Chapter 2 will first describe the physical characteristics and hydrogeology of the Upper Santa Cruz Sub-basin and Avra Valley Sub-basin. Then, it describes the significance of the Santa Cruz River and its tributaries in the development of water resources in the Tucson AMA, estimating the flow of the river and the amount of effluent discharged into it. Following that, there will be a brief description of the occurrences, locations, and the amounts of groundwater in the Tucson AMA and their annual natural and incidental recharge. Next, a general description of the collection and treatment of effluent in the Tucson AMA will be presented, including an estimation of the recharge occurring as a result of discharging it into the Santa Cruz River. Finally, there will be a description of the Central Arizona Project, including its significance to the Tucson AMA and its current underutilization due to the problem of water quality.

Chapter 3 presents an overall perspective of water use by the major water consumers (municipal, agriculture and industry) and also identifies the water providers for each sector. The purpose of chapter 4 is to describe the institutional settings and the water laws and regulations that govern water use and supply in the Tucson basin.

Chapter 5 contains a detailed description of: (1) the proposed basin and streambed recharge schemes and their alternatives that are being considered for development within and outside of the Central Wellfield (CWF); (2) the four scenarios that have been designed to measure and compare the costs and benefits of each recharging scenario; and

(3) the methods that are used to measure the costs and benefits with and without recharge in the Tucson basin.

The purpose of Chapter 6 is to describe the costs associated with the scenarios described in Chapter 5. These costs can be subcategorized into: (1) costs associated with the baseline scenario of continued pumping of groundwater, and (2) those costs associated with the alternative recharging projects.

Chapter 7 will, (1) estimate the economic benefits related to reducing pumping lift and groundwater saved in the Tucson basin, and (2) assess CAP water recharge institutionally in terms of its effectiveness in meeting the legal requirements of the CPA and in meeting the SY goal. Chapter 8 will describe the results of the economic and institutional assessment of groundwater recharge in the Tucson basin. Credibility of the result of this study will be described. Finally, Chapter 9 presents conclusions of this study and recommendation for future research.

Chapter 2: Overview of Tucson AMA Water Resources

2.1. Introduction

The unique geology of the Santa Cruz River Valley historically provided abundant water resources for the inhabitants in spite of the absence of free flowing surface water. Water resources in Tucson AMA basically consist of: (1) several reaches of perennial water streams, (2) groundwater, (3) treated wastewater (better known as effluent), and (4) imported water from the Colorado River via the Central Arizona Project (CAP). While the main purpose of this chapter is to present an overview of water supplies derived from the CAP, effluent, and groundwater, this chapter will first describe the physical characteristics and hydrogeology of the Upper Santa Cruz and Avra Valley Sub-basins. The Upper Santa Cruz Sub-basin will be examined thoroughly due to the fact that the city of Tucson is located here, where increasing population and economic development are the major driving forces in the use of water. Next, it describes the significance of the Santa Cruz River and its tributaries in the development of water resources in the Tucson AMA.

This chapter continues with a brief description of the occurrences, locations, and amounts of groundwater in the Tucson AMA, and the annual natural and incidental groundwater recharge. A general description of the collection and treatment of effluent in the Tucson AMA is presented, including an estimation of the recharge occurring as a result of discharging effluent into the Santa Cruz River. Finally, there is a description of the Central Arizona Project, including its significance to the Tucson AMA and its current under-utilization due to the problem of water quality.

2.2. Physical Characteristics and Hydrogeology

The Tucson Active Management Area (Tucson AMA) is one of the four original AMAs in the state, the others being the Phoenix, Pinal, and Prescott AMAs. These four were established pursuant to the 1980 Groundwater Management Code (Figure 1.1). The Tucson AMA is the southernmost of the Active Management Areas, and encompasses the Upper Santa Cruz Sub-basin and Avra Valley Sub-basin. The Santa Cruz River Valley, which is known as the Upper Santa Cruz Valley Sub-basin is on the east side of the AMA. In the west, the Altar and Avra Valleys are collectively known as the Avra Valley Sub-basin. The two Sub-basins are separated by the Atascosa, Tumacacori, Sierrita, Black, Tucson, and Tortolita Mountains. Both Sub-basins are located in the eastern part of Pima county, and consist of a large portion of Pima county and small portions of Pinal county.

The Tucson AMA is characterized as a broad, gently-sloping alluvial basin, separated from north to northwest by trending fault-block mountains (ADWR-RRC, 1996). It is surrounded on the west by a continuous mountain chain comprised of the Baboquivari, Quilan, Coyote, Roskruge, and Silver Bell Mountains. It is bounded on the east by the Santa Rita, Rincon, and Santa Catalina Mountains. The surface area of the Tucson AMA is 3,866 square miles.

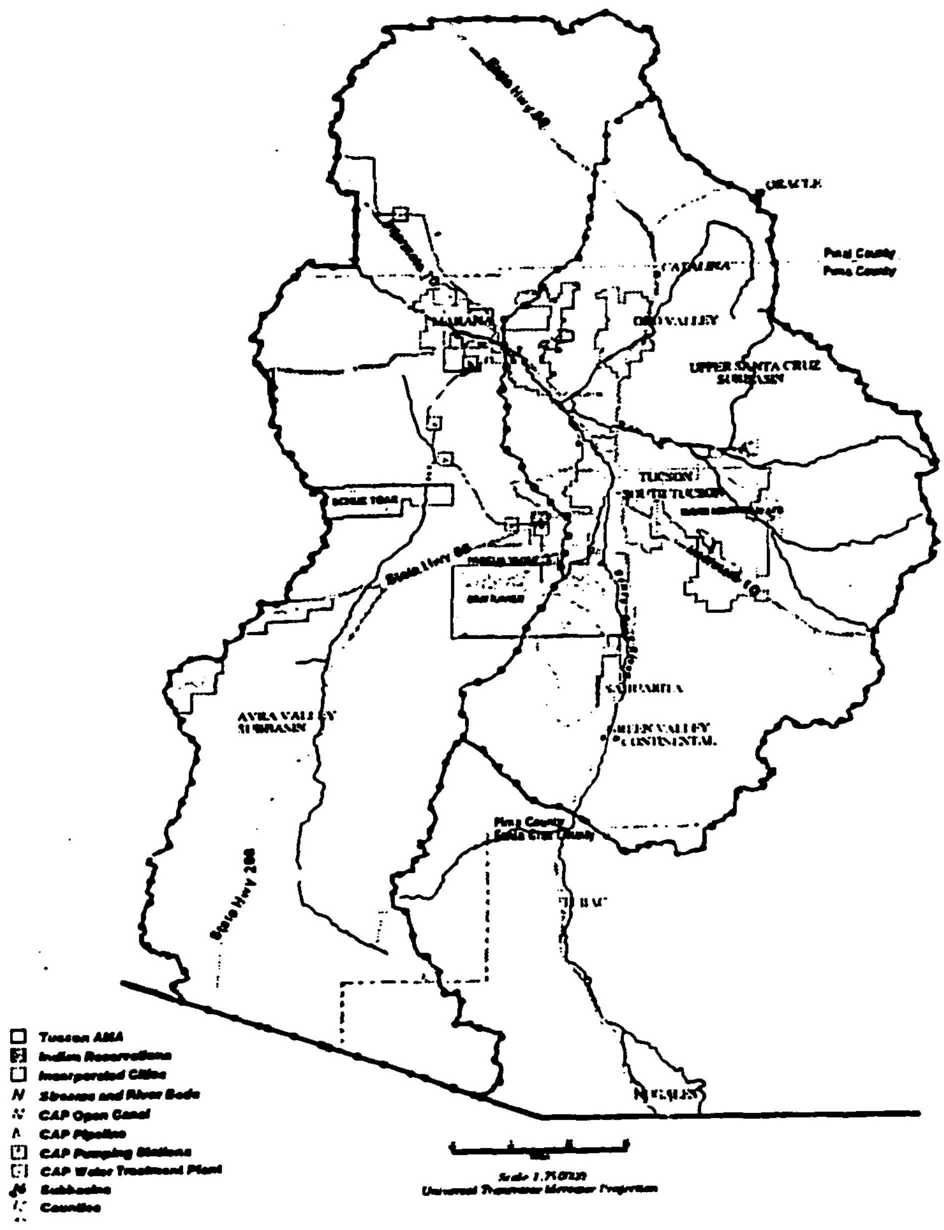

Figure 2.1. Tucson Active Management Area (ADWR,1994)

2.2.1. Upper Santa Cruz Valley Sub-basin

Based on sediment thickness and geology, the Upper Santa Cruz Valley Sub-basin has been divided into northern and southern sections. The Northern section has the best-investigated portion of the geology of the Tucson AMA. This area, which contains the city of Tucson, is often referred to as the Tucson basin. It is the area located between the northern border line of Pima-Santa Cruz county and eastern area of the Avra Valley Sub-basin (Figure 2.1).

Details of a cross section of the subsurface geology of the Tucson AMA have been described by Davidson (1973), Murphy and Hedley (1984), City of Tucson (1989) and ADWR (1991). The Tucson basin consists of a wide valley with sediments in excess of 11,000 feet thick (Oppenheimer and Sumner, 1980). Davidson (1973), in his report to the U.S Geological Survey, stated that, based on hydrologic characteristics, the Tucson basin-fill sediments can be divided into four units; the surficial alluvial deposits, the Fort Lowell Formation, the Tinaja Beds, and the Pantano Formation. These units are hydraulically connected and form the main aquifer of the Upper Santa Cruz Sub-basin (ADWR, 1994) as shown in Figure 2.2.

The four units are described by (ADWR-RRC, 1996) as follows: The surficial deposits are usually less than 100 feet (ft) thick, and are located above the water table. They are significant primarily as infiltration conduits that allow surface water flood flows to recharge the underlying basin-fill units. The Fort Lowell Formation and Upper Tinaja Beds, where saturated, are typically the most productive units of the aquifer. The Lower

Tinaja Beds and Pantano Formation are much less productive. Groundwater generally flows to the primary wellfields (central, southside, and Santa Cruz) and parallels the direction of the surface water drainage.

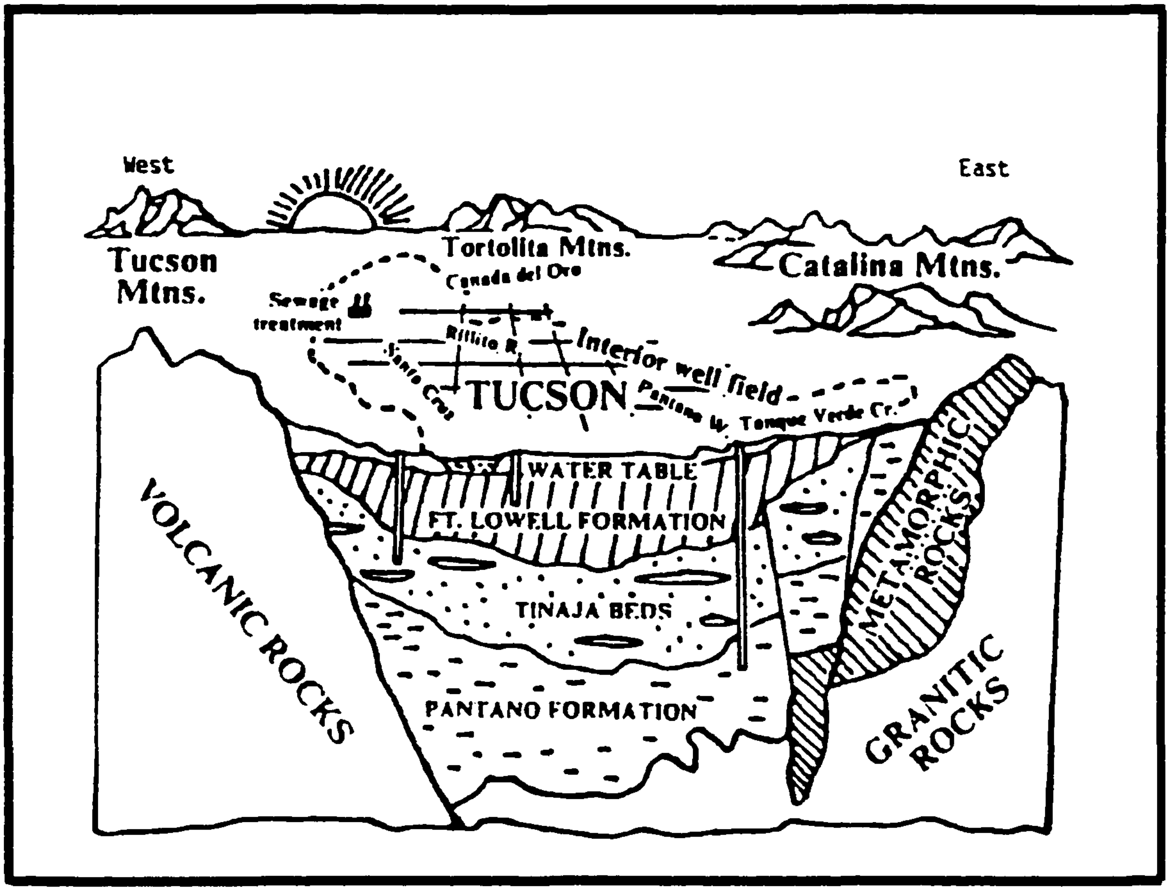

Figure 2.2. Cross Section of the Tucson AMA (ADWR-RRC, 1996)

The hydrology of the Canada del Oro basin is similar to that of the Tucson basin. The Fort Lowell Formation ranges from 100 to 300 ft in thickness through most of the area, thinning to zero feet near the mountain fronts. Groundwater generally flows to the southwest, in the direction of flow in the Canada del Oro Wash. Groundwater flows are only slightly influenced by groundwater withdrawals.

2.2.2. Avra Valley Sub-basin

The development of extensive groundwater usage in the Avra Valley started in early 1950. Although the Avra Valley Sub-basin includes both the Avra Valley and the Altar Valley, it is usually referred to simply as the Avra Valley Sub-basin. The Avra Valley Sub-basin is about 70 miles long, and it is a wide alluvial valley that slopes downward to the north and northeast. It is filled with sediments that divide it into two units, known as the upper alluvial unit and the lower alluvial unit (Hanson et al., 1990). The two units are hydrologically connected, and form the main regional aquifer. The composition of the upper alluvial unit consists of silt, sand, and sandy gravel, and the composition of the lower alluvial unit consists of gravel and conglomerates along the margins of the sub-basin. The thickness of the upper unit ranges from less than 100 ft to as much as 1,000 ft (Hanson et al, 1990). The lower unit is thousands of feet thick. The sediment thickness in the Avra and Altar Valleys were estimated to be 9,600 ft and 4,800 ft respectively (Oppenheimer and Sumner, 1980).

2.3. Climate

The climate in the Tucson AMA can be described as consisting of hot summers, mild winters with some cold spells, and two distinct rainy seasons. Climate variations within the Tucson AMA are due to elevations which range from 1,860 ft above mean sea level at the northwestern end of the Tucson AMA near Red Rock, to 9,453 ft above sea level at the Santa Rita Mountains (ADWR, 1994).

In the following section, two climate indicators will be discussed: temperature and precipitation. The data in this section is adapted from the Weather Almanac (Wood, 1995)

2.3.1. Temperature

The average monthly temperature in the Tucson AMA varies depending on the season and the location. As shown in Figure 2.3, the Tucson AMA has a long hot season; the average high temperature during the summer, which lasts from May through September, is above 90 degrees. During June and July, temperatures frequently reach over 100° F, with generally low humidity until July. In terms of annual average temperature, there is not much difference from one year to another. As shown in Figure 2.3, the cycle of 1993 temperatures is very similar to those in 1991 and 1992

2.3.2. Precipitation

Precipitation in the Tucson AMA is unevenly distributed and varies seasonally. In terms of average annual precipitation, the Tucson AMA can be classified as an arid to semi-arid area (Beaumont, 1993). The average monthly precipitation varies widely from one season to the other (Figure 2.4).

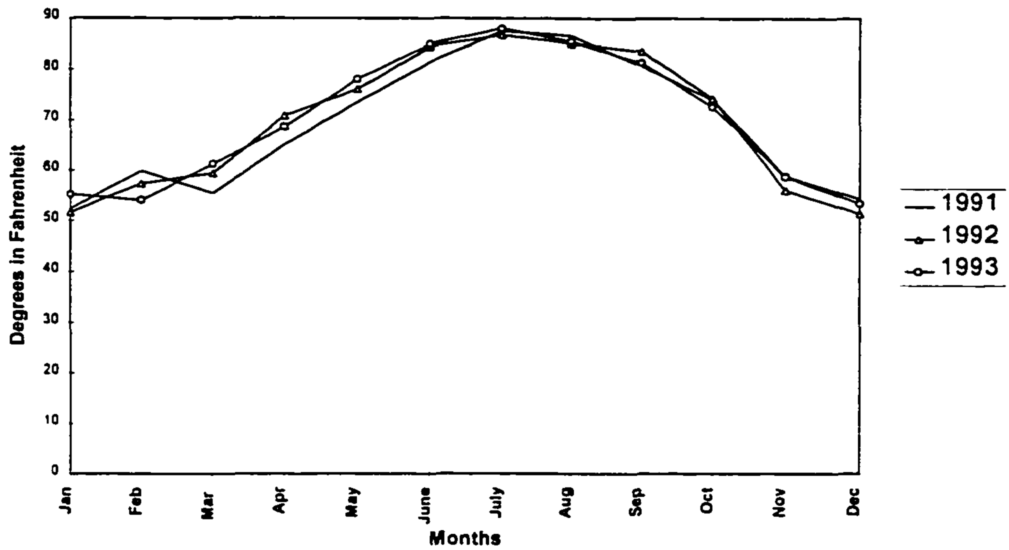

Figure 2.3. Tucson's Average Monthly Temperatures (Wood, 1995)

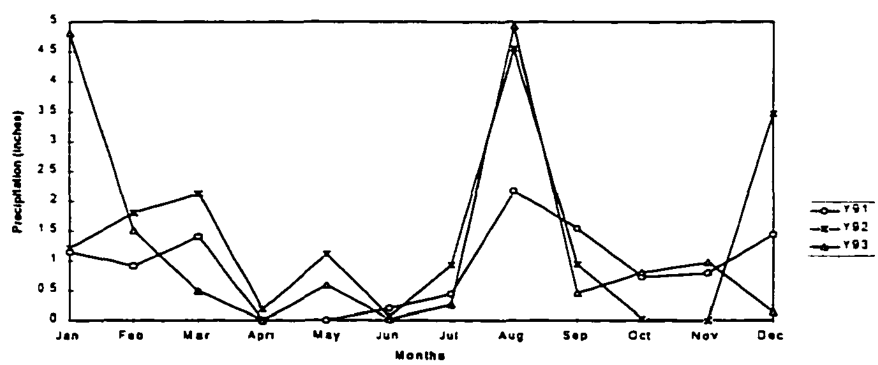

Figure 2.4. Tucson's Monthly Precipitation (Wood, 1995)

More than 50 percent of the annual precipitation falls between July 1 and September 15, and over 20 percent falls from December through March. Summer rain is highly intensive with high runoff. During the months of December through March, precipitation occurs as prolonged rainstorms that replenish the groundwater. Snow often falls at the higher mountain elevations, but snow in Tucson is infrequent, particularly in accumulations exceeding an inch in depth (Wood, 1995).

2.4. Tucson Basin Water Supply

The early settlement of Arizona took place near perennial stream flows. In the Tucson basin, several communities grew up along the Santa Cruz River, which contained several segments of perennial flow. Water from this river was used for domestic and small irrigation purposes. However, as the communities grew, and the agricultural development expanded during the 1930s and 1940s, these perennial streams eventually ceased flowing. The only source left was groundwater, which has been considered the main and most reliable water supply for the Tucson AMA up to this day. The population growth in the Tucson basin, that took place since 1940 induced the Tucson government to start using wastewater (Lieuwen, 1990). As a result, wastewater collection and treatment became another source of water for the Tucson AMA.

Finally, in October 1992, after a long period of legislation, litigation and construction, CAP water from the Colorado River arrived in Tucson (the history and objective of CAP are discussed in section 2.4.5.). The CAP water is now considered the only reliable surface water supply, and the second major source of water for the Tucson AMA. At the present time the primary water supplies come from groundwater, CAP, and effluent. For example, of the 300,000 acre-feet (af) that were used in the Tucson AMA in 1994, approximately 89 percent came from groundwater. Of this groundwater, approximately 52 percent came from mining[3] groundwater and 48 percent from renewable[4] groundwater. Eight percent of the total usage was imported water from the Colorado River through the Central Arizona Project (CAP), and the final three percent was effluent (ADWR-SAMA, 1996).

2.4.1. Perennial Streams within the Tucson AMA

2.4.1.1. Historical Perspective

Given the arid nature of the Tucson AMA, surface water supplies are virtually non-existent within its borders, except for limited surface water from several perennial streams. Therefore, flowing streams were valued highly as important sources of water and communities were most often established along these streams (Tellman, 1992). The streams and their length are shown in Table 2.1.

Table 2.1. Perennial Streams within Tucson AMA (ADWR, 1994)

Stream Reach	**Reach Length (miles)**
Santa Cruz (near Tucson)	9
Cienega Creek	4
Sabino Creek	10
Canada Del Oro	2
Arivaca Wash	3

In general, most of the rivers and streams in Arizona have experienced dramatic changes in the past hundred years. While they once flowed dependably throughout the year, now they flow only part of the year (Kulakowski and Tellman, 1994). There is a

[3] Groundwater discharge that is greater than groundwater recharge.
[4] Groundwater recharge that is greater than groundwater discharge.

general belief that the agricultural and mining activities that took place around these streams led to the depletion of many of them (Kulakowski and Tellman, 1994).

One of the best examples of this situation is the dramatic change in the flow of the Santa Cruz River in the Tucson AMA. The Santa Cruz River is the main stream within the Tucson AMA. It flows from the San Rafael Valley south into Mexico, and then turns back north into the United States through the Upper Santa Cruz Valley. It continues flowing north from Nogales to Tucson. When it reaches Tucson it turns northwest and flows across the northern part of the Avra Valley Sub-basin before exiting the Tucson AMA northwest of Marana.

Historically, there were three reaches of the Santa Cruz River that contained perennial flows (Brown, 1981). These reaches were from the International Border to Canoa, a segment near the San Xavier Del bac Mission, and a segment west of Tucson. ADWR (1994) found that prior to 1889, about 25 percent of the reaches of the Santa Cruz River in the Tucson area flowed perennially. However, due to the flooding that took place between the 1890s and 1930s, the valley floor was incised with an arroyo, which lowered the water table and eliminated the perennial reaches (Hanson, 1994).

Furthermore, the extensive agricultural and mining activities that took place along the river during 1930s caused the river to completely dry out by the mid 1940s (ADWR, 1994). Recently, the Santa Cruz River has had a natural, ephemeral flow that materializes only in response to heavy rainfall. However, there is only one segment at the terminus of Santa Cruz river that now has a perennial flow due to effluent discharge.

2.4.1.2. The Significant Aspect of the Santa Cruz River for Tucson AMA

One of the physical aspects of the Santa Cruz river is that it passes through the city of Tucson and drains much of the water during the rainy season. It is also connected to several major tributary washes, including Sonoita Creek, Sapori Wash, Rillito Creek, and Canada del Oro. Further, the Santa Cruz meets Brawley Wash at the western edge of the Avra Valley, which drains the western portion of the Tucson AMA. The Santa Cruz, and Altar and Avra valley drainage systems tie into the southern portion of the lower Gila River drainage system.

The Santa Cruz River, as well as other washes, are important as recharging sites, feeding the wells within the central areas of the city of Tucson. Another aspect of the Santa Cruz River is that it has been used as a discharge site for effluent that comes from the City of Tucson and Green Valley areas. About 53,000 af of effluent was discharged into the Santa Cruz River in 1994 (ADWR-RRC, 1996).

2.4.2. Groundwater

Beginning in the twentieth century, groundwater withdrawal in the Tucson basin started near the Santa Cruz River to support farming and mining. In general, economic activities are more concentrated in the Upper Santa Cruz Valley than in the Avra Valley Sub-basin. The Arizona Water Commission (AWC, 1975) estimated that the annual groundwater withdrawal in the Upper Santa Cruz Valley was 7,000 af in 1915. In contrast, groundwater withdrawal in Avra Valley did not even began until 1935. It is likely that along with the discovery of new well drilling technology in the 1930s, the drilling of wells in Avra Valley was motivated by the extension of agricultural development to the northern part of the Avra Valley Sub-basin near Marana.

The AWC (1975) estimated that groundwater withdrawal started in Avra Valley in 1935, with 1,000 af pumped that year. The total groundwater withdrawal in the Tucson basin (which included the Upper Santa Cruz Sub-basin and the Avra Valley Sub-basin in what it is now the Tucson AMA), was 29,000 af in 1935 as shown in Figure 2.5 .

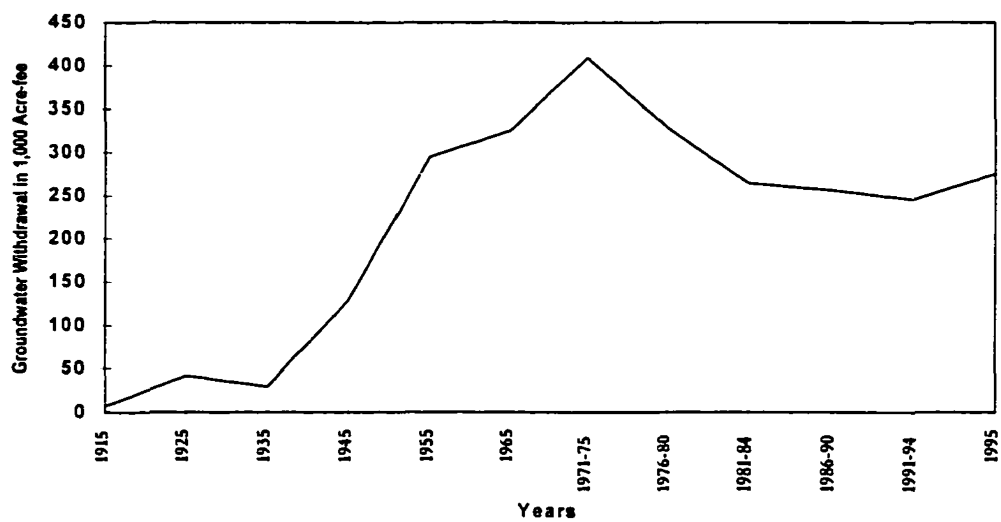

Figure 2.5. Estimated Annual GW Withdrawal from Tucson AMA (AWC,1975; ADWR, 1994)

Figure 2.5 shows the average groundwater withdrawal in the Tucson AMA from 1915 to 1995. Between 1935 and 1945, the total withdrawal in both Sub-basins increased more than four-fold. From the early 1950s to the late 1970s a combination of increasing cotton production and the improvement of drilling and irrigation technology prompted an increase in groundwater withdrawal in Avra Valley. Withdrawal increased in Avra Valley from 23,000 af in 1945 to 157,000 af in 1970. In the Upper Santa Cruz valley, the groundwater withdrawal increased from 106,000 af in 1945 to 240,000 af in 1970 (AWC, 1975).

In 1994, the ADWR (1994) estimated that the average annual groundwater withdrawal in the Tucson AMA Sub-basin between 1971 and 1975 was 409,000 af, while between 1976 and 1980, it had declined to 329,000 af. Between 1981-1984, groundwater withdrawal had declined dramatically to 264,000 af, and then further to 256,446 af between 1985-1990.

One of the main reason for such dramatic decrease of groundwater withdrawal during the 1970s and early 1980s was the result of the decline in agricultural usage. Historically, water was mostly used by agriculture. From the 1940s to the 1980s, the percentage of agricultural water use exceeded the combined percentage of municipal and industrial usage.

However, since 1985, agricultural water use has been declining, while municipal water use has been increasing. The decrease in agricultural water use is largely due to the urbanization that took place around the city of Tucson, and to the reduction of agricultural commodity prices, particularly the price of cotton which represented 80 percent of the total crop production in the Tucson AMA for the last two decades (AAS, 1997). For instance, while water use in 1985 was 40 percent for agriculture, 41 percent for municipal use, 14 percent for mining, and 5 percent for other industrial activities, it was only 32 percent, 47 percent, 16 percent and 5 percent, respectively, in 1994. The following section describes the current groundwater situation in Tucson AMA.

2.4.2.1. Groundwater Occurrence

Groundwater in the Upper Santa Cruz Valley Sub-basin occurs in both confined (artesian) and unconfined (water table) conditions (ADWR, 1994). It is shallowest along the Santa Cruz River and in the major washes and deepest near the mountains. In the Avra Valley Sub-basin groundwater occurs in unconfined (water table) conditions throughout the Sub-basin. However, drilling wells deeper than 1000 ft may encounter confining conditions caused by less permeable clay layers. In addition, a large, perched[5] water-table area exists in northeast Avra Valley. This perched zone has been caused by the downward percolation of irrigation return flows being impeded by fine-grained beds in the basin-fill (Reeter and Cady, 1982; Cuff and Anderson, 1987).

The groundwater movement in the Upper Santa Cruz Sub-basin is from the mountain-front recharge areas towards the central axis of the valley. It then moves north and northwest, parallel to the surface-water drainage. However, the general direction of groundwater movement in the Avra Valley Sub-basin is north and northwest, parallel to the surface-water drainage (ADWR, 1994).

2.4.2.2. Groundwater Yields

In the Upper Santa Cruz Valley, water levels range from 100 to 550 ft below land surface (City of Tucson, 1989). The yield of wells typically ranges from 500 to 1,500 gallons per minute in the Fort Lowell formation, and up to 600 gallons per minute in the

[5] An excess of water over the water table line.

Tinaja Beds (Davidson, 1973). Due to the great depth of the water in the Pantano Formation, it is not used as source of groundwater.

The water level in the Altar Valley and Avra Valley ranges from 14 to 720 ft, and from 140 to 600 ft below the surface, respectively. It is shallowest along the central axis of the Avra valley near the Altar and Brawley Washes, and deepest under the alluvial fans along the mountains (Reeter and Cady, 1982; City of Tucson, 1989). The capacity of irrigation wells located along the central axis of the Avra Valley can yield more than 3,000 gallons per minute. However, yields decrease towards the basin margins where the basin-fill thins (Travers and Mock, 1984).

2.4.3. Groundwater Quantities

In central Arizona large quantities of water stored in alluvial aquifers have accumulated over thousands of years. ADWR (1994) estimated that the total groundwater storage in the Tucson AMA (when it included Santa Cruz County) was about 71,000,000 af at a depth of 1,200 ft. However, since the rate of groundwater withdrawal in the Tucson AMA has exceeded the rate of natural recharge for several decades, that figure would be lower today. The total groundwater withdrawal from within the Tucson AMA through 1987 was about 13,760,000 af (Hanson, 1994).

The greatest amount of natural recharge generally occurs along mountains fronts or in major stream channels. Griffin (1980) stated that about one third of the total groundwater recharge occurred in the mountain front and the other two thirds came from stream channel infiltration during the rainy seasons. In recent decades additional recharge has come from the infiltration of effluent discharged into the Santa Cruz River and the seepage of irrigation water. The following section describes the amount of natural and incidental recharge in the Tucson AMA.

2.4.3.1. Natural Recharge

Natural recharge is defined as the amount of water from precipitation and groundwater flow that recharges the groundwater basin. In the Tucson AMA the net natural recharge is defined as the natural augmentation of groundwater storage from rainfall events and groundwater flow into the basin (ADWR, 1991).

There are various studies estimating the annual natural and incidental recharge of groundwater in the Upper Santa Cruz Valley and the Avra Valley Sub-basins. The annual recharge to the Avra and Altar Valleys was estimated by Osterkamp (1973) and Brown (1976) to be 30,000 af. For the Upper Santa Cruz Valley Sub-basin, the pioneer study was conducted by Davidson (1973) in his report to the U.S. Geological Survey. His study was based upon values estimated by Anderson's electrical analog of the flow of groundwater in the Tucson basin conducted in 1973. Davidson gave a comprehensive description of the Tucson basin, including estimates of the amount of recharge occurring each year and the amount of water in storage in the basin. He estimated the annual recharge in the Upper Santa Cruz Valley to be 77,000 af.

Another study estimating the groundwater recharge in some parts of the Upper Santa Cruz Valley Sub-basin was conducted by Matlock and Davis (1972), but this study was based on water budget analysis. They found the annual recharge in their study area to be 55,000 af. However, when adding the estimated groundwater recharge for the rest of the Upper Santa Cruz Valley Sub-basin from Davidson's estimate (which was not included by Matlock and Davis), the total annual recharge for Upper Santa Cruz is estimated to be 81,000 af.

Matlock and Davis's estimation of the amount of annual recharge agreed very closely with Davidson's 77,000 af. Later, in 1975, there was an official estimate of annual groundwater recharge by the AWC for the Upper Santa Cruz of 65,000 af. The AWC based its estimation on the value of recharge indicated by Anderson's electrical analog model. This estimate was much lower than the estimates produced by Matlock and Davis and by Davidson. Table 2.2 shows the past and current estimates from these different studies. In the 1991 Second Management Plan (SMP), the ADWR estimated the total amount of net natural recharge in the Tucson AMA at 62,000 af per year, of which 46,000 af per year occurs in the Upper Santa Cruz Sub-basin and 16,000 af per year in the Avra Valley Sub-basin. This estimate is substantially lower than Davidson's estimation of 77,000 af per year.

Recently, within the report on the State of the AMA (ADWR, 1996), the ADWR revised the estimation of the amount of water recharge in Tucson AMA. It stated that the natural recharge in the Tucson AMA is 59,090 af per year, of which 56,600 af per year occurs in the Upper Santa Cruz Valley and 2,490 af occurs in the Avra Valley Sub-basin (ADWR-SAMA, 1996). This amount is different from what the ADWR reported in the Second Management Plan 1990-2000 (SMP), due to the fact that: (1) the amount of recharge in the Santa Cruz AMA has been separated from the Tucson AMA, and (2) even more significantly, the ADWR had evaluated the computer model utilized by the United States Geological Survey (USGS) and one of the changes they made was that the effluent discharge into the Santa Cruz River was not considered as one of the components of net natural recharge as shown in Table 2.3.

2.4.3.2. Incidental Recharge

Incidental recharge is defined as the return flow of water pumped or diverted which percolates back to the water table. This includes such things as the irrigation return and wastewater effluent discharge into the Santa Cruz River. In 1991, ADWR estimated the amount of incidental recharge for the SMP at 59,000 af per year within the Tucson AMA. However, in the reports on state of AMAs of 1996, ADWR estimated the incidental recharge was 72,100 af in 1990, and 77,200 af in 1995.

Table 2.2. Various Studies of Groundwater Recharge

Studies	Upper Santa Cruz Sub-basin (AF)	Avra Valley Sub-basin (AF)
Matlock and Davis (1972)	81,000	
Davidson (1973)	77,000	
Osterkamp (1973)		30,000
Brown (1976)		[6]30,000
AWC (1977)	65,000	
ADWR (1991) (SMP)	46,000	16,000
ADWR-SAMA (1996)	[7]56,600	[8]2,490

Source: Formed from various studies included in the table.

6 under groundwater outflow was not subtracted.
7 Santa Cruz county's part is excluded.
8 see Table 2.3 for more detail.

Table 2.3. The Components of Net Natural Recharge in 1996

Elements of Net Natural Recharge	Upper Santa Cruz Sub-basin (AF)	Avra Valley Sub-basin (AF)	Total (AF)
Mountain Front Recharge	27,000	12,350	39,350
Stream Channel Recharge	34,000	7,140	41,140
Groundwater Inflow	8,600	13,000	21,600
Groundwater Outflow	-13,000	-30,000	43,000
Total Net Natural Recharge	56,600	2,490	59,090

Source: Adapted from ADWR-SAMA (1996)

This amount, in fact, is subject to change, depending on the quantity and efficiency of water applications to irrigated land, the level of mining activity, and the quantity of effluent discharged into stream channels below the discharge point. In the State of AMA (SAMA)'s report, the ADWR (1996) projected that incidental recharge would be 83,100 af in 2000 and 103,000 af in 2025. Generally, incidental recharge comes from effluent, municipal, mining, industrial, and agricultural water use. Table 2.4 shows the components and percentages of the incidental recharge

Table 2.4. Incidental Recharge Percentage in 1994

Source	Municipal	Industrial	Agriculture	Mining	Effluent
Percentage	4	5	20	25	75

Source: Adapted from State of AMA, April 1996.

This table shows that 4 percent of the total water used by municipal water users was returned to the groundwater table. Also, seventy five percent of the effluent discharged into the Santa Cruz River was returned to the water table; the remaining 25 of this effluent percent was lost through evaporation.

2.4.4. Effluent and Reclaimed Water

2.4.4.1. General Observations

Effluent and reclaimed water are generally considered a third source of water in arid regions. For the Tucson AMA, effluent represents one of the most important renewable resources due to its ability to increase along with population growth, and due to the possibility of using it in instead of groundwater. Essentially, the amount of effluent depends on the rate of indoor water use, because most of the water used indoors by residential, commercial, and industrial users is non-consumptive, and thus is typically routed to treatment facilities.

In Arizona, there are two major types of wastewater treatment facilities. The first type is known as a Waste Water Treatment Plant (WWTP), and is a facility designed to treat municipal wastewater for subsequent discharge of the effluent into river and stream beds. This type of treatment plant must meet federal and state water quality standards for discharge. The effluent can be used on cropland as a fertilizer (Lieuwen, 1990).

A second type of treatment facility is known as a Water Reclamation Plant (WRP), which is usually designed to treat municipal wastewater to levels required to meet various state standards for specific uses. This water is usually called "Reclaimed water", because quality standards for this type of water are often more stringent than quality standards for effluent (Lieuwen, 1990). In the following section, I will assess the existing and projected supply of effluent and reclaimed water in the Tucson AMA and describe the utilization and distribution of both effluent and reclaimed water within Tucson AMA.

2.4.4.2. Effluent Treatment Facilities

There are two large waste water treatment plants in the Tucson area, the Roger Road and the Ina Road plants. Also, there is a small plant in the Green Valley area to treat municipal waste water. Pima County operates these plants together via its Wastewater Management Department. The Roger and Ina plants treat over 90 percent of the discharged effluent, and the Green Valley plant treats the remaining 10 percent (Lieuwen, 1990). The existing and the planned capacities of each of these plants are shown in Table 2.5

2.4.4.3. Reclaimed Water Treatment Facilities

There are currently two WRPs within the Tucson AMA to treat effluent to be used for turf and agricultural irrigation. The Randolph Park WRP is owned and operated by Pima County. It treats effluent to be used in the Randolph South golf course. The Tucson Water Department (TWD) owns the Roger Road WRP plant, which is used to treat effluent for turf facilities, recharge, and underground storage.

Table 2.5. Tucson AMA Wastewater Plant in million gallon per day (mgd)

	Current Capacity (mgd)	Planned Capacity (mgd)	Effluent Treated (af/yr.)
Green Valley	2.1	2.1	na
Ina Road	25	37	28,805
Roger Road	35-40	41.00	35,000

Source: Personnel Communication with Munden, John, March, 1997

2.4.4.4. Effluent Distribution

In 1994, the Roger Road and Ina Road plants treated about 64,000 af of effluent in the Tucson area (ADWR-RRC, 1996). The City of Tucson has the right to use 90 percent of the effluent produced in the Tucson AMA by Pima county facilities under the 1979 Intergovernmental Agreement (City of Tucson, Resolution No. 10860, 1978). Pima County has the right to use only 10 percent of the effluent produced. As part of the Southern Arizona Water Rights Settlement Act of 1982, 23,000 af and 5,200 af of the reclaimed water produced in the Tucson AMA, were allocated to the San Xavier and the Schuk Toak Reservations Districts respectively. This water should be at least suitable for agricultural use. At the present time, none of these allocations are used by the Indian tribes.

2.4.4.5. Effluent and Reclaimed Water Utilization

In Arizona, many water resource specialists are trying to incorporate effluent use into water management plans (Lieuwen, 1990). One of the goals is to use effluent for purposes that are compatible with its quality. Approximately 64,000 af of effluent were produced in 1994 within the Tucson AMA. Of this amount, only about 11,000 af were reused as reclaimed water on turf facilities or delivered to agricultural users. The remaining 83 percent, or 53,000 af, was discharged into the downstream channel, where it supports riparian habitat as well as recharging the groundwater aquifer in the Santa Cruz River (ADWR-SAMA, 1991).

In general, the total amount of reclaimed water used has increased from 5,001 af in 1985 to 7,119 af in 1994 (Figure 2.6). The municipal reclaimed water is primarily used for golf courses, parks, schools and for median irrigation through the City of Tucson's reclaimed system. Of the total reclaimed water used in 1994, the golf courses, parks and cemeteries used 6,529 af (Figure 2.7). The city of Tucson plans to spend about 43 million dollars over the period from 1989 to 1999 for constructing new treatment plants, pipelines, storage facilities, and other facilities as necessary to serve more customers with its reclaimed water system (Lieuwen, 1990).

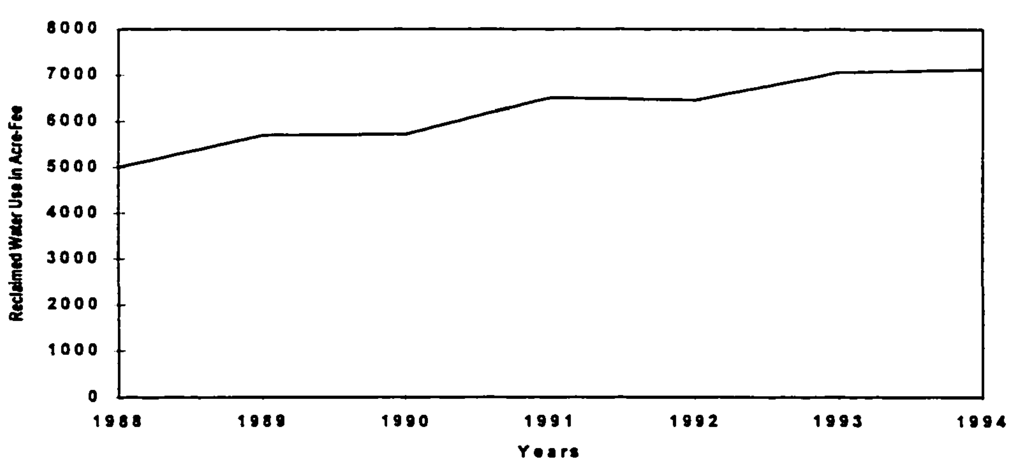

Figure 2.6. Municipal Reclaimed Water Use (ADWR-SAMA, 1996)

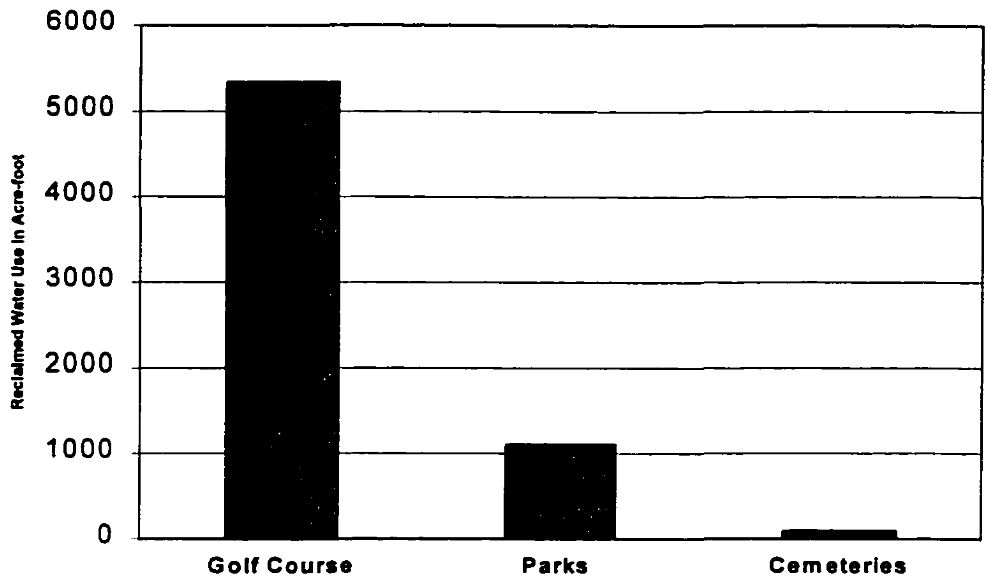

Figure 2.7. The Amount of Reclaimed Water Use by Major users (ADWR-SAMA, 1996)

2.4.5. Central Arizona Project

2.4.5.1. Background

The origin of the Central Arizona Project began in 1923 when Arizona refused to ratify the 1922 Colorado River Compact (CRC). The CRC had divided the Colorado River between the lower basin (Nevada, Arizona, and California), and upper basin (Colorado, New Mexico, and Utah), by allocating 7.5 million acre feet (maf) per year for each basin (City of Tucson, 1974). Following the CRC, the U.S. Congress passed the Boulder Canyon Project Act (BCPA) in 1928 in spite of the fact that Arizona had not ratified the CRC. The BCPA required California to limit its use of Colorado River water, and it also invited the lower basin states to agree upon the division of the 7.5 maf as follows: 300,000 af/year (yr) for Nevada, 2.8 maf/yr for Arizona and 4.4 maf/yr for California.

California continued developing projects to utilize Colorado river water during the 1930s and 1940s. When California constructed a 240-mile long aqueduct from the river to the Los Angeles area in the early 1930s, Arizona's portion was still underdeveloped. In 1944, the State of Arizona realized the importance of utilizing its share of the Colorado River for its continuing economic growth. The Arizona legislature in 1944 ratified the Colorado River Compact of 1922, and at the same time it signed a contract with the Department of the Interior for 2.8 maf per year as specified in the 1928 Boulder Canyon Project Act (City of Tucson, 1974).

In 1947, the U.S. Bureau of Reclamation completed the feasibility study for the Central Arizona Project and concluded that the project could pay for itself through the sale of water and hydroelectric power (Bradly et al., 1984). Within the same year as the U.S Bureau of Reclamation's feasibility study of the CAP, Arizona submitted its first proposal to Congress. What followed were two attempts in the 81st and 82nd Congress to pass project authorization bills. However, both of them failed due to the strong opposition of California and other states. In 1952, Arizona filed a suit against California to clear its entitlement to Colorado River water. In 1963 the U.S. Supreme Court issued its decision in favor of Arizona. By 1964, Congress had passed a decree affirming Arizona's right to 2.8 maf per year from mainstream water. Finally, in 1968, the Central Arizona Project Act was passed. This act authorized the construction of the Central Arizona Aqueduct Project

2.4.5.2. CAP System

The CAP is a 336 mile aqueduct carrying water from Lake Havasu on the Colorado River to the Phoenix and Tucson Areas. There are 14 pumping stations along the canal; of these, 9 are along the Tucson aqueduct (Figure 2.8). The main aqueduct consists of the Granite Reef, Salt-Gila, and Tucson aqueducts. The completion of the Tucson aqueduct was the last stage of CAP construction. The CAP was completed in the summer of 1992, when CAP water arrived in the city of Tucson. The total capacity of the CAP aqueduct is designed to deliver an average of 1.2 maf of water per year. Such amount provides a relatively secure source of water to supplement existing groundwater resources in central Arizona. It is divided among Maricopa, Pinal and Pima Counties and Native American tribes.

2.4.5.3. CAP Water for the Tucson AMA

Since there is no appreciable surface water supply within the Tucson AMA, water from the CAP is considered to be an important source for Tucson. This is because it is the only easily renewable water resource available. The main purpose of bringing CAP water to the Tucson AMA is to replace the use of groundwater, which is now being rapidly mined, and to provide water for the future growth of the city of Tucson.

The city of Tucson began receiving CAP water in November, 1992. The CAP allocation for the Tucson AMA, including the 37,800 af set aside for Native American use, is 231,000 af per year (ADWR,1994). The total allocation is expected to increase to 243,184 af by 2040 when Arizona will use its total share of Colorado River water (ADWR, 1994).

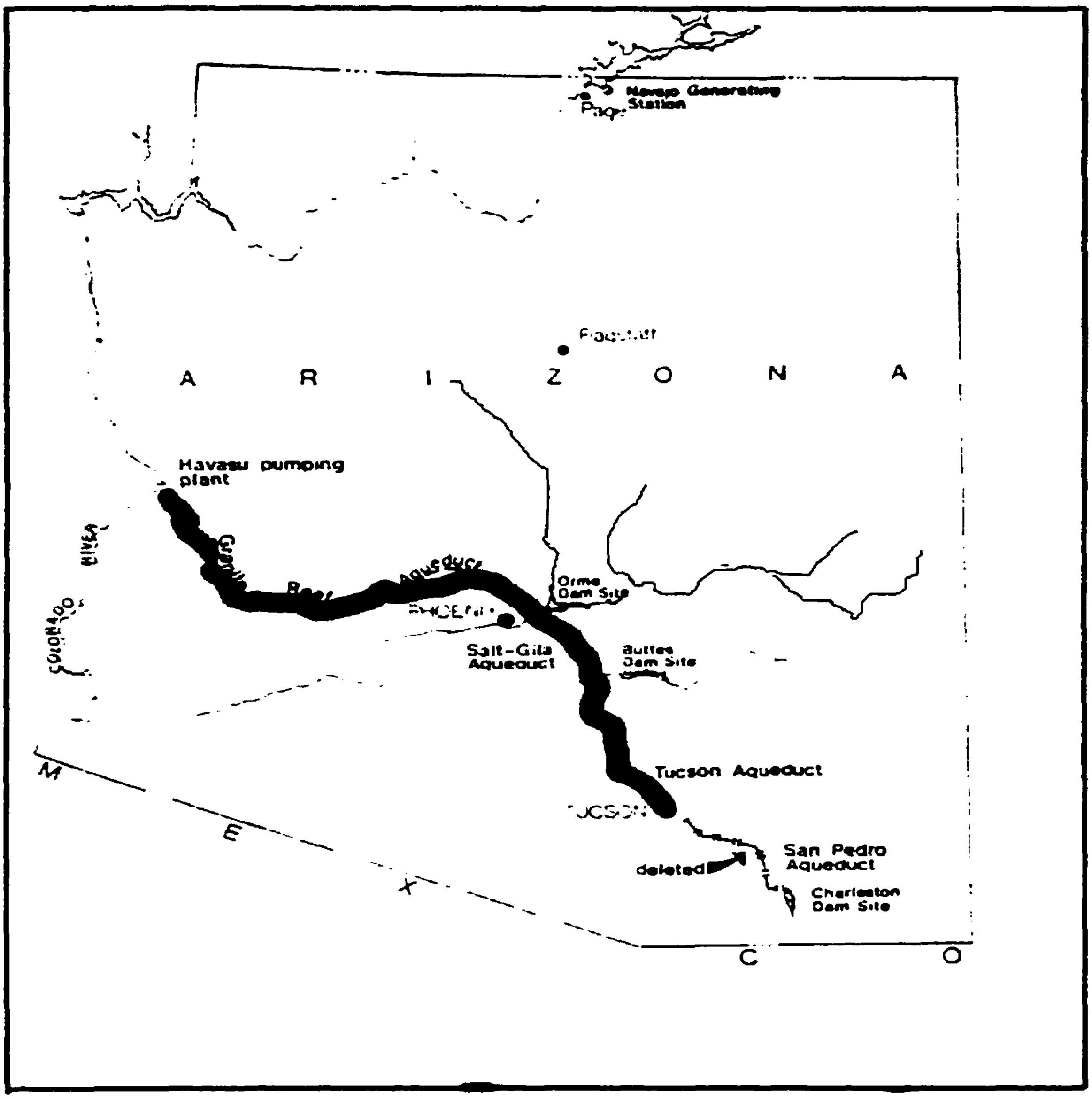

Figure 2.8. Central Arizona Project Aqueduct (City of Tucson, 1974)

Although contracts were offered to both agricultural and mining users within the Tucson AMA, all of them declined due to the CAP water's cost and quality. Therefore, the primary use of CAP water is through municipal contracts. The total CAP water that has been contracted in 1996 was 215,333 af. Table 2.6 indicates that the highest allocation of CAP water is for the city of Tucson at 148,420 af per year. This allocation was intended to cover the demands of several other water providers in the region, and also allow for the increasing demand associated with population growth. The remaining 95,113 af of the Tucson AMA's CAP allocation is to state land, Native American lands, and smaller water companies. The annual CAP water allocation for the San Xavier District is 27,000 af, and for Schuk Toak is 10,800. The total for the Tohno' Odham will be 37,800 af of CAP water.

Currently, CAP water is not fully utilized by any of the CAP contractors due to a quality problem that was exposed in 1993. The main quality problem with CAP water is that it has roughly twice the total dissolved solids (TDS) of groundwater in the Tucson aquifer. As discussed in Chapter 1, when CAP water was delivered through Tucson Water Department (TWD) in late 1992 and early 1993, the chemical properties of CAP water damaged the old pipe systems and created some taste and quality problems. As direct and dramatic consequence, the Consumer Protection Act (better known as Proposition 200) was enacted in November, 1995 as a result of a city wide vote.

Table 2.6. CAP Water Contracts within the Tucson AMA in 1996

Entity	**Allocation (af)**
City of Tucson	148,420
Midvale Farms	1,500
Canada Hills Water Company	1,652
Comm. Water Company Green Valley	1,100
Del Lago Water Company	786
Green Valley Water Company	1,900
New Pueblo Water Company	237
Spanish Trail Water Company	3,037
Cortaro WIA	47
Flowing Wells Irrg. District	4,354
Schuk Toak (Tohon O'odham)	10,800
San Xavier (Tohno' odham)	27,000
Pasqua Yaqui	500
State Land Department	14,000
Total	**215,333**

Source: Adapted from ADWR-SAMA (1996)

The Consumer Protection Act (CPA) states that CAP water cannot be used directly unless it is treated to meet the same standard of water quality as Avra Valley groundwater. However, since such treatment is so expensive, the only option left is to find other ways to use CAP water. One of the primary options is to utilize CAP water through recharging programs. Since there are no recharge facilities that could utilize such large quantities of water, the city of Tucson is conducting three different pilot projects to examine the possibility of utilizing CAP water through recharge.

2.4.6. Water Quality and Land Subsidence in the Tucson AMA

2.4.6.1. General Observations

Given the Tucson metropolitan area's dependency on groundwater for almost 100 percent of its drinking water supply, the protection of groundwater quality is of utmost concern. Groundwater in the Tucson AMA is generally suitable for most uses. In the Upper Santa Cruz Valley Sub-basin, fluoride concentrations in the Sub-basin range from 0 to 7.0 mg/l (Murphy and Hedley, 1984), with most samples below the maximum allowed contaminant levels of 4.0 mg/l. The level of total dissolved solids (TDS), found in Tucson AMA groundwater typically ranges from 200 mg/l to about 500 mg/l (ADWR-SAMA, 1996). These levels are considered low, and present few restrictions for use of the area's potable groundwater supplies. However, the TDS level in CAP water reaches more than 700 mg/l (ADWR-SAMA, 1996).

In addition, CAP water contains certain organic compounds, referred to as "precursors." These can, in combination with chlorine, react to form (Trihalomethanes) THMs, which have been shown to cause cancer in laboratory animals (ADWR-RRC, 1996). Therefore, the quality of CAP water poses special problems either directly or indirectly, despite the fact that without CAP water, the Tucson AMA will continue to be totally dependent on groundwater.

2.4.6.2. Groundwater Contamination

Within the Tucson AMA, there are several groundwater sites that have been identified as contaminated. The sources of such contamination stem from the past practices of a wastewater treatment facility, landfills, and abandoned feedlots (ADEQ, 1990). These practices elevated levels of nitrate, sulfate, TDS, and volatile organic compounds (VOCs) within certain areas of the Tucson AMA. For example, VOCs have been reported in groundwater at and near both the Silverbell and Camino Del Cerro landfills located adjacent to the Santa Cruz River, the Broadway North Landfill located adjacent to Pantano Wash, and near the Rillito River at Shannon Road (ADWR, 1994). The nitrate, sulfate, and TDS levels were also elevated in the areas around Green Valley. TDS levels have reached to 2,500 mg/l near mining operations (Green Valley), and reached to 600 mg/l downstream from agricultural activities in the northern part of the Avra-Alter Sub-basin along Brawely Wash. Nitrate has historically been detected in El Camino Del Cerro area since the first nitrate analysis conducted in the 1940s, and it is estimated that groundwater in the area has nitrate levels exceeding the maximum allowed contaminant level (MCL). Groundwater sampling performed at the Broadway Landfill area, in the downgradient of the landfill has detected VOC levels, including PCE at 36.9 ppb, trichloroethylene (TCE) as high as 3.17 ppb, and dichlorodifluoromethane at 22 ppb (ADWR-RRC, 1996).

Another groundwater investigation conducted near the location of the Hughes Aircraft Company by the Tucson Airport Area, revealed elevated levels of several organic compounds, including TCE. In this area, there is one major plume and two smaller plumes. The major plumes are more than four miles long and one-half mile wide. The smaller plume is less than one-half mile in diameter and length. Generally, these plumes are being remediated through a pump-and-treat system, where TCE-tainted water is pumped from these areas and transported by a pipeline network to a water treatment plant located west of I-19 and north of Irvington Road. The treated water was blended with groundwater and then distributed to the downtown area. However, the passage of Proposition 200 prevents delivery of such water to the potable water system (ADWR-SAMA, 1996). Currently, groundwater pumped from those wells is treated and then discharged into the Santa Cruz River.

In the northern part of the Tucson International airport, immediately adjacent to the Burr-Brown property, the groundwater is contaminated with TCE. This groundwater has been extracted at about 40 gallons per minute and treated at the Burr-Brown facility since 1992, and used at the facility for irrigation and industrial uses. The Pima County Health Department discovered VOCs in groundwater near the Silverbell Jail and the Miracle Mile area during the fall of 1983 (ADWR-SAMA 1996).

2.4.6.3. Land Subsidence

As shown previously in Figure 2.5, there was a dramatic increase in groundwater withdrawal from the 1940s up to 1971-75. Generally, the rate of groundwater withdrawals in the Tucson AMA exceeded the rate of natural recharge for several decades. The excessive groundwater withdrawal resulted in clearly observable lowering of groundwater levels, mining of groundwater, and reducing the amount of groundwater stored in the aquifers. In the central Tucson basin, water levels have declined by as much as 170 ft since 1940. Water levels declined by more than 100 ft in most of the northern

Avra valley, and by more than 200 ft in the very northwestern part of the valley, south of Pichacho Peak (Cuff and Anderson, 1987; Hanson et al., 1990). In the lower Canada del Oro basin, water levels have declined from 10 to 30 ft since the 1940s (ADWR-SAMA 1996).

Hanson (1989) reported that the decline of the water table in both the Upper Santa Cruz and Avra valleys has been associated with an aquifer compacting which has led to 0.5 and 1.1 ft in land subsidence, respectively. However, since 1972, the groundwater table has been stable in Avra Valley due to the retirement of agricultural land purchased by the city of Tucson. However, the groundwater levels in Tucson Water's central Wellfield have created a large cone of depression underlying the city (ADWR-SAMA, 1996). A cone of depression also exists in the Green Valley area, with isolated declines in the water table of up to 140 ft since 1940.

2.5. Summary

Overall, one can conclude that the Tucson AMA has limited long term water resources, given current groundwater use and the dependency on it. Further, the low levels of precipitation and the high temperatures during summers lead to high evaporation levels. These indirectly contribute to the historic water table decline. However, despite these problems, Tucson AMA does not suffer from a shortage of water, given the completion of CAP and the continuous development of effluent water resources which have not only increased the Tucson AMA's renewable resources, but indeed have created a water surplus. Yet the Tucson AMA continues to rely on groundwater (more than 95 percent) to support nearly all economic activity.

Generally, there has been some recovery of the water levels since the mid 1980s between the southern AMA boundary and Green Valley. Likewise, there has been some recovery of water levels in the northern Avra Valley, which had historically declined up to 100-200 ft. Water levels in the upper Canada del Oro basin have been relatively stable, despite an increase in groundwater pumping in that area. Further, the geology of the groundwater in the Tucson AMA is not a serious problem that limits the overall water supply, but it does limit the utilization of some of it for drinking purposes. The CAP water quality problem is indeed limiting the Tucson AMA water supply due to the fact that CAP water cannot be used directly for municipal purposes. Yet, there are several options under examination to utilize CAP water through recharge of Tucson AMA's aquifers, or for agricultural, turf, mining, and landscaping irrigation.

Chapter 3: Water Use in the Tucson AMA

3.1. Introduction

In Arizona, the structure of the water economy differs from one area to another, depending upon natural climatic conditions, the availability, accessibility, and quality of the water resources, and economic development. In the Tucson AMA, for several decades preceding 1984, groundwater withdrawal varied from year to year, depending on a combination of factors including, economic activities, population level, and weather conditions (AWC, 1975). As discussed in Chapter 2 (Section 2.4.2), between the 1940s and early 1980s, most of the groundwater withdrawal was used by agriculture. However, since 1985, agricultural water use has been declining, while municipal water use has been increasing. Presently, municipal use exceeds mining and agricultural usage combined, and is expected to continue increasing (see section 2.4.2). The purpose of this chapter is to present an overall perspective of water use by the major consumers (municipal, agriculture and industry) and also identify the water providers for each sector.

3.2. Municipal Water Use

Municipal water use in the Tucson AMA consists of numerous distinctly different demands that can be loosely categorized as either residential or non-residential. Residential use, sometimes called domestic use, consists of such indoor activities as laundering, garbage disposal, cooking and food preparation, house cleaning, and evaporative cooling, as well as personal uses such as toilet flushing, bathing, drinking. This category also includes outdoor activities that include the irrigation of landscape and turf, water for swimming pools, and car washing. The non residential usage includes commercial users: colleges, hospitals, government offices, parks and golf courses, and other commercial enterprises and industry. The proportion of resident to non-resident water usage in the Tucson AMA is shown in Table 3.1.

Table 3.1. Water Use Trends: 1985-1994 in Gallon Per Capita Per Day (GPCD)

Year	Population	Total Municipal Water Uses	Residential	Non residential	Total
		Af/yr	GPCD	GPCD	GPCD
1985	556,850	113,695	113	51	182
1986	582,538	120,619	112	55	185
1987	609,302	126,777	115	58	186
1988	617,086	128,560	116	57	186
1989	628,190	137,295	122	60	195
1990	635,076	126,187	113	51	177
1991	643,415	129,262	114	50	179
1992	663,763	131,365	110	50	177
1993	686,255	134,158	111	51	175
1994	**712,898**	**142,202**	**114**	**51**	**178**

Source: Adapted from the State of AMA, ADWR-SAMA (1996)

As shown in Table 3.1, the average water use during the period 1985-1994 for residential activities was about 64 percent of the total, while non-resident activities consumed about 28 percent. The other 8 percent was reported as lost, either through use in fire fighting, or through system leakage. Table 3.1 also indicates that total water use by the municipal sector increased from 113,695 af in 1985 to 142,202 af in 1994. This increase was actually small relative to the population growth from 556, 850 in 1985 to 712,898 in 1994. However, while the average per capita water use decreased from 182 gallons per capita per day (GPCD) in 1985 to 178 gpcd in 1994, overall municipal water use increased by 21 percent.

3.2.1. Municipal Water Providers

In the Tucson AMA, there are a total of 151 water providers for municipal purposes. These providers are divided into two distinct groups. Providers that have the capability to provide 250 af/year are considered large providers. In this case, large providers are subject to the conservation programs of the Second Management Plan (SMP). Based on this distinction, there are 18 large providers and 133 small providers. Ninety-six percent of the total volume of water supply for municipal purposes in the Tucson AMA is provided by the 18 largest providers, and only 4 percent is provided by the 133 small providers.

Among the 18 largest providers, the Tucson Water Department (TWD) is by far the largest water provider within the Tucson AMA. It provides about 74 percent of the total water use. The Tucson Water Department's GPCD rates are lower than the combined rates of the other large providers. This is partly due to a higher proportion of customers in the central area where there are small lot sizes, fewer swimming pools and golf courses, and more multifamily housing.

The total water supply provided by 18 largest provider was 135,083 af and their average per capita water use was 169 GPCD. The number of people and the volume of water provided by the 18 largest providers are shown in Table 3.2. Comparing the average GPCD of Table 3.2. for the largest providers with the average GPCD in Table

3.1, the average GPCD for the largest providers is about 96 percent of the total average GPCD in Tucson. The other 4 percent, 7,119 af, is provided by the smaller providers.

As mentioned previously, the smaller providers supply only four percent of total water use and typically have little conservation potential. Such providers generally lack resources to implement conservation programs. Therefore, the SMP has a simplified regulatory approach for small providers. They are encouraged to (1) minimize waste of all water supplies (2) maximize efficiency in outdoor water use activities, and (3) reduce total gallons per capita per day. The types and water use of small providers is shown in Table 3.3.

3.2.2. Municipal Geographic Areas

Within the Tucson AMA, there are seven municipal geographic areas: Central, Northern, Marana, Southwest, Southeast, Green Valley and Oracle (Table 3.4). The Oracle area is outside the Tucson AMA, but it receives its water from wells within the Tucson AMA. Approximately 70 percent of the Tucson AMA population lives within the Central area. However, since the total population of the seven distinctive areas (718,022) was greater than the total population of Tucson AMA (see Table 3.1; 3.2), the total water use is less than the total water use in Tucson AMA, but greater than the total water supply provided by the 18 largest providers due to the fact the data in Table 3.4 include the small providers that have considerable growth potential and consequently will have an impact on the geographic area in the near future. Table 3.4 shows the population, total water use and residential and non-residential water use.

Table 3.2. Total and Per Capita Water Use by each Provider in 1994

Name of the Company	**People served**	**Water Use (AF/yr.)**	**Total GPCD**
Tucson Water	583,636	104,736	160
Metro Water District	38,811	8,768	202
Flowing Wells District	14,922	2,897	173
Canada Hills Water Company (WC)	14,016	3,466	223
Community WC of Green Valley	12,285	1,991	145
David-Monthan Air Force Base	6,191	1,566	226
University of Arizona	5,695	1,633	256
Lago del Oro WC	4,707	1,409	267
Avra Water Cooperative	4,604	730	142
Ray WC	4,606	621	120
Rancho Vistoso WC	4,122	1,494	324
Hub WC	3,938	1,073	243
Green Valley WC	3,835	2,183	508
Arizona Water Company	3,627	361	89
AZ State Prison complex	3,086	533	154
Cortaro Water Users Association	2,005	299	133
Marana-Pic Rocks Water Service	1,971	428	194
Forty-niner WC	842	864	916
Total	**712,898**	**135,083**	**169**

Source: Adapted from ADWR-SAMA (1996)

Table 3.3. Small Providers in the Tucson AMA 1994

Provider Type	**Number**	**Water Use (af)**
Well Coops	41	1,067
Private Water Company	34	2,258
Mobile Home Park	33	1,432
Miscellaneous	19	525
Institutional	5	452
Municipal	1	73

Source: Adapted from ADWR-SAMA (1996)

Table 3.4. Municipal Use by Geographic Area of Tucson AMA 1994

Area	**Population 1994**	**Water use (af)**	**Residential GPCD**	**Non-Residential (GPCD)**
Central	496,083	91,161	111	40
North	128,558	31,657	146	63
Marana	25,619	4,343	129	3
Southeast	9,631	2,081	146	2
Southwest	35,208	5,758	137	0
Green Valley	19,297	4,776	117	95
Oracle	3,627	361	64	9
Total	**718,022**	**139,954**		

Source: Adapted from ADWR-SAMA (1996): P 21

The Central area is located south of the Rillito River, west of Saguaro National Park (East), north of Tucson International Airport and east of Tucson Mountain Park. There are eight large providers for water in the Central area. The TWD provides 90 percent of the municipal water use in the Central area.

The second largest area is the Northern area, which is located north of the Rillito River, west of Houghton Road, south of the Pinal county line and east of I-10. There are five large providers serving the northern area, including TWD. In this area, the ratio of non-residential water use to residential is higher than in the Central area due to the large numbers of private swimming pools and larger lots. The Marana area is predominantly rural and agricultural with large lots and manufactured housing common for the residential neighborhoods. The municipal water demands in the Southwest and Southeast, Green Valley, and Oracle areas are mostly met by small providers (ADWR, 1994).

3.2.3. Municipal Water Sources

Groundwater is the primary source for municipal water in the Tucson AMA. In 1994, 79 percent or 117,315 af of the municipal demand was supplied by groundwater, 16 percent by CAP and 5 percent by effluent. Since 1994, CAP water was not delivered for potable purposes and will not be directly delivered until at least 2001 due to conditions laid out by Proposition 200 (Chapter 4). Therefore, groundwater will be the primary source until at least 2001. The Tucson Water Department (Malcolm Pirnie, 1996) estimated that 134,300 af of groundwater are going to be withdrawn annually from Tucson aquifers to meet demands for potable water up to year 2001.

The TWD, as a major provider of water for municipal purposes, has supplied its system from four main wellfields for the last two decades; Central, South, Santa Cruz, and Avra Valley. In 1994, approximately 156 million gallons per day of groundwater were withdrawn from these wellfields[9]. Of this total, about 60 percent was produced from the Central Wellfield, 13 percent was produced from the Santa Cruz Wellfield, 13 percent was produced from the Avra Valley Wellfield, and 5 percent from the Southside Wellfield (Malcolm Pirnie, 1994).

Furthermore, since September 1994, additional groundwater supplies have been obtained from nine extraction wells in the Tucson Airport Remediation Project (TARP) area. The groundwater from TARP is treated to remove volatile organic compounds, including trichloroethylene (TCE). This treated water used to be delivered for use in the

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[9] The amount of groundwater withdraw is greater than the water use reported in Table 3.1. because of evaporation and systems leakage.

downtown area, away from the TCE-affected area. However, passage of Proposition 200 prevents the delivery of this water to the potable system. The city is currently treating and discharging it into Santa Cruz River.

Table 3.5 demonstrates the number of wells and the capacity yield of each wellfield area including TARP. The highest number of wells are located in the Central Wellfield areas. The total groundwater overdraft from the Central Wellfield presently is about 60,000 to 70,000 af per year (Malcolm Pirnie, 1994).

Table 3.5. Water Withdrawal from Major Wellfields in 1994

	Central	South	Santa Cruz	Avra Valley	TARP
Number of Wells	200	13	27	22	9
Yield (mgpd)	110	3	13	30	10

Source: Tucson Water Department, (Malcolm Pirnie, 1994)
Mgpd = (million gallon per day)

3.2.4. Factors that Influence Municipal Water Use

Municipal water use in the Tucson AMA is influenced by several factors. One of the major factors is weather conditions. Approximately 28 percent of municipal water use is utilized in outdoor activities such as irrigating turf, golf courses and landscaping, and evaporative coolers. Historically, the use of water in the Tucson AMA increases by about 50 to 100 percent during the summer months which last from May to October. The major factor for higher water consumption during summer season is landscape irrigation. Figure 3.1 demonstrates the Evapotranspiration Rate (ET). The ET is an indication of the amount of water transpired by vegetation based on precipitation and temperature. It also shows residential water use in gallons per capita per day (GPCD).

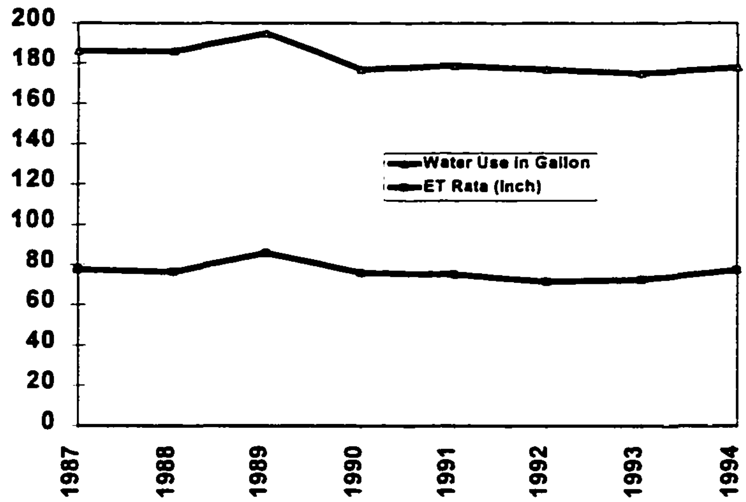

Figure 3.1. The Comparison Between Water Use and ET Rate (ADWR-SAMA, 1996)

As indicated in Figure 3.1, there is a close correlation between ET and GPCD water use. For example, GPCD water in 1988 was 188 gpcd and ET was 76.44 inch (in). However, when ET was 85.93 inches, in 1989, the per capita water use increased to 195 gpcd.

There are some other significant factors that influence the rate of municipal water use in the Tucson AMA. The two major factors are (1) the number of residents per water meter; and (2) the household income level. Woodard (1984) found that the number of people per water meter has a significant impact on water use in the city of Tucson. He stated that the more people there are in a household, the more likely they are to have water-intensive amenities. He also stated that the more the residents can afford, the greater the household water demand. Generally, the wealthier communities in the city of Tucson have more commercial establishments per resident and more golf courses and other public facilities that require irrigation.

3.3. Agricultural Water Use

Most of the agricultural activities that took place in Pima County over the last several decades were within the Tucson AMA. When Hardt (1989) estimated that agricultural water use in Pima County was 238,000 af in 1975, it was actually the agricultural water use within the Tucson AMA that he was measuring. Table 3.6 demonstrates the annual agricultural water use for 1984 through 1994.

As shown in Table 3.6, the amount of agricultural water use has decreased by half since the early 1980s. For example, it was 116,625 af in 1984 and it decreased to 85,765 af in 1993, and 97, 945 af in 1994. Although agricultural water use has decreased in the area surrounding Tucson, groundwater withdrawal is high due to municipal and industrial growth. The decrease in agricultural water use has largely been due to the urbanization that took place around the city of Tucson, and to the drop in agricultural commodity prices, particularly the cotton price. Cotton represented 80 percent of total crop production in the Tucson AMA for the last two decades (AAS, 1997).

3.3.1. Major Agricultural Water Users

There are three major agricultural water users in the Tucson AMA, Cortaro-Marana Irrigation District (CMID), Avra Valley Irrigation District (AVID) and the Farmers Investment Company (FICO) as shown in Table 3.7. Native American agricultural activities are expected to use large amounts of water within the next two decades. About 1,000 acres of irrigated land have been developed in the San Xavier District south of Tucson. Given the outcome of the Southern Arizona Settlement Act, which grants about 76,000 af of CAP, effluent and groundwater for Native American reservations in the Tucson AMA, it is anticipated that this class of agricultural water use is going to increase from 1,000 af in 1990 to 16,000 af in 2015 and to 22,000 af in 2025 (ADWR-SAMA, 1996).

3.3.2. Factors that Influence Agricultural Water Use

There are three major factors that impact agricultural water use within the Tucson AMA. One of these factors is irrigation efficiency. Under the Tucson AMA's arid conditions, crop water use is considered highly consumptive, because much of the water is lost through evaptransporation. Therefore, improvement of agricultural water use efficiency through improvements in the conveyance and distribution system, and through a better field application will decrease agricultural water use. Since 20 percent of agricultural water use is returned to the groundwater table through incidental recharge, greater efficiency of water use by the agricultural sector may decrease the amount of incidental recharge. In general, however, the net saving of groundwater might be more than if agricultural irrigation efficiency measures are not applied (ADWR, 1994).

Table 3.6. Annual Water Use by Agriculture

Year	Agriculture Water use (af)	Total Water Use (af)	Percentage
1984	116,625	270,249	43
1986	105,310	270,969	39
1988	106,172	279,039	38
1990	90,849	265,227	34
1992	86,880	269,158	32
1994	97,945	320,327	32

Source: Michael Caporaso, written information from ADWR, Jan, 1997

Table 3.7. Major Agricultural Water Users

Provider	Irrigation Acres	Ave. water us 1987-1994 (af)	1994 Water Use (af)
CMID	12,149	34,500	35,649
AVID	12,272	26,250	24,652
FICO	5,889	27,695	26,886
Total	**30,310**	**88,545**	**87,187**

Source: Adapted from the State of AMA, ADWR-SAMA (1996)

The second factor that influences agricultural water use is the type of crop irrigated, because there is high variation in the amount of water needed to grow an acre of crop in the Tucson AMA. For example, the amount of water required to grow an acre of barley is 2.08 af, while for pecan it is 5.83 af and for alfalfa 3.06 af (see Figure 3.2). Within the Tucson AMA, cotton is the major crop. It represents about 80 percent of AVID's acres, and 70 percent of CMID's acres. For example, if the total irrigated land assigned by GMA for AVID and CMID equals 25,000 acres, it is probable that 75 percent of their irrigated land is going to be used for cotton production. This requires 65,000 af of water, given 3.48 af per acre of cotton as shown in Figure 3.2.

The third factor that impacts agricultural water use is crop prices. For example, when cotton prices began to decline in the early 1980s, the number of acres planted with cotton declined from 19,000 acres in the 1980s to 13,000 acres in 1995 (Wilson, 1992).

There are some other factors such as GMA conservation strategies that have a direct impact on agricultural water use in the Tucson AMA. One of the examples of declining agricultural water use is in the irrigation district of CMID as shown in Figure 3.3. This resulted from decreasing cotton prices, conservation regulation, and some other economic factors (Condit, 1995).

3.4. Industrial Water Use

Industry uses large volumes of water for cooling, processing, cleaning and removing wastes. With industrial use, most of the water is returned through water recycling, but this water is often heavily polluted with chemicals and heavy metals. The primary industrial users in the Tucson AMA are metal mines, turf facilities, sand and gravel operations, and electric power plants. Industrial water use in the Tucson AMA is the highest of any AMA, due to mining operations, which accounted for 60 percent of the industrial water use, and represents 25 percent of the total water use in the Tucson AMA in 1993.

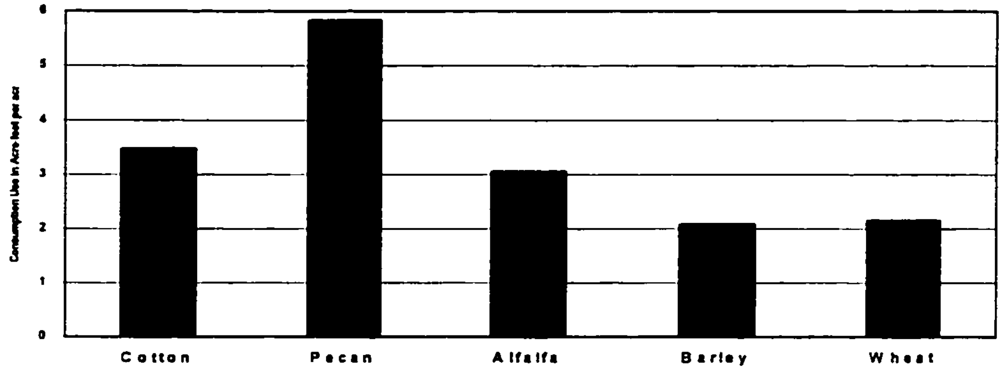

Figure 3.2. Per Acre Water Use by Major Crop Grown in Tucson AMA (ADWR, 1991)

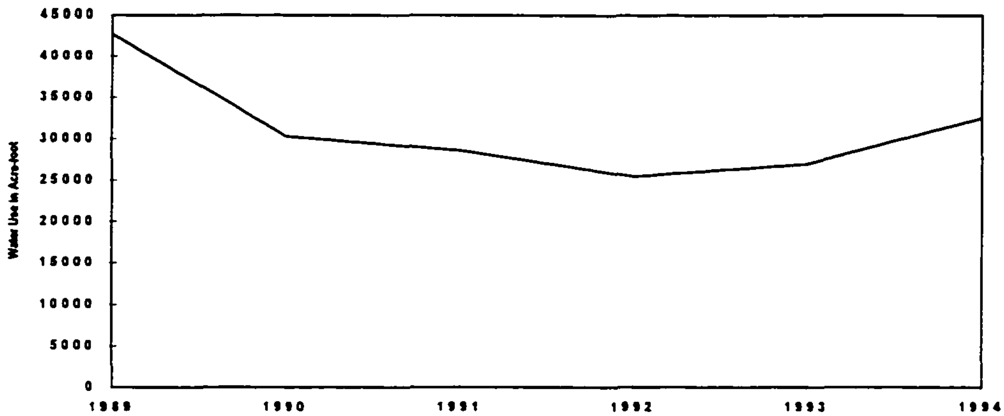

Figure 3.3. Cortaro Marana Irrigation District (Caporaso, 1997)

Table 3.8. The Percentage of Water Use by Industrial Sector in 1994

Sector	**Water use**	**Percentage**
Metal Mines	43,659	60
Turf Related Industry	18,500	25
Sand and Gravel	4,258	6
Electric Power	2,524	5
Dairies	70	4
Total	**69,052**	**100**

Source: Adapted from ADWR-SAMA (1996)

3.4.1. Metal Mines

There are four copper mines in the Tucson AMA. The use of water by the mining sector depends on how active the mines are. The level of mining activity fluctuates with the price of copper and technological advances, as well as other economic factors. When copper prices are low, there is a high temptation for copper investors to close down some of the mining operations. This situation has occurred in Tucson during the late 1970's (Griffin, 1980). However, when prices are high, there may be a switchover to maximum copper production. For instance, the use of water by the four metal mines in Tucson has increased significantly in recent years, from about 22,200 af in 1987 to 43,700 af in 1994 due to recovery of a depressed copper market in the mid 1980s. The level of mining activity fluctuates with the price of copper and technological advances as well as with other economic factors (ADWR, 1996).

Each step in mining copper requires different amounts of water, but the procedure of using water in copper processing is the same. It is first used in the milling process to produce a suspension of finely-crushed ore. Then, after the metal-bearing minerals are removed, the water is returned to the mill for reuse. Water is also recovered from tailing ponds, either via surface pumps or through interceptor wells beneath the ponds, and reused in the milling process. Large amounts of water are lost to evaporation and seepage in the process of tailing disposal.

3.4.2. Sand and Gravel

The use of water by sand and gravel operations has fluctuated from a low of 2,300 af in 1991 to a high of 4,500 af in 1994, representing between 3-8 percent of the industrial sector usage. Water is used to wash unconsolidated alluvial deposits after mining to remove fine grained particles. Water is also used to control dust, wash vehicles and equipment and to produce concrete, bricks, block and asphalt. The wash water is sent to disposal ponds where, after clarification, it is recycled back to the plant to wash more aggregate and to be used for other purposes. Figure 3.5 demonstrates the average water use by sand and gravel industries.

3.4.3. Turf-related Facilities

The water use by Turf-related facilities in the Tucson AMA has been fairly stable, with about 17,900 af used in 1987 and 18,500 af in 1993. In 1994, the total water use by major related facilities was about 19,000 af as shown in Table 3.9. There are 68 turf-related facilities in the Tucson AMA, including golf courses, parks, schools and cemeteries.

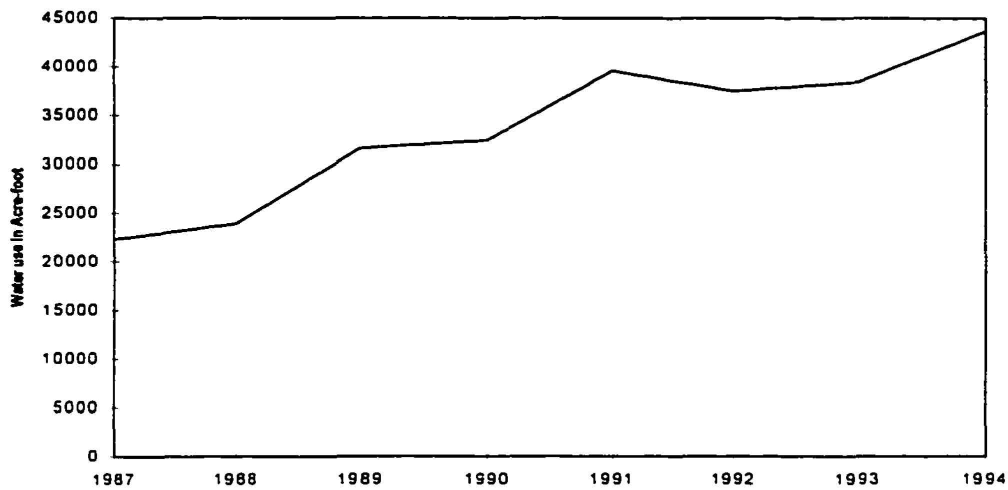

Figure 3.4. Metal Mining Water Use (Caporaso, 1997)

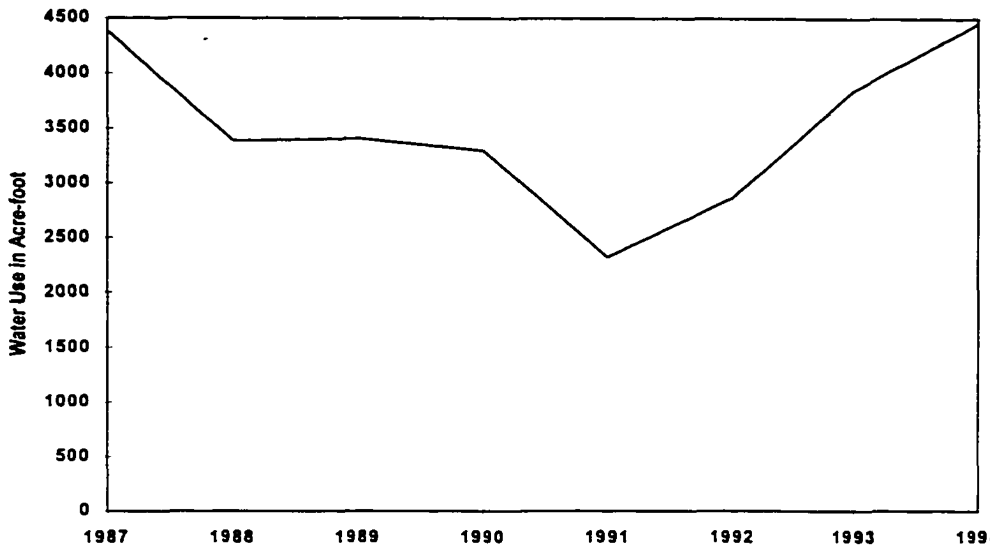

Figure 3.5. Sand and Gravel Water Use (Caporaso, 1997)

Table 3.9. Water Sources for Turf-Related Facilities in 1994

Type		Use	Source of Water		
	Facilities	**Turf Acre**	**Surface**	**GW**	**Effluent**
	Number	***Acre***	***Acre***	***Af***	***Af/acre***
Golf Course	29	3,115	94	9,394	5,335
Parks	25	608	47	1,368	1,102
Cemeteries	4	180	0	576	92
Schools	10	202	0	722	0
Total	**68**	**4,105**	**141**	**12,060**	**6,529**

Source: Adapted from ADWR-SAMA (1996)

3.5. Conclusion

This chapter indicates that the main driving force behind high water demand in the Tucson AMA has been the rapid increase in the population of the city of Tucson over the past three decades. As discussed earlier, between the 1940s and early 1980s, most of the groundwater withdrawal was used by agriculture. However, since 1985, agricultural water use has been declining, while municipal water use has been increasing. Presently, municipal use exceeds mining and agricultural usage combined, and is expected to continue increasing. The next three decades will experience similar increases in demand for water resources, due largely to the increasing affluence of the urban population relative to the availability of resources. From 1960 to 1995 the Tucson population increased from 260,000 to 750,000. It was one of the most rapid rates of urban growth in the entire nation. The Department of Economic Security expects the population of the Tucson AMA to reach 1.3 million by 2025 (ADWR, 1996).

Tucson AMA water resources will continue to be stressed due to the scarcity of water within the area, and will require better management if they are to keep up with water demand. From the three water resources, the supply of CAP water appears necessary in order to meet the expected growth in water demand.

Chapter 4: Water Law and Institutions in Tucson AMA

4.1. Introduction

In Arizona, there are a variety of statutes, regulations and policies at the federal, state, and local levels that contribute to the formation of current water rights and institutions in Arizona generally, and in the Tucson Active Management Area in particular. However, while federal and state laws are generally applicable to the entire state, local policies are only applicable to particular regions. Therefore, it is impossible to discuss the Tucson AMA's water rules without having a full understanding of state water laws.

Furthermore, in coming to any understanding of the present water rights and water institutions in the Tucson AMA, it is important to review the laws from a historical perspective. Before bringing water from Colorado River through CAP, the Tucson AMA was primarily dependent on groundwater. Furthermore, the value of groundwater in the Tucson AMA is more precious than in any other part of the state. This, coupled with the dramatic population and economic growth that has been taking place in the Tucson AMA as well as Native American water litigation, has sparked considerable debate about the constraints posed by limited groundwater resources. This has resulted in extensive litigation among the competing groundwater users in Tucson. This litigation has directly and indirectly contributed to the evolution of the Arizona Groundwater laws (Kyl, 1982).

The purpose of this chapter is first to give an account of the litigation involving the competing users in the Tucson basin that might have contributed to the enactment of the Groundwater Management Act (GMA). Second, it presents a brief description of the GMA and its Assured Water Supply Rule. Third, it describes the Consumer Protection Act of 1995 and its rule of groundwater recharge. Finally, it gives a brief description of the major institutions that governing water use and supply in Tucson.

4.2. Tucson and the Revamping of Groundwater Law[10]

Historically, groundwater was the sole water resource for the city of Tucson and the Tucson AMA. Until 1980, the right to use groundwater in Tucson AMA had fluctuated between English Common Law and the American "Reasonable Use" rule. Common law classifies groundwater as part of the soil, and the exclusive right to extract, regardless of the consequences to competing users, was assigned to the overlying property owner. The Reasonable Use rule states that groundwater can be used only for "reasonable" purposes on the overlying land, and cannot be exported from it.

The Reasonable Use rule dominated the rights of water use up to 1970s, when several factors emerged that indirectly contributed to the revamping of groundwater law in Arizona by 1980. These factors could be summed up as (1) the depletion of groundwater in central Arizona; (2) pressure from the federal government threatening to cut CAP's funding if there was no commitment to conserving water in Arizona; (3) the dramatic increase in population, particularly in Tucson (which was reported to be the

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[10] Unless otherwise stated, all material in this section derives from Kyle (1982); Connall (1982); and Doyle (1983).

largest city in the nation totally dependent upon groundwater); and (4) and a new lawsuit and claims by Arizona's Native Americans over their right to surface and groundwater resources. While to one degree or another these factors have pressured Arizona law makers to enact the new groundwater law, the conflict among groundwater users in the Tucson basin which resulted in a series of federal and state decisions, might have had the greatest impact on the evolution of Arizona groundwater law.

In the Upper Santa Cruz Valley in which the city of Tucson is located, groundwater pumpage increased from 160,000 acre-feet (af) in 1950 to 280,000 af in 1973, and in Avra Valley on the west side of the city of Tucson it increased from 41,000 af to 157,000 af within the same period. It was reported that this increase in groundwater pumpage was caused not only by the expansion of land used to grow irrigated cotton in the Tucson basin, but also by the expansion of the city of Tucson itself, which had grown by 40 percent (Saliba, et al, 1987). Tucson's population increased from 60,000 in the 1940s to 350,000 by 1970, resulting in water demand increases for municipal use purposes.

Since the majority of groundwater use in the basin in the 1940s was for the agricultural sector, to accommodate large water demand increases for the city of Tucson, the city's water authority started to search for additional water supplies in the Avra Valley as early as 1940 (Saliba et al, 1987). This search focused only on developing groundwater resources rather than on surface water. In 1968, the city of Tucson began drilling several wells in the Avra and Altar Valleys west of the city. The city proposed to pump up to 30,000 af per year and transport it to the metropolitan area.

However, since the wells lie in a critical groundwater area as designated under the 1948 code, plaintiff Jarvis and other irrigating farmers in the valleys petitioned for enjoining the State Land Department from allowing the city to transport groundwater through a pipeline over state lands. The State Supreme Court issued an injunction preventing Tucson from doing so despite the fact that the city had incurred almost $3 million in project costs. In Jarvis II, however, the court relaxed its earlier stand and allowed the Tucson water authority to deliver water to Tucson, provided the city purchased and retired irrigated land. The city was allowed to withdraw the amount of water equal to the historical annual wells' maximums. Later, the court defined the amount that could be transferred as the consumptive use prior to retirement.

While the Jarvis case was being decided west of Tucson, another case was emerging south of Tucson, in the Santa Cruz Valley basin, where the Farmers Investment Company (FICO) and copper mining companies were located. The FICO owned and irrigated 5,000 acres of pecan orchards in a designated critical groundwater area, and there are also rich ore deposits mined by four separate companies, including Anamax. After Anamax acquired wells very close to FICO's wells, FICO petitioned the Arizona Supreme Court to enjoin Anamax from pumping and transporting water four miles away because it damaged FICO's own wells. The ASC enjoined Anamax from pumping and transporting groundwater away from where the wells were located. Anamax responded to this by assuring that the water it pumped would be used on the land from which it was withdrawn.

At the same time, the city of Tucson intervened, claiming FICO and Anamax were polluting the water that Tucson depended upon for domestic use. Anamax counterclaimed, using the same reasoning that FICO had used against them, that the city should be enjoined from pumping water for transportation away from the area. The ASC enjoined both Anamax and the city of Tucson from transporting water. This decision was in favor of FICO, and it shocked both the city and the mining companies. Such a rule threatened the existence of the mining industry in Tucson, and the city's ability to meet a growing urban water demand. In response to this threat, an informal political alliance between the cities and the mines was created to formulate a new law that would allow groundwater transportation within the same basin.

After this case, FICO did not pursue the matter further, perhaps it thought that any such further action would probably result in the closing down of the Anamax mine which would have left 6,000 workers unemployed. Later, FICO participated in a negotiated effort to allow the mines and cities to continue moving groundwater, partly because some irrigation districts and large farms were moving groundwater too. This coalition among the major water users in the Tucson basin led the Arizona legislature to realize that the strict existing laws preventing the transfer of groundwater were jeopardizing the economy and well-being of the people of the state, and preventing certain necessary distributions of Arizona's groundwater resources. This resulted in the amendment to the 1977

Groundwater Transfer Act (GTA), a temporary measure to allow groundwater to be used away from land from which it was drawn. A more significant provision in the GTA for future development was the creation of the Groundwater Management Study Commission (GMSC) to study Arizona's water problem and to draft a comprehensive groundwater law. This act, together with the 1948 groundwater code, led ultimately to adoption of the 1980 Groundwater Management Act (GMA).

4.3. The 1980 Groundwater Management Act

The GMA has three major goals: The first of these is to control the severe groundwater overdraft occurring in many parts of the state. The second goal is to provide means to allocate the state's limited groundwater resources to most effectively meet the needs of the state. The third goal is to augment Arizona's groundwater through water supply development. To accomplish these major goals, the GMA set up four comprehensive management frameworks by: (1) creating several management areas; (2) setting an ultimate management goal for each area by 2025; (3) establishing a new water institution, the Arizona Department of Water Resources (ADWR); and (4) directing ADWR to establish a five-tiered management planning process over a 45-year period (1980-2025).

4.3.1. Management Areas

Since groundwater pumping varies from one basin to another within the state of Arizona, the GMA divides the state's surface area into several management areas based on groundwater basins and sub-basins rather than on the political lines of cities, towns or counties. These areas are shown in Figure 1.1. The major criteria for creating management areas are: (1) the rate of groundwater pumping and (2) the economic activities in that particular area. Since groundwater depletion is most severe in the major areas of Phoenix, Pinal, Pima and Santa Cruz counties, and in the town of Prescott, the GMA created four Active Management Areas (AMAs) in 1980, which are known as the Phoenix, Tucson, Pinal and Prescott AMAs. In 1994, a fifth, the Santa Cruz AMA, was formed from a portion of the Tucson AMA. These AMAs include 80 percent of the state's population and three major urban areas. In addition, 60 percent of the State's irrigated acreage is located in the Phoenix, Pinal, and Tucson AMAs (ADWR,1994).

In the rural farming areas, the groundwater overdraft is still a problem, but is less severe than in the AMAs. The GMA defined these areas as Non-Expansion Irrigation Areas (INAs). In 1980, the GMA created two INAs, including Douglas and Joseph City. In 1982, the Harquahala INA was established.

The purpose of creating management areas is to manage water resources objectively in order to achieve sustainability. This does not mean that water resources management in the rest of the areas of the state will be less supervised. The resources will be managed closely, and ADWR reserves the right to designate new AMAs and INAs if necessary to protect the water supply, or on the basis of an election held by local residents of an area.

4.3.2. Management Goals

As mentioned above, the creation of management areas was based on the rate of groundwater pumping and economic activities. Therefore the GMA established different management goals for the AMAs and INAs based on their groundwater conditions. In the AMAs where the magnitude of the overdraft is more severe, they are subject to a high level of management regulation. However, such high management regulation may be more progressive in one AMA and less progressive in other areas. In the Phoenix, Prescott, and Tucson AMAs, where major urban areas are located, the primary management goal is to achieve safe-yield status by the year 2025. "Safe-yield" (SY) is defined as a long-term balance between the annual amount of groundwater withdrawn from the AMA and the annual amount of natural and artificial recharge.

However, in the Pinal AMA, where a predominantly agricultural economy exists, the goal is not to achieve safe-yield, but rather to allow the development of non-irrigation water uses, extend the life of the agricultural economy for as long as it is feasible, and preserve water supplies for future non-agricultural uses. In the Santa Cruz AMA, where significant riparian and groundwater/surface water issues exist, the goal is to maintain SY, but also to prevent local water tables from experiencing long term declines. Each AMA carries out its programs in a manner consistent with the overall goals, while considering and incorporating in its processes the unique character of each AMA and its water users.

The groundwater management for INAs is less regulated, and it is even less for the other areas of the state. The purpose of creating INAs is to prevent any further expansion of irrigation acreage in those areas due to the possibility of groundwater depletion. Therefore, their management goal is to continue pumping groundwater for irrigation and to report the amount of groundwater pumped on an annual basis.

4.3.3. Water Institutions

In order to administer water resources and to ensure dependable long-term water supplies for Arizona's growing communities, the GMA established the Arizona Department of Water Resources (ADWR) in 1980. The ADWR administers state water laws (except those related to water quality), explores methods of augmenting water supplies to meet future demands, and works to develop public policies that promote conservation and equitable distribution of water. The ADWR oversees the use of surface and groundwater resources under state jurisdiction and negotiates with external political entities to protect and augment Arizona's water supply.

4.3.4. Water Management Plans

In order for the ADWR to manage groundwater resources in ways that lead to the achievement of SY goal in the AMAs, the GMA delineated five key provisions: (1) establishing new groundwater rights and permits; (2) creating progressive conservation strategies; (3) enforcing management policy; (4) requiring a demonstration of an assured water supply for any new growth; and (5) encouraging groundwater augmentation.

4.3.4.1. The Scope of the GMA Rights System

Historically, the right to groundwater use is the most complicated issue in Arizona's groundwater management. Since 1906, it has been considered as the backbone of the water problem in Arizona. George Smith, head of the department of Agricultural Engineering at the University of Arizona in 1937, became convinced after conducting several studies in the northern Tucson basin, that there was a need for an institutional change in the property right of groundwater usage. Smith recommended adoption of a property right that was more adapted to a desert climate as a necessary first step for restraining groundwater overdraft (Dunbar, 1977, P.5).

The right to withdraw groundwater assigned by the GMA is generally based on the higher value of water use. While the industry, mining and cities have more access rights to water than the agricultural sector, the right of cities to use water takes precedence over all other uses. Basically, the agricultural and industrial sectors that had existed before 1980 were given a *Grandfathered right,* in which the right to use water was based on the average of groundwater usage between 1975 and 1980. Municipal users within the cities, towns, and even irrigation districts have been granted the *service areas right,* in which they have the absolute right to withdraw as much water as they need. Generally, all of the sectors in the AMAs have been allowed to continue using groundwater at the same rate as during 1980.

However, since the GMA was the product of reconciliation and compromise among these three sectors, each of which had its own interest in using groundwater, an extra *permit right* was issued to industrial users. Therefore there are a total of four methods of acquiring groundwater rights in the AMAs, including the use of common law. While the GMA was created to govern groundwater use only in the AMAs, it did not alter the common law method of acquiring the rights of groundwater use in the areas lying outside the AMAs. The rule of common law, that groundwater becomes the property of the overlying landowner, is still effective outside the AMAs.

4.3.4.1.1. Grandfathered Rights

The Grandfathered Rights are divided into Irrigation Grandfathered Rights (IGR) and Non-irrigation Grandfathered Rights (NGR). The IGR are appurtenant to the land for which the right is granted. While the agricultural users have a vested right of groundwater usage, the amount of groundwater usage is limited by three measures: The first of these is that since irrigation of new (non-Native American) acreage is prohibited, the highest number of acres that were actually irrigated during any year between 1975 and 1979 are the ones which are going to be issued a certificate of irrigation grandfathered rights. Second, for each irrigation acre, a *water duty acre* is assigned for them, which is the actual water use per acre or the water requirement per acre. And, finally the third measure is that an *irrigation water duty* is assigned that could be expressed in acre-feet per acre. This is the reasonable amount of water to apply in the annual irrigation of crops historically grown on a particular farm.

The irrigation water duty can be calculated by dividing the water duty per acre by the *target efficiency* to get the *Irrigation water duty.* The *target irrigation efficiency* is a conservation method figured out by ADWR for each region, and it is expressed in a percentage number. After finding the *Irrigation water duty*, the maximum annual groundwater allotment can then be calculated by multiplying the *Irrigation water duty* by the *Water duty acres*.

While the GMA limits water use for agriculture by the previous methodology, it gives the farmers a *flexibility credit option* to utilize the maximum amount of their annual water allotment at any time. This policy permits the farmers to borrow or bank groundwater from year to year to allow for varying climatic and agricultural market conditions. It is the difference between the actual water use and the water duty assigned to farmers. For example, if in one year a farmer withdrew less than the irrigation water duty, the remaining amount can be withdrawn in the following years, or if he/she withdraws in excess of the irrigation water duty, the amount of groundwater which may withdraw in later years is reduced.

The Non-Irrigation Grandfathered Right consists of Type-1 and Type-II rights. Type-1 is the right to withdraw three acre feet of water per acre per year when a farmer retires irrigated land for non-irrigation purposes. The Type-II right is the amount of water assigned to non-irrigation users, such as industry and municipal users. The amount of Type-II water rights is usually exceeded by the amount of Type-1 water rights.

4.3.4.1.2. Service Area Right

The Service Area Right is given to the cities, towns, private water companies and irrigation districts to withdraw as much groundwater as is needed from within their service areas. But this right is limited. First, the groundwater use is subject to the conservation requirement. Second, the service area for the cities cannot be extended for the purposes of (1) including a well field; (2) serving a disproportionately large user, unless approved by the director; (3) including irrigated land in the service areas in order to extinguish the right to convey that land for a non-irrigation use; or (4), providing irrigation water service. Further, the grandfathered rights for the irrigation districts are limited to their usage as of January 1,1977, in which they could (1) pump from within their service areas as much as necessary to satisfy the irrigation grandfathered rights for member lands; (2) contract for CAP water or effluent; or (3), continue, but not expand, non-irrigation water service within the district.

4.3.4.1.3. Permits Right

The Permits Right is basically a water allowance given to the industrial sectors because of their contribution to the Arizona economy. Since either the shortage of groundwater or water quality problems could hinder industrial processes, the permits rights give the industrial sectors the flexibility to acquire groundwater in excess of their grandfathered rights for emergency purposes. There are seven types of groundwater withdrawal permits: (1) dewatering permits; (2) mineral extraction and metallurgical processing permits; (3) general industrial use permits; (4) poor quality groundwater permits; (5) temporary permits for dewatering or for electric power generation; (6) drainage water withdrawal permits; and (7) hydrologic testing permits.

4.3.4.2. Conservation Strategies

Since AMAs include about 80 percent of the state's population and over 60 percent of the irrigated acreage, the GMA directs ADWR to develop and implement water conservation requirements for agricultural, municipal and industrial water users in a five-tiered management planning process over a 45-year period as follows:

First Management Period: 1980 - 1990
Second Management Period: 1990 - 2000
Third Management Period: 2000 - 2010
Fourth Management Period: 2010 - 2020
Fifth Management Period: 2020 - 2025

The management plans were based on projections of higher irrigation efficiencies for farmers and lower per capita water use for cities. With each consecutive period, the management plans will contain more stringent water regulation. For example, in the 1980-1990 First Management Plan (FMP), the goal was to register groundwater rights and calculate water duties for agricultural users, which represents a conservation standard that is a compromise between a probation reduction schedule and compensated land retirement. Under each successive plan, irrigation water duties will be reduced. Industrial users will be required to use the best available technology to conserve water supplies. Residential users will be subjected to a per capita reduction. The Second Management Plan (SMP) for the period 1990-2000 was designed to delineate a conservation program that reflects "prudent long-term" farm management practices within areas of similar farming conditions, considering the time required to amortize conservation investment and farming costs.

4.3.4.3. Policy Enforcement

To enforce the regulations, violations of any management plan requirement are against the law and subject to a fine. The GMA grants ADWR the right to enforce the regulations and punish any violations of GMA's provisions, primarily to support the groundwater management goals. The enforcement rules require groundwater right holders who pump groundwater from non-exempt wells in an AMA to measure those withdrawals using an approved measuring device or method and report annual pumpage to ADWR. This provision helps ADWR determine how much water is being used and where it is being used.

The GMA also requires payment of an annual groundwater withdrawal fee. The fee is used to offset the cost of managing this resource. Revenues from the fee pay for half of the cost of administering the GMA; the other half comes from Arizona's general fund. Withdrawal fees may also be used for conservation assistance, augmentation projects, and retirement of irrigated land.

4.3.4.4. Assured Water Supply

The 1980 GMA created the program of Assured Water Supply (AWS) requiring that all new subdivisions within Active Management Areas demonstrate the availability of an AWS. It was established to ensure that water supplies are adequate to meet the long-term needs of new development. The AWS requires new subdivisions within the

AMAs to demonstrate that sufficient water supplies of adequate quality are physically, continuously, and legally available for 100 years.

For any new development, a water supply sufficient for 100 years can be demonstrated two ways: (1) obtaining a Certificate of Assured Water Supply for a given development, or (2) the developer may locate the proposed development within the service area of a city, town, or private water company that has already received a Designation of Assured Water Supply from ADWR. New rules associated with this program promote the use of renewable supplies, such as effluent and water delivered via the Central Arizona Project, as components of an assured supply.

Most providers in the Tucson AMA are deemed to have an AWS, especially if they have a CAP contract. After 2001, however, they will have to demonstrate that they will continue to have adequate water. The ADWR implements the program and evaluates each AWS application based on three criteria required by state law: (1) the water must be physically and legally available for 100 years, (2) it must be of adequate quality for the proposed use, and (3) the use of water must be consistent with the management goals of the AMA and the management plan of the AMA.

Generally, for areas outside AMAs, the Adequate Water Supply Program requires that a potential buyer be informed of the water status of the property, but does not prevent the sale of property when a 100-year supply is not available. Requirements under these programs serve to protect consumers against the sale of subdivided land that lacks an available long-term source of water.

4.3.4.4.1. The Rule of AWS in the Tucson AMA

Under the conditions of AWS, TWD is currently deemed to have an assured water supply until 1998 because it has signed a subcontract for CAP water. After 1998, TWD must demonstrate to ADWR that it has an assured water supply for at least 100 years. In general, the total volume of groundwater supply that the TWD has the right to pump is 5 million acres feet (maf). This includes 2 maf in the Avra Valley as credit, 1.6 maf as mined groundwater, and 1.4 maf from other sources as shown in Table 4.1.

Table 4.1. AWS Groundwater Supplies for Tucson Water Department

Supply Source	Formula	Estimated Acre-feet
Avra Valley Water Right	Extinguishment	2,000,000
Mined Ground Water Allocation	15 multiply by 1994 total Water Demand	1,660,000
Incidental Recharge	4 percent of annual demand	810,000
TARP ((Treated Water)	9,500 af/yr	190,000
Other credits	Exchange programs	50,000
Total		5,055,000

Source: Duston, Karen. TWD planing department, 1997

With this amount of groundwater supply, as augmented by CAP water and reclaimed water resources, the TWD has been designated as having an AWS for the next 100-year period. However, based on population projections prepared by the Arizona Department of Water Resources (ADWR), the projected total water demand for the 100-years is more than 20 maf. This indicates that if the TWD continues groundwater pumping without utilizing other sources, it will run out of its groundwater stock within the next three decades, and therefore, would not meet the AWS rule.

To avoid violating AWS, the TWD would need to either utilize all its allocation of CAP water or join the Central Arizona Groundwater Replenishment District (CAGRD). The CAGRD is an authority established by Arizona legislature to recharge CAP water within AMAs. Since it is required for any water provider to have an AWS, the AWS could be obtained by either having a CAP water contract through Central Arizona Conservation Water District (CACWD) or applying to CAGRD which will issue the water provider a credit to use groundwater. However, CAGRD needs to recharge an equivalent amount of CAP water within the designated area of the applicants.

4.3.4.5. Recharge Programs[1]

The 1980 GMA regulation allows injection of surface water or treated wastewater into an aquifer for storage. Through recharge programs, surplus renewable water supplies can be stored for use in the future. "In 1986 the Arizona Legislature established the first program to allow storage of renewable water underground and recovery at a later time. During the next few years, the Legislature added several other programs related to underground water storage programs. In 1994 these various programs were consolidated into a unified program by passage of the Underground Water Storage, Savings, and Replenishment Act (UWS), administered by the ADWR.

The UWS program has two sets of goals. The first set of goals encourage the use of renewable water supplies to satisfy existing needs, to allow for effective and flexible

[1] Unless otherwise referenced, all material in this section derives from an article written by Cindy shimokusus of Tucson Office of ADWR, published in WATERWORDS newsletter (SAWARA, 1997)

storage of renewable water supplies not currently needed, and to preserve non-renewable groundwater supplies. The UWS program, consistent with the Arizona Groundwater Management Act of 1980, encourages the direct use of renewable water over the use of non-renewable groundwater. Renewable water is generally surface water that comes from precipitation and municipal effluent. In contrast, non-renewable groundwater is relatively finite and is supplied slowly, if at all.

The second set of goals facilitates the efficient and cost-effective management of water supplies by allowing storage of water in one location and recovery in a different location. Therefore, water may be stored near its source (such as the CAP canal) and recovered where it is needed (a wellfield, for example). Although the UWS program contains some restrictions to this "transportation" of water, the program may be used to legally deliver water to a user without the expensive construction of canals and pipelines that physically convey the water." (Shimokusu, 1997).

In 1996, the Arizona legislature created the Arizona Water Banking Authority, a twenty-year state sponsored recharge program. By storing surplus Colorado River water in central and southern Arizona, the Authority will help safeguard against future shortages on the Colorado River and assist in meeting the state's groundwater management goals.

4.3.4.5.1. Arizona Water Banking Authority

"The Arizona Water Banking Authority (AWBA) was created with the intention of storing unused portions of Arizona's Colorado River allocation to meet future needs by: 1) assuring an adequate supply to municipal and industrial users in times of shortages or disruptions of the CAP system; 2) meeting the management plan objectives of the GMA; 3) assisting in the settlement of Indian water rights claims; and 4) exchanging water to assist Colorado River communities.

The AWBA had approximately $9.4 million in calendar year 1997 to spend on recharge. The revenues were generated from groundwater pump taxes collected in the Phoenix, Pinal and Tucson Active Management Areas from a four-cent property tax collected in Maricopa, Pinal and Pima counties and from an annual appropriation from the State's general fund. Earlier in 1997 the AWBA developed a storage facility inventory for each AMA that found that existing facilities were inadequate in the Tucson area to meet its needs. Therefore, the AWBA is developing a plan for additional storage facilities. The Regional Recharge Planning Process was initiated in 1995 by the Tucson Office of ADWR with support from the Groundwater Users Advisory Council. The goal of this collaborative, on-going effort is to develop a coordinated approach to recharge activities in the area.

The planning process is addressing needs identified by area water users including 100-year assured water supply demonstrations, reliability of CAP deliveries, and increasing the use of renewable water supplies, principally CAP water. Cooperative planning is expected to enhance the region's ability to take advantage of incentives, secure outside support, and improve the cost-effectiveness of regional recharge projects. The AWBA is basing its facilities plan on the information produced by this planning process. The Regional Recharge Plan was expected to be finalized by the end of 1997." (Shimokusu, 1997).

4.3.4.5.2. Recharge Methods

"The UWS program recognizes two general categories of recharge facilities: Groundwater Saving Facilities (GSF) and Under-ground Storage facilities (UGF). The GSF also called "in-lieu" recharge projects, is an entity with an excess supply of renewable water (such as a water provider) that delivers this water to a facility (such as a farm) that would otherwise have pumped groundwater. The recipient then uses the renewable water in lieu of groundwater. The supplier of the renewable water then earns credits to recover this water at a later date from any place within the Tucson AMA that meets the requirement set by ADWR."(Shimokusu, 1997). There are three GSF in Tucson AMA: (1) the Cortaro Marana Irrigation District, (2) the BKW Farms, and (3) the Picacho Farms.

The aim of Under-ground Storage Facilities (USF) is to add water physically to an aquifer by a number of different means. There are four facilities in the Tucson AMA that will be used for under-ground storage. These include: (1) Tucson Water's Sweetwater site, (2) The Avra Valley Airport Pilot site, (3) The Pima Mine Road site, and (4) Tucson Water's Central Avra Valley Storage and Recovery Project Pilot sites (Shimokusu, 1997).

There are other projects which may be used as future GSF. These are currently being reviewed by the ADWR. These include: (1) The Lower Santa Cruz Recharge Project, (2) The High Plains site, and (3) The Avra Valley Irrigation District.

4.3.4.5.3. The Future Recharge in Tucson AMA

"Recharge is increasingly becoming a key component of groundwater management in the Tucson AMA. The regional recharge planning process has estimated that by the year 2007, the Tucson AMA will have a demand for recharge capacity of 75,000 to 250,000 acre-feet. The current capacity of permitted long-term projects is 36,530 acre-feet. If the existing pilot projects go to full scale and the Lower Santa Cruz Recharge Project is permitted, an additional 97,000 acre-feet of capacity will become available. Therefore, depending upon the actual recharge demand of area water providers and the AWBA, additional capacity may be needed within the next 10 years." (Shimokusu, 1997).

4.4. Consumer Protection Act

The Consumer Protection Act (better known as Proposition 200) was passed in 1995, and emphasizes the utilization of groundwater for drinking purposes and CAP water for replenishing the Tucson aquifer through recharge. The Act was a response to a water quality problem created by the direct delivery of CAP water through the TWD's potable water delivery system. The Act was introduced as a citizen initiative, after sufficient signatures had been submitted to place the Act on the November, 1995 General Election ballot, where it was approved by the voters.

The primary objective of the Act is to preclude the use of CAP water for potable purposes unless it is treated to the same quality as Avra Valley groundwater for hardness, salinity and dissolved organic material. In order to achieve this water quality, advanced treatment is required. This is very expensive and has never been applied on a large scale, so CAP water cannot be used for potable purposes at least until 2001. However, the Act encourages the use of CAP water through (1) sale or exchange with agriculture, mines and other industries; (2) recharge through basins and in stream beds of the Tucson AMA; and (3) replenishment of the Central Wellfield through recharge to replace the dramatic decline of the groundwater table in this area.

Since the major aim of this dissertation is to evaluate the economic value of groundwater recharge in the Tucson AMA, the following section will describe the second and third objectives of the CPA.

4.4.1. Provision to Augment Tucson's Groundwater Supply

The purpose of this provision is to mitigate potential subsidence and to replenish the groundwater supply. Utilizing CAP water to augment Tucson's aquifer has been considered for the last two decades, because land subsidence can be caused by further excessive pumpage in the city of Tucson, as found by Hanson (1994). Historically, 60 percent of Tucson Water's current withdrawals occur within the Central Wellfield (CWF). Due to massive groundwater pumping from the CWF, water tables have dropped up to 250 feet, and it is therefore necessary to recharge 60,000 to 70,000 af per year in this wellfield. The CPA require that about 300,000 af be recharged by 2001. At present, the capability to recharge such large volumes of CAP water in the CWF does not exist.

4.5. Institutions Governing Water Supply and Use

In the Tucson AMA there are two branches of the state government and several other local water institutions that have direct and indirect involvement in managing CAP water use. The branches of the state government in the Tucson AMA that are involved with CAP water includes the Arizona Department of Water Resources (ADWR), which is the most important branch for allocating water and managing water resources in the Tucson AMA. Also, there are several state agencies designated to implement federal projects and legislation, the most important of these being the Central Arizona Water Conservation District, created in 1972 to supervise the water that comes from the Central Arizona Project. In addition, there are federal agencies, such as the Bureau of Land Management, U.S. Forest Service, the National Park Service, and the Bureau of Indian Affairs. Collectively, these agencies manage water on Native American Reservations, national parks, and military bases.

In the Tucson AMA, in addition to the state and federal agencies, there are local water organizations such as the Tucson Water Department (TWD) which is a public utility, and several public corporations that provide water for either irrigation or for municipal purposes. The main objective of both the public utility and corporate entities is to obtain and distribute water to service-area members. The purpose of this section is to describe the legal authority of the state agencies and local water agencies in the Tucson AMA that have some responsibility for to the management of CAP water.

4.5.1. State Agencies

4.5.1.1. Arizona Department of Water Resources[12]

In Arizona, water is a public resource whose use is regulated by state law. ADWR is the state agency designated to implement all state water legislation. It was created in 1980 by the GMA. The ADWR has the authority, powers, duties and responsibilities of the Arizona Water Commission and the state water engineer relating to surface water, groundwater, dams, and reservoirs. The main purposes of the ADWR are: (1) to manage and administer water related programs within the state; (2) to stabilize the use of groundwater according to management practices, procedures, standards, and plans; and (3) to compile and maintain information necessary for the intelligent management, administration, and planning for water resources and programs.

Institutional power for managing water resources in Arizona is most heavily vested in the Director of the ADWR according to the GMA. The authority of the ADWR is administered through the director who is granted the general control and supervision of surface water, its appropriation and distribution, and of groundwater to the extent provided in the power and duties of director in the Arizona Revised Statues (Title 45-105). The director has the power to create new Active Management Areas if s/he finds a

[12] The description of ADWR is taken from Arizona Revised Statutes 45-103, 105, and 107.

shortage in meeting future water needs, land subsidence, or the use of groundwater resulting in water quality degradation. The director is appointed by the governor and is approved by the state legislature.

4.5.1.2. Central Arizona Water Conservation District

Generally, CAP water is considered to be the second source for the Tucson AMA. While CAP water is important to alleviate groundwater depletion, it is extremely important since it is one of the primary sources of water supplies to be used in the Native American settlement. Therefore, it is necessary to describe the water agency that oversees the allocation of CAP water among water users within the Tucson AMA.

At the national level, the U. S. Bureau of Reclamation (BR) is the primarily federal agency that manages the water that comes from federal projects such as the Central Arizona Project. The federal reclamation policy requires the receiver states of federal projects to be represented by an entity with the legal and fiscal capability to contract with the federal government for repayment of capital costs, to repay operation and maintenance costs, to operate the project, and to contract with water users to collect repayment charges. This requirement could be fulfilled with quasi-government entities that levy taxes, issue bonds, and contract with the federal government.

Given the fact that CAP is one of the nine projects built by the federal government in Arizona, the Arizona legislature in July 1971 created the Central Arizona Water Conservation District (CAWCD) pursuant to the federal Central Arizona Project Act (1968) for the purposes of contracting the delivery of CAP water and arranging repayment of assigned costs. The CAWCD is not actually a state agency, but it could be described as a multi-county district, since it operates and maintains the CAP physical plant, which only serves Maricopa, Pinal and Pima counties.

The main duties of the CAWCD are to contract with water users for CAP water and to collect payment. It has the authority to levy property taxes in its three member counties (Maricopa, Pinal, and Pima) up to the rate of 10 cents per $100 assessed valuation to meet its obligations. It also has the authority to establish and cause to be collected charges for water consistent with federal reclamation law and contracts entered into between the district, and to then cooperate and contract with the United States Secretary of the Interior to carry out the provisions of the Reclamation Act of June 17, 1902, and acts amendatory thereof or supplementary thereto, including the Colorado River basin project act.

The CAWCD works as follows: the federal government sells water to the CAWCD, and the CAWCD in turn sells water to irrigation districts, mines, cities, and other large users. The City of Tucson's role with the CAWCD is simply to either contract or not to contract for CAP water. If the city buys CAP water, it provides the CAWCD with a delivery schedule, and makes a payment on June 1 and December 1 of each year.

4.5.2. Local Water Agencies

In the Tucson AMA, there is only one organization that is considered as a pure public entity for providing water for municipal purposes. This is the Tucson Water

Department (TWD). However, there are four other incorporated water districts within Tucson AMA. Two provide water for municipal uses which are Metro Water District and Flowing Wells District. The other two that provide for irrigation purposes are Cortaro-Marana Irrigation District and Avra Valley Irrigation District. These four have been classified by the Arizona Revised Statues (1994) as public water providers even if they have been formed by private users and suppliers. According to the American Water Works Association, publicly owned water utilities are not operated for a profit, but rather attempt only to cover the total annual operating requirements' costs. The level of annual revenue requirements of a municipal water utility provides the basis for determining water rates. Since this study is concerned with groundwater recharge by CAP water, this section will only describe the TWD, which it is largest water provider.

4.5.2.1. Tucson Water Department

The Tucson Water Department (TWD) is a public municipal provider. It is the major water suppliers in the Tucson AMA and serves about 78 percent of the Tucson AMA's population. It is operated and maintained as a self-supporting municipally owned utility. Although it is organized as a department of the city, it is operated in a manner similar to private business enterprises. It is financed primarily by user charges and has a fund structure separate from other city accounts.

The TWD's authority and responsibility is derived from the Tucson City code. To assist with the task of operating an enterprise water system, the Mayor and Council have adopted water service policies recommended by the Citizen's Water Advisory committee. The TWD has an intergovernmental agreement with the Pima County regarding the treatment and the use of effluent. The City of Tucson has the right to use 90 percent of the effluent produced in the Tucson AMA by Pima county facilities under the 1979 Intergovernmental Agreement (City of Tucson, Resolution No. 10860, 1978). Pima County has the right to the remaining 10 percent of the effluent produced.

4.6. Conclusion

This chapter has shown that Arizona generally and the city of Tucson particularly has experienced dramatic changes in the policies that affect and the institutions that govern their water use over the last four decades. There are three significant changes in the state of Arizona: (1) the enactment of Groundwater Management Act of 1980 (GMA), (2) the establishment of a new water state agency (Arizona Department of Water Resources, (3) the construction of Central Arizona Project. At the Tucson Basin level, two of the most significant changes are: (1) the arrival of CAP water to Tucson and (2) the enactment of Consumer Protection Act of 1995 (CPA), prohibiting the use of CAP water for potable purposes.

Chapter 5: Research Methodology

5.1. Introduction

The enactment of the Consumer Protection Act (CPA) in late 1995 precluded the use of CAP water directly through injection wells unless it was treated using advanced treatment technologies and free of disinfection by-products. The CPA recommended basin and streambed recharge instead.

The aim of this chapter is to: (1) give a brief description of the proposed basin and stream-bed recharge schemes and the alternatives that are being considered for development within and outside the CWF; (2) describe four scenarios that have been designed to measure and compare the costs and benefits of each recharging scenario; and (3) describe the methods that are used to measure the costs and benefits with and without recharge in the Tucson AMA.

5.1.1. Basin and Streambed Recharge

In compliance with the CPA, TWD proposed three recharge schemes[13] utilizing CAP water: (1) recharging it within the Central Avra Valley (CAV scheme); (2) recharging it within the CWF area through a Reclaimed Water System (RWS scheme); and (3) a combination of recharging CAP within the CWF and near the Davis-Monthan Air Force Base (DMAFB scheme). One of the TWD's main goals in any recharging scheme is minimizing the construction costs of recharging facilities and maximizing the utilization of the existing potable and reclaimed water distribution system. Altogether, the TWD considered five alternatives for

[13] The basic data for the recharge schemes were obtained from the Tucson Water Department (TWD), *Assessment of CAP Water Recharge Alternatives*: City of Tucson, March, 1996.

delivering CAP water from the CAP canal to the recharge sites, as indicated in Table 5.1 and Figure 5.1.

Table 5.1. CAP water Recharge Schemes and Alternative

Recharge schemes	Annual CAP Use (af)	Alternatives	Length of pipeline (miles)	Recharge Basin (acres)	Recharge Within CWF (af)	Recharge Outside CWF (af)
CAV	60,000	CAV	2	660	0	60,000
RWS	30,000	Tangerine	14.1		17,000	0
		HUTP	0		17,000	0
DMAFB	60,000	Terminus	53	375	26,000	34,000
		Technical Dr.	40	375	26,000	34,000

Source : Data obtained from TWD(1996)

As shown in Table 5.1. and Figure 5.1, for the CAV scheme, there is only one alternative for delivering CAP water from the CAP canal to the recharge site. In the RWS scheme, there are two alternatives; one, to deliver untreated CAP water from the CAP canal at Tangerine Road to the RWS, and two, to deliver treated CAP water from the Hayden-Udall Treatment Plant (HUTP) to the RWS.

For the DMAFB scheme there are two alternatives: the first alternative would deliver CAP water from the CAP Terminus at Pima Mine Road to a recharge basin at DMAFB, and to construct pipelines to deliver 26,000[14] af of CAP water to be recharged along the Pantano, Tanque Verde and Rillito Washes, with the rest to be recharged within the recharge basin of DMAFB. The second alternative is to deliver CAP water from Technical Drive Reservoir to a recharge basin at DMAFB, and then construct a pipeline

[14] This is the maximum amount of annual recharge capacity along a favorable stream-channel in CWF. The favorability of recharge was identified by (1) the long-term infiltration rate, (2) the distances from known landfills and areas of groundwater contamination.

to recharge CAP water along the Upper Pantano Wash Reach. In addition, this plan would also require the construction of two pipelines to deliver CAP water from Technical Drive to the Tanque Verde and Rillito Washes.

5. 2. Description of the proposed recharge schemes

5.2.1. Central Avra Valley (CAV)

The CAV scheme was initially designed to recharge and recover a volume of CAP water equal to the current annual groundwater withdrawal from the CWF within the Tucson basin. The current groundwater pumpage from the CWF is 60,000 af per year. To recharge and recover 60,000 af/yr in the CAV would require the leveling of a recharge site and the construction of at least 25 specially designed production wells, one pump station, and two main transmission lines: one transmission line to convey CAP water from the CAP canal to a recharge site, and approximately 11.5 miles of transmission lines to transport recovered CAP water from the CAV to the potable water reservoir at the Snyder Hill Pumping Plant. The recovered CAP water would then be piped through the pumping plant to the Clearwell Reservoir, and then delivered by gravity to the City's potable distribution system through existing main transmission lines (see Figure 5.2.)

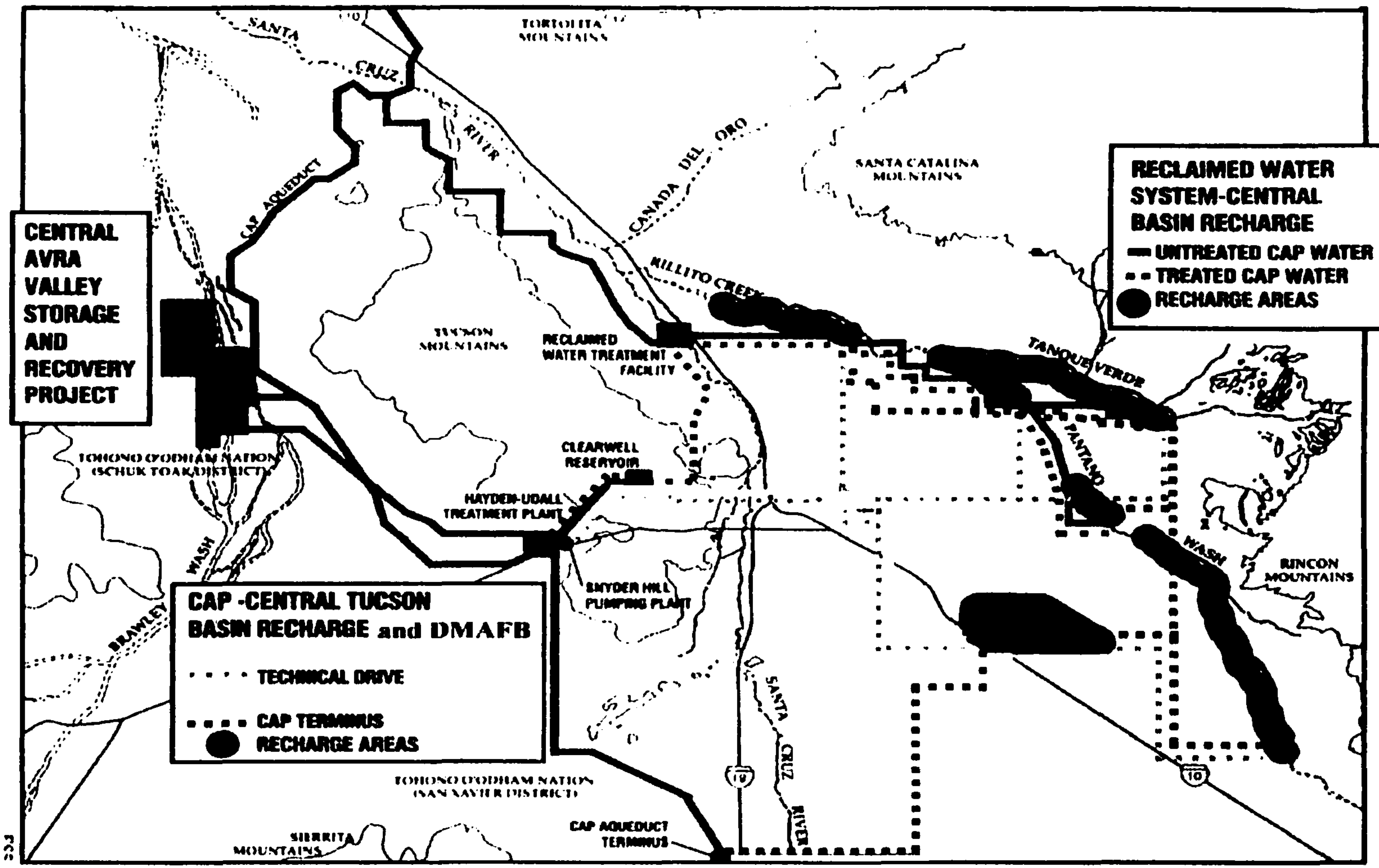

Figure 5.1. CAP water Recharge Alternatives (TWD, 1996)

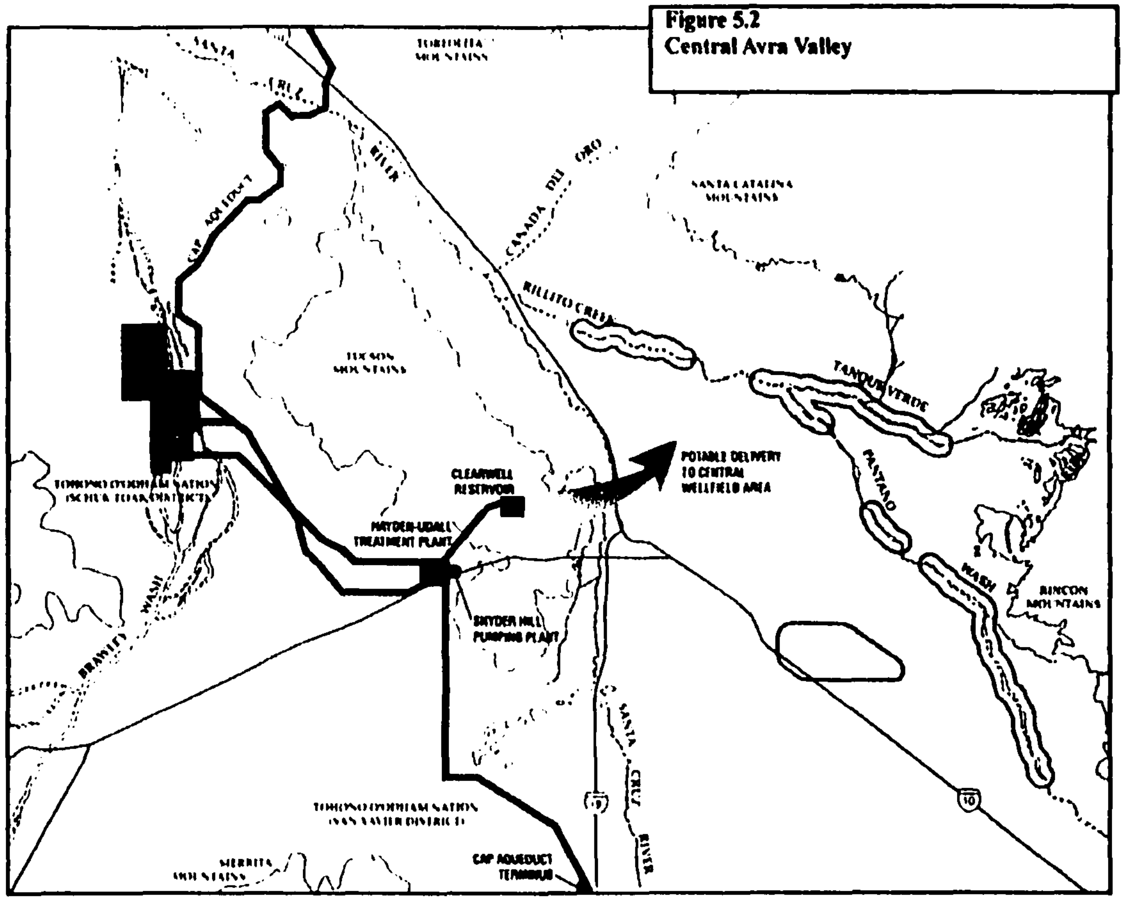

Figure 5.2. CAP Water Recharge in the Central Avra Valley (TWD, 1996)

5.2.2. Reclaimed Water System (RWS)

The RWS scheme is designed in compliance with one of the CPA's provisions to replace treated effluent used in the existing reclaimed water distribution system with either treated or untreated CAP water. Since the capacity of the reclaimed water distribution system within the border of the CWF area is 30,000 af/yr, the purpose of this scheme is to convey 30,000 af/yr of CAP water through the City's reclaimed water system to the CWF area.

However, since this scheme will utilize the City's Reclaimed Water Distribution System, of the 30,000 af/yr of CAP water, 13,000 af/yr is estimated to replace reclaimed water for non-potable water use, and the other 17,000 af/yr would be recharged into an identified stream channel within the CWF. There are two alternatives for delivering CAP water to the reclaimed water system. The first alternative is to deliver CAP water from the CAP canal at Tangerine Road to the reclaimed water system, which would require the construction of a pipeline 14.1 miles long. The second alternative is to pump 30,000 af/yr of treated CAP water from the Hayden-Udall Treatment Plant (CAP water treatment plant) into the Clearwell Reservoir, and have it flow from there directly to the reclaimed water system. This requires the construction of an interconnection between the potable and non-potable systems, in order to channel the flow from Clearwell Reservoir to the reclaimed water system as demonstrated in Figure 5.3.

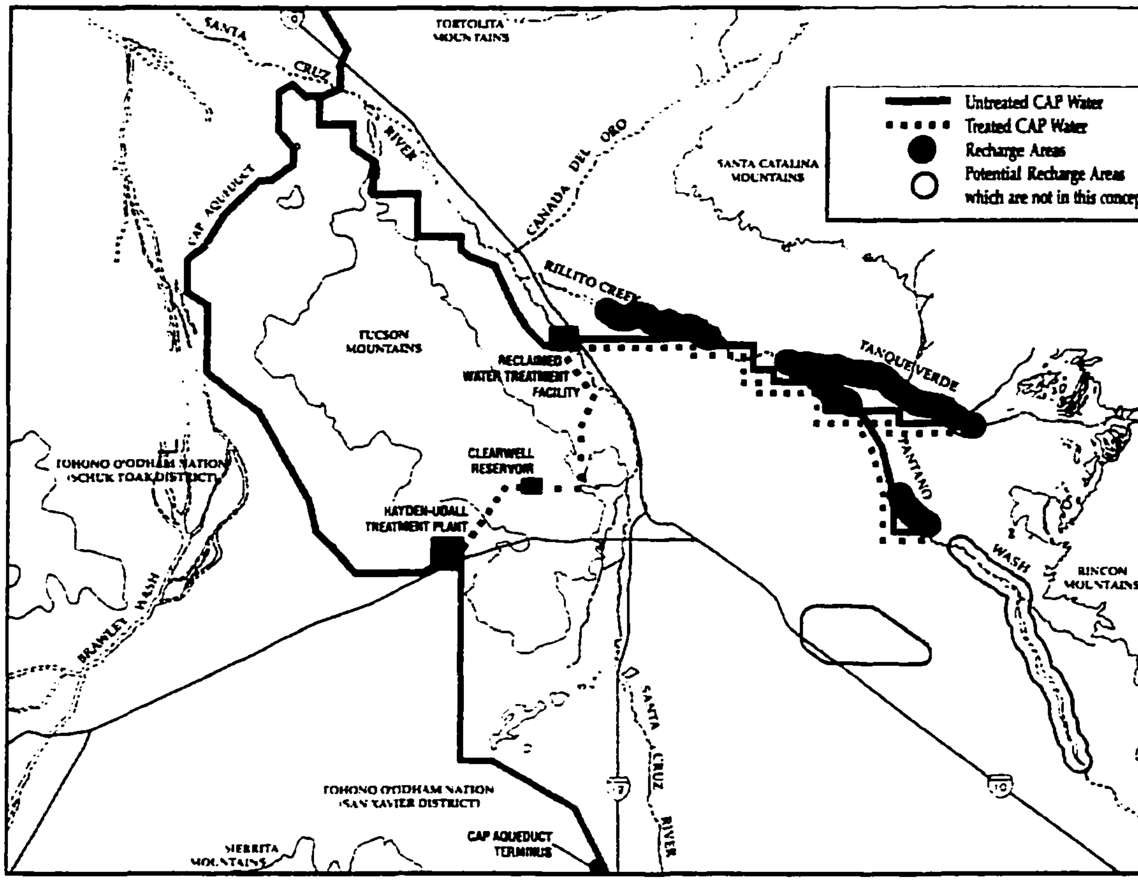

Figure 5.3. CAP Water Recharge through Reclaimed Water System (TWD, 1996)

5.2.3. DMAFB Scheme

The major aim of this scheme is to recharge 60,000 af/yr of CAP water. There are two alternatives for conveying this amount of CAP water to the recharge sites. The first alternative is to convey CAP water from the CAP Terminus to the recharge areas. This would require the construction of a 60 inch pipeline to transport 60,000 af/yr by gravity from the CAP terminus near Pima Mine Road to a point south of DMAFB as demonstrated in Figure 5.4

One of the main advantages of the first alternative is that CAP water would be recharged within the CWF, preventing subsidence and augmenting Tucson's basin aquifer. Of the 60,000 af/yr of CAP water conveyed from the CAP Terminus, 34,000 af/yr would be recharged within 375 acres of recharge basin south of DMAFB, and 26,000 af/yr would be pumped to the CWF through a 37 mile network of pipelines consisting of 12,16,24, 30 and 48 inch pipes.

The second alternative would convey CAP water from the Technical Drive Reservoir to the same recharge sites as demonstrated in Figure 5.4. This would isolate the potable water system from the Snyder Hill pump station through the Clearwell Reservoir and the CAP East Transmission Main to the Technical Drive Reservoir. In addition, 54 to 84 inch pipelines would need to be constructed beyond Technical Drive Reservoir in order to deliver CAP water from the Hayden-Udall Treatment Plant to recharge sites along selected reaches of the Pantano, Tanque Verde, and Rillito river channels, as well as in off-channel areas in or around Davis-Monthan Air Force Base. Also, two booster pump stations would need to be installed, and 375 acres would be need to be purchased as a recharge basin for 34,000 af/yr. As in the CAP Terminus alternative, of the 60,000 af/yr of CAP water conveyed from Technical Drive, 34,000 af/yr would be recharged within 375 acres of recharge basin south of DMAFB, and 26,000 af/yr would be pumped to CWF through a 37 mile network of pipelines consisting of 12,16,24, 30 and 48 inch pipes (see Figure 5.4).

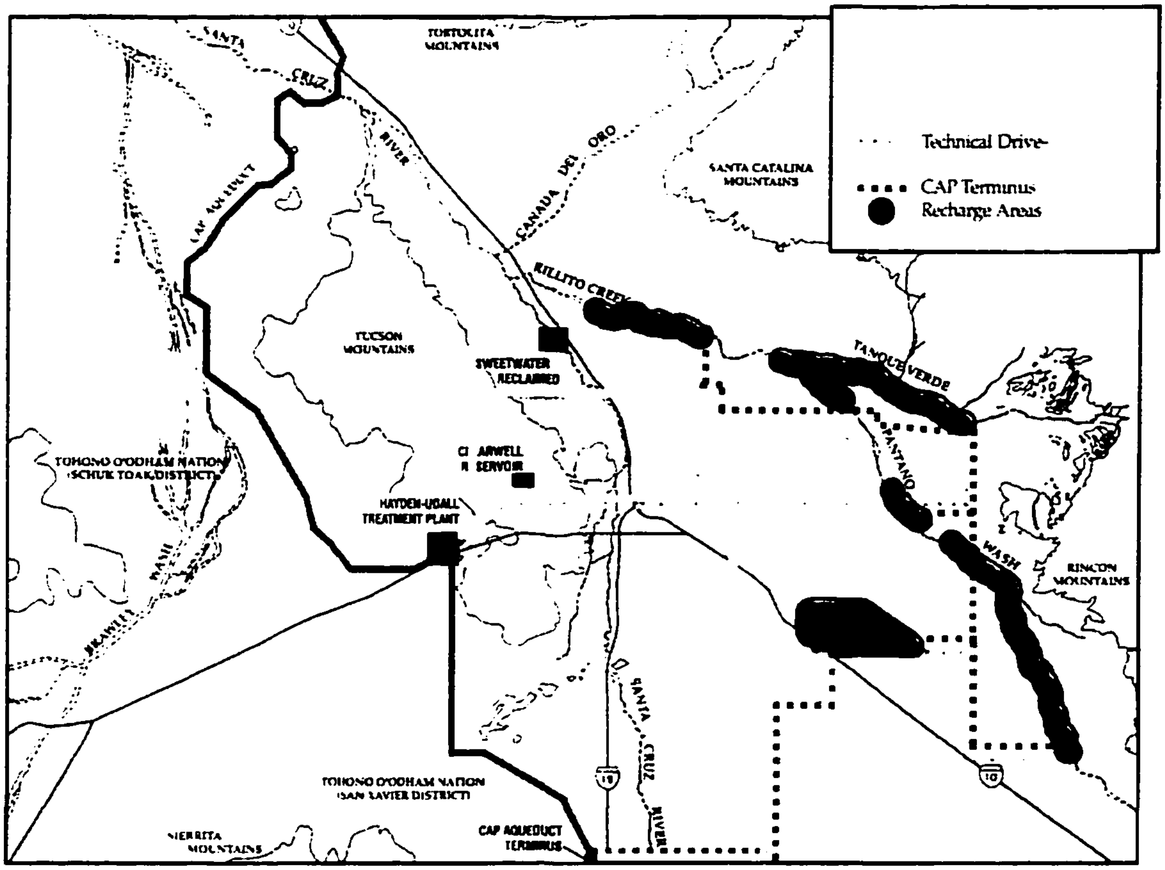

Figure 5.4. CAP Water Recharge in the CWF and DMAFB (TWD, 1996)

5.3. Assumptions of the Research

Of particular interest in this dissertation is the assessment of the economic benefit of each recharge alternative. However, given that the distribution system overlaps in the five proposed recharge alternatives, this study will examine only those alternatives that are distinctly independent from each other in terms of distributing water to recharge sites. Based on this criteria, there are only three alternatives: (1) the CAV scheme, (2) the RWS scheme with the Tangerine Road alternative; and (3) the DMAFB scheme with the CAP Terminus.

5.3.1. Description of the Assumed Planning Scenarios

To assess these alternatives of recharge schemes economically, four planning scenarios are designed to measure and compare the costs and benefits of each recharge scheme with the costs and benefits of continued groundwater pumping. The first scenario represents a benchmark from which to measure the benefits associated with each scenario. The other three scenarios would incorporate different volumes of CAP water recharged within the Tucson and Avra Valley basins. In general, due to the impact of the volume of CAP water used in each scenario on groundwater pumping from the CWF, each scenario has different economic and institutional benefits based on its capabilities to slow or stop groundwater level decline in the CWF. For convenience, Table 5.2 summarizes the descriptions of the recharging scenarios. Detailed descriptions of the scenarios follow.

Table 5.2. Assumed Planning Scenarios

Scenario	Description
Baseline	- No CAP water is used by TWD and there is total dependence on (1) pumping groundwater, (2) reclaimed water and (3) water saving from conservation
Scenario 2	- This scenario assumes 60,000 af/yr of CAP water out of 148,000 af/yr would be recharged and recovered simultaneously according to the CAV scheme to replace groundwater pumping from the CWF.
Scenario 3	- This scenario combines aspects of the CAV scheme and RWS scheme, where 60,000 af/yr of CAP water would be recharged and recovered simultaneously from the CAV scheme, 17,000 af/yr of CAP water would be recharged within the CWF area, and 13,000 af/yr would be used for non-potable water use.
Scenario 4	- This scenario constitutes aspects of the CAV scheme and DMAFB, where 60,000 af/yr of CAP water would be recharged and recovered simultaneously from the CAV scheme, and of 60,000 af/yr delivered from the CAP Terminus, of which 26,000 af/yr would be recharged within CWF and the rest (34,000 af/yr) would be recharged near DMAFB

5.3.1.1. Baseline Scenario

In this scenario, no CAP water is recharged or used for drinking purposes by Tucson Water Department (TWD). This assumption does not mean that the existing CAP water and CAP facilities will not be utilized within the Tucson AMA; it might be used by other water users outside the service area of the TWD. The second assumption is that potable water demand in the TWD service area would be satisfied solely by pumping additional groundwater, which would increase from 105,000 af in 1997 to 143,502 af by 2025. This projection of water demand is not based on economic factors, such as price and income. It is mainly based on population projections prepared by the Arizona Department of Water Resources (ADWR). However, it is assumed that water demand would decrease gradually over the entire planning period as a result of: (1) reclaimed water use increase from 11,500 af in 1998 to 20,934 af in 2025, and (2) the conservation policy impact on decreasing water demand growth from 192 acre-feet in 1998 to 5,176 acre-feet by 2025 (Malcolm Pirnie, 1996).

This scenario is considered a baseline and can be used as a benchmark from which to measure the benefits associated with reductions in groundwater level declines in the CWF area. Comparison of the benefits and costs of this scenario with other scenarios provides a means of assessing the opportunity costs of not utilizing CAP water.

5.3.1.2. Scenario 2, Minimum CAP Water Recharge

This scenario represents the TWD's current policy of recharging and recovering CAP water in the Central Avra Valley (CAV). At the present time, this project is still in a pilot-study phase to examine hydrogeological parameters, such as infiltration rates, changes in water table elevations, and water quality. However, assuming that the results of the hydrogeological parameters in this scenario will be favorable for recharging CAP water within CAV, this scenario assumes that 60,000 af/yr of CAP water would be recharged and recovered from CAV throughout the next 27 years (1998-2025) to replace the groundwater pumped from the CWF. The TWD has tentatively included the CAV project as part of its long-range planning to meet water supply needs (Malcolm Pirnie, 1996).

5.3.1.3. Scenario 3, Moderate CAP Water Recharge

In addition to the volume of CAP water that is going to be recharged in scenario 2, scenario 3 assumes that 17,000 af/yr of CAP water would be recharged within the

CWF area and 13,000 af/yr of CAP water would be used instead of reclaimed water. Therefore, the total amount of CAP water that would be recharged within the Tucson AMA would be 77,000 af/yr (60,000 af/yr in the CAV plus 17,000 af/yr in the CWF). This scenario implies that the reclaimed water system would be used for conveying CAP water to the identified stream-channel reaches that have acceptable long-term infiltration rates, and that are at least a half mile away from known landfills or areas of groundwater contamination. Thus, the recharging of CAP water would not only replace the volume of groundwater withdrawn annually from the CWF, thereby halting water level declines, but actually would increase water levels, at least during the early 2000s.

5.3.1.4. Scenario 4, Maximum CAP Water Recharge

Scenario 4 assumes that 120,000 af of CAP water would be recharged in the CAV, DMAFB and CWF. As indicated in Table 5.2, this would include 60,000 af of CAP water that would be recharged and recovered in the CAV, as described in scenario 2. The other half (60,000 af) would be recharged south of the Davis-Monthan Air Force Base (DMAFB) and Central Wellfield (CWF) areas: 26,000 af within the CWF area, and 34,000 af near DMAFB.

Scenario 4 is similar to scenario 3 in the recharging of CAP water within the CWF area. The differences are: (1) the total amount of CAP water recharged in the CWF in scenario 4 would be 26,000 af/yr, compared to 17,000 af/yr in scenario 3; (2) CAP water in scenario 3 would be conveyed by the City's existing reclaimed water system, while in scenario 4, new pipeline would need to be constructed from the CAP Terminus, as shown in Figure 5.4; and (3), 34,000 af/yr of CAP water would be recharged in areas up-gradient from the CWF in scenario 4.

5.4. Methodologies of this Research

In designing and justifying a project, the objective is to maximize benefits and minimize costs. Since the financial costs of recharge schemes have been estimated by TWD (1996), this study will: first, estimate the opportunity costs of not utilizing CAP water and then, assess the economic and institutional benefits from using CAP water through recharge. Second, the economic evaluation techniques of discounted Cost-Benefit Analysis will be used to evaluate the costs and benefits of the recharge scenarios.

The aim of using Cost-Benefit Analysis (CBA) is to analyze the worth of a project by comparing the total costs of the project with the total benefits. The basic rule of CBA is that an expenditure is to be judged economically worthwhile if its benefits exceed its costs, where costs and benefits are identified. The criteria of CBA that a project's benefits should exceed its costs can be expressed as follow:

$$\text{Net benefit} = TB - TC \qquad (5.1)$$

Where TB = Total Benefits

TC = Total Costs

Expression 5.1. indicates that when the net benefit for a particular project is greater than zero, that project should be considered for acceptance. The CBA is probably the most widely used tool to determine the economic value of water projects. However, CBA will not be appropriate for this study, because the costs and benefits of the recharge scenarios occur over the entire planning period (1998-2025). For example, while the capital costs of each recharging scenario are incurred within the initial year of construction, the operating and maintaining costs, as well as the benefits, are incurred over the lifetime of the project. Therefore, the costs and benefits of all the recharge scenarios have been calculated using the present value criteria. The difference between the total present value of benefits and costs is called net present value (NPV)

The NPV is a tool that is designed to assist a decision-maker in identifying a preferred choice among possible alternatives where benefits or costs are distributed across time. For the purposes of this study, there are three alternatives for CAP water recharge in the Tucson AMA. However, estimating the annual present value of costs and benefits is not very useful for policy purposes unless they are discounted to reflect the time value of future benefits. Such discounting would help to determine whether the current investment is worthwhile in the long run. This can be done by dividing total costs and total benefits by the appropriate discount factor, as shown in the following expressions:

$$\sum_{t=0}^{T}([\frac{B_t}{(1+r)^t}]-[\frac{C_t}{(1+r)^t}]) = \text{NPV} \qquad (5.2)$$

Where B_t = benefits in time t, with the specification B_0 =0

C_t = costs in time t

t = is the period in which costs and benefits are calculated.

r = discount rate, as a decimal fraction compounded annually

$(1+r)^{-1}$ = present value or discount factor for year t.

For a project to merit adoption and implementation NPV ≥ 0

A detailed description of the techniques used to quantify the costs and benefits of groundwater recharge will follow.

5.4.1. Discount Rate Estimation

One approach to choosing an appropriate discount rate is to use the opportunity cost of capital based on a government loan rate (Lind, 1990). The 1998 Treasury bond rate for more than 20 years term maturity, derived from a daily yield curve, is 6.07 percent (Wall Street Journal, April, 14, 1998). Adjusting it for inflation by subtracting the rate of change in the GDP deflator between 1995 and 1996, which is 2.3 percent, yields around 4 percent. For the purpose of this study, the initial analyses in Chapter 6 and 7 will be based on a 4 percent discount rate for evaluating the costs and benefits of CAP water recharge.

5.4.2 Methods of Estimating Cost

5.4.2.1. Method of Estimating Groundwater Level Decline

In general, pumping costs increase as groundwater levels decline. Given the projections of groundwater pumpage from the CWF, the projected groundwater level decline over the entire period (1998-2025) can be computed by employing the following model (Bredehoeft et al, 1982).

$$L_t = (GRS_t/SA) \qquad (5.3)$$

where L_t = average groundwater level decline in time t

S= average specific yield

GRS_t = quantity of water removed from storage in time t

A = affected land area in acres

As mentioned in Chapter 1, the CWF is the study area which has been considered in the above model as the affected area (A). The CWF encompasses nearly 200 squares miles (127,849 acres). The average specific yield (S), is the ratio of the volume of water which rock or soil, after being saturated, yields by gravity relative to the volume of the rock and soil. The average specific yield is used to estimate the storage property of the Tucson aquifer. Given the differences in the storage properties of the Tucson aquifer from place to place, it is difficult to determine the storage capacity of the aquifer (Hanson and Benedict, 1994). Estimates of specific yields in the upper part of the Tucson aquifer range between 0.03 and 0.25 with an average value between 0.12 and 0.15 (Anderson, 1972; Davidson, 1973; Freethy, 1986; Anderson and others, 1990). In this analysis, 0.10 of specific yield is used because it is the same as what the TWD is utilizing (Elder, 1997).

For example, given these variables and assuming groundwater overdraft to be 30,000 af/yr., the rate of groundwater level decline could be calculated as follow:

Lt= 30,000 /(0.10*127,849) which equals 2.3 feet per year.

5.4.2.2. Methods of Estimating Capital, and O&M Costs

As mentioned above, all data on capital and O&M costs for each recharging system used in this study are derived from TWD (1996). The estimates of total capital costs in the TWD's report are expressed in current values. The operation cost reflects only the average pumping cost. The costs of various pumping lifts are calculated in terms of energy consumption. A pump operating at 100 percent efficiency requires 1.024 kWh to lift one acre-foot of water by one foot. A recent TWD survey of wells reported an average pumping efficiency of 60 percent in the CWF (TWD,1996). A pump with a 60 percent efficiency requires 1.707 kWh of energy per acre-foot per foot of lift. Multiplying this by an energy cost of $0.06/kwh (based on Tucson Electric Power Company charges) yields a unit pumping cost of $0.10242 per af per foot of lift.

Given that the historical maintenance expense for groundwater pumping facilities in the Tucson basin is 13 percent of power costs, multiplying $0.10242 by 13 percent, yields a maintenance cost of $0.0133 per af per foot. Adding $0.0133 per af per foot of lift to the pumping cost raises it to $0.115 per af per foot. For example, the average pumping lift in the CWF area is 250 feet. To estimate the pumping cost per acre feet in the CWF, multiply $0.115 per af per foot by 250 feet, yielding $28.93 per af. The annual cost of pumping 60,000 af/yr would be $28.93 * 60,000 af = $1,736,019.

In the baseline scenario, continued groundwater pumping would induce the groundwater level to fall. As shown in Appendix A, the current water table decline is 4 feet in 1998, and the rate of groundwater level decline would increase further until it reaches 6 feet in year 2025 as the amount of groundwater pumping increases per year over the planning period (1998-2025). As a result of groundwater level decline, there would be additional costs: (1) the additional O&M costs for pumping per feet decline, (2) the additional maintenance costs of 13 percent of energy costs per ft decline, (3) the deepening cost per ft decline which was estimated to be \$0.02/af.

5.4.3. Methods of Estimating Recharge Benefits

5.4.3.1. Method of Estimating Pumping Lift Change

The annual lift change per unit of water recharged could be estimated by the following equation under the following two assumptions (Supalla et al 1982): (1) the effect of recharge on aquifer decline is the same as an equivalent reduction in pumpage, and (2) the affected area is well enough specified.

$$L_t = (R_t/SA) \qquad (5.4)$$

where L_t= change in lift in feet per year

S= average specific yield (0.10)

R_t = quantity of water recharge in acre feet per year

A= affected land area in acres (200 square miles or 127,849 acres)

This model has been used by Bredehoeft, Papadopulos and Cooper (1982), as shown above, to estimate groundwater decline. Given the size of the CWF area and its specific yield, as described in section (5.4.2.1), this model will be useful in estimating groundwater level changes in CWF at different rates of CAP water recharge in the same area. However, since the direction of groundwater movement in the Tucson Basin is generally northward in the southern part of the basin and northwestward in the northern part of the basin, this study assumes that the total amount of natural and artificial recharge in the Pantano Wash, Tanque Verde and Rillito Creeks would be recovered within the CWF area without loss by underground water movement.

5.4.3.2. Method of Estimating Benefits of Reduced Pumping Lifts

With the recharging of CAP water, groundwater levels might be either maintained or possibly recovered. This in turn would help to reduce pumping costs, specifically energy costs, and would avoid well deepening costs and land subsidence. The benefits of reduced pumping lifts are calculated in terms of savings in energy costs. Energy cost saving is equal to the difference in the amount spent on pumping with the recharge project versus what would have been spent without it. The annual recharge benefits from reduced pumping costs can be computed by the following equation (Reichard et al, 1984)

$$B_t = E_t\, L_t\, P_t; \quad t = 1 \text{ to } 27 \qquad (5.5)$$

Where B_t = Benefits from reduced pumping lift in year t ($/af);

E_t = Energy cost per acre foot pumped, per foot of lift, in year t;

L_t = Groundwater level reduction in year t (feet);

P_t = Pumping of water in year t (af)

t = is the period in which costs and benefits are calculated

As shown in this equation, an estimate of the benefits from pumping cost savings as a result of groundwater recharge requires first, a computation of the annual lift effect per unit of water recharged for each recharging site, and second, a computation of the pumping cost per acre foot pumped per foot of lift. The pumping cost per af per foot was estimated in the previous section ($0.115 per af per foot).

5.4.3.3. Methods of Valuing Groundwater Saved

Supalla (1982) stated that when groundwater mining is occurring, recharge may extend the aquifer life through the saving of groundwater over the planning period. The economic benefits from recharging CAP water within the CWF area are not only in reducing pumping lift and preventing land subsidence, but also in the volume of groundwater saved. This benefit could be estimated in terms of the value of groundwater saved that results from reducing or reversing groundwater pumpage through recharge.

However, since Arizona's constitution declares that the waters of the state (including groundwater) are owned by the public, it is very difficult to find economic measures of water in situ underground. Furthermore, the current price for municipal users does not reflect the value of the groundwater itself, but reflects the costs of pumping, disinfecting, and delivering the water (Colby, 1997, personal communication). Lieuwen (1989) measures the value of the saved groundwater as a result of effluent usage increase by using the market price of leasing an acre-foot of groundwater in the Tucson area per year, which was $100 per af.

Since the value of groundwater saved represents only an average cost of an acre-foot of in situ groundwater, and does not represent the marginal value of groundwater, this study assumes the price of in situ groundwater to be the same as the price of surface water charged to farmers by the Cortaro-Marana Irrigation District (CMID), which is $30/af (CMID, 1998). Different prices of groundwater saved will be examined in

Chapter 8. For the initial analyses in Chapter 6 and 7, the value of groundwater saved will be valued at $30/af.

There would be two volumes of groundwater being saved as a result of CAP water recharge in Tucson AMA. First, the amount of natural recharge, which is 16,750 af per year, plus the amount of CAP water that has been recharged into Tucson aquifer. The value of the groundwater saved through natural and artificial recharge could be computed by the following equation:

$$TV = P\Sigma_t \left[\frac{Q_t}{(1+r)^t}\right] \qquad (5.6)$$

Where TV = total value of groundwater saved.

Q_t = groundwater saved from natural and artificial recharge in time t.

r = is the discount rate as a decimal fraction

P = the approximated price of saved groundwater ($/af).

t = is the period in which costs and benefits are calculated.

Second, since CAV would be designed to initially recharge and recover a volume of CAP water equal to the current annual groundwater withdrawal from CWF, an equivalent amount of groundwater is saved in CWF which otherwise would be withdrawn for use to meet project water demand if CAP water is not recharged in CAV. Historically, CWF supplies about 65 percent of TWD's water supply, roughly 60,000 to 70,000 af/yr. Of this amount, 16,750 af/yr of natural recharge is considered renewable, the rest of the groundwater withdrawn from CWF is overdraft. This study assumes that as a result of recharge, the annul groundwater overdraft is considered as a saved groundwater that can be computed by the following equation:

$$TV = P\Sigma_t \left[\frac{S_t}{(1+r)^t}\right] \qquad (5.7)$$

Where TV = total value of groundwater saved.

S_t = saving groundwater overdraft t

r = is the discount rate as a decimal fraction, compounded annually.

P = the approximated price of saved groundwater.

t = is the period in which costs and benefits are calculated.

5.5. Sensitivity Analysis

Given the uncertainty associated with some of the parameter values calculated by the previous methods, and the fact that external forces may change some of the values, it is appropriate to consider how sensitive the recharge benefits are to physical and economic parameters. The physical parameters determine the impact of recharge on pumping depth and on well yield, and the economic parameters determine the significance of the physical impacts in terms of reduced pumping cost and saving groundwater. Since this assessment is focused more on with the economic benefits, a sensitivity analysis of the economic parameters of the discount rate and of the value of groundwater saved will be performed to evaluate the economic benefits of the different recharge scenarios.

First, in addition to a 4 percent discount rate, a 3 percent and 5 percent discount rate will be used in order to evaluate how sensitive the recharge costs and benefits are to discount rate changes.

Second, this study assumes three different prices for in situ groundwater saved. One, as explained in Section 5.4.3.3., the value of water will be estimated from the surface water rates charged to farmers in CMID, which is $30/af. Two, the value of water will be calculated from the estimated average pumping cost for irrigation water in Pima County in 1996 ($58 per af) (Daugherty & Thacker, 1996). Three, the value of water will be approximated from the estimated price of an acre-foot of CAP water contracted to municipal users. The current charge for a CAP water contract is $67 per acre-foot. It is projected to increase to $103 by 2005 (Malcolm Pirnie, 1996), and this price will be used for one estimate of the value of in situ groundwater.

Third, the other factors that will be simulated in this study are the impact of changing the value of using CAP water instead of reclaimed water in the CWF and the cost saving of not treating effluent to be used in CWF. The economic benefits from using CAP water instead of reclaimed water will be measured as follows: First, the variable costs of treating, pumping and distributing reclaimed water to the users in the CWF area will be avoided by using CAP water instead of reclaimed water. This study assumes that because of the potential use of CAP water, there is no need for treating effluent in order for it to be used for non-potable purposes within the CWF. The total O&M cost of providing reclaimed water are, generally, the costs of labor, energy, and chemicals required to operate and maintain the system. Table 5.3 summarizes the O&M costs of potable and reclaimed water of TWD.

Table 5.3. TWD's Potable and Reclaimed Water Rates in 1996

	Units	Reclaimed Water	Potable Water
Total Water Use	Cubic Feet	329,226,500	4,384,691,600
Total Water Use	acre-foot *	7558	100,659
Total O&M Cost	$	1,705,000	$46,932,000
O&M cost per acre-foot	$	225.59	466.25
Fixed Cost	$	381.41	292
Actual Total Costs	$	607.00	758.00
Subsidized Charge Rate	$	462.00	771.00

* To convert a Cubic Feet to an acre-feet, you need to divide the total cubic feet by 43,560 af
Source: Obtained from Table 18 and 19 in *1996 Water Rate Study* (R.W. Beck, 1996)

As shown in Table 5.3, the O&M Costs per af of reclaimed water is $225 per af. For the base case analysis in Chapter 6 and 7, the value of saving cost will be calculated at $225 per af. For the simulation analysis in Chapter 8, this study assumes the future cost of treating effluent to increase by 1 percent per year, and at a maximum, 2 percent per year.

The second benefit from using CAP water instead of reclaimed water is its sale for higher prices. This study postulate that if CAP water is used instead of reclaimed water, it would be marketed at one of the following prices: one it could be marketed at the current reclaimed water price of $462 per af, or two it may be marketed at the current cost of providing an acre-foot of reclaimed water which is $607 per af. In fact, the difference between current price and the cost of reclaimed water is subsidized by potable water users (Buss, 1997; R.Beck, 1996). Three, this study assumes that CAP water would be sold at a maximum price of $758 per af, which is the current cost of an acre-feet of groundwater for municipal users.

5.6. Summary

In this chapter, five recharge alternative schemes have been briefly described. Four planning scenarios are designed to measure and compare the costs and benefits of each recharge scheme with the costs and benefits of continued groundwater pumping. Table 5.3. shows the costs and benefits components that have been calculated for each scenario.

Table 5.4. Costs and benefits components

	Present Value of Costs				Present Value of Benefits					
	Capital Cost	CAP Water	O & M Costs		Value of Saving from			Value of not		Value of
			CAP	GW	Reduced Pumping	Eliminating Overdraft	Recharge	Constructing New Wells	Treating Effluent	CAP water sale
S 1	x			x						
S 2	x	x	x	x	x		x	x		
S 3	x	x	x	x	x	x	x	x	x	x
S 4	x	x	x	x	x	x	x	x		

Si = Scenarios

Chapter 6: Cost and Financial Impact

6.1. Introduction

When CAP water was delivered to the Central Wellfield (CWF) service area in 1992, the decline of the groundwater level in this area was stopped. However, after the direct delivery of CAP water was halted by the Consumer Protection Act (CPA) in 1995, groundwater again became the sole source of water supply for potable purposes and, as a result, further groundwater level decline became inevitable. Further decline could cause serious environmental damage, including aquifer depletion and land subsidence (Hanson, 1994), and the capital, operating and maintenance (O&M) costs would increase annually.

The purpose of this chapter is to describe the various costs associated with the scenarios described in Chapter 5. These costs can be categorized into: (1) costs associated with the baseline scenario of continued pumping of groundwater, and (2) costs associated with the alternative recharging projects. Before describing costs, it is important to give a brief description of the existing wellfields in the Tucson basin.

6.1.1. The Capacity of Tucson Water Department Wellfields

As mentioned in chapter 3, demand for potable water has historically been met solely by groundwater withdrawal from the Tucson and Avra Valley basins. In fact, even if CAP water is fully utilized in the short and long term, the groundwater stock will still provide the principal alternative water supply during periods when the availability of CAP water is disrupted. However, the reliable and sustainable long-term capacities for the existing four wellfields are dependent in large measure upon the hydrologic conditions, which could change in each wellfield in response to over-pumping or reduced pumping.

Table 6.1 demonstrates the current and long-term capacities of the four existing wellfields. In determining long term capacity, the assumption was made that pumps and motors and some of the wells would be replaced in order to maximize water production.

Table 6.1. Current and Long-term Capacities of the Existing Wellfields.

Wellfield	**Central**	**Santa Cruz**	**Southside**	**Avra Valley**	**Total**
	af/yr	af/yr	af/yr	af/yr	*af*
Current Capacity	80,000	15,600	7,800	26,000	129,400
long-term Capacity	100,800	38,400	7,800	31,000	178,000

Source: Adapted from Table ES-5 (Malcolm Pirnie, 1994)

At the current capacity of TWD's existing wellfields of 129,400 af/yr, the projected groundwater demand would exceed this amount by year 2015 as demonstrated in Appendix A. Even if the capacity of existing wells could increase to 178,200 af per year, new wellfields would be required in order to provide a reliable groundwater supply. This study assumes that new wellfields would need to be constructed by year 2015. Furthermore, there is a need to improve the pumping and distribution systems, including the replacement of existing transmission and distribution infrastructure, and the improvement of storage and pumping plants (Malcolm Pirnie, 1994).

Given the assumptions in the baseline scenario that groundwater pumping would continue from the CWF to meet projected water demand, and that CAP water would not be utilized, this section is concerned with the increasing costs associated with future groundwater pumping up to the year 2025. The projected capital and O&M costs associated with continued groundwater pumping will be discussed under the following assumptions:

First, capital and O&M costs would increase annually as additional amounts of groundwater would be pumped every year to meet continuous increases in water demands. Second, since continued pumpage would cause groundwater level declines, eventually it will reach those poorer groundwater quality levels in the depth of the aquifer in which there are extra capital and O&M costs associated with water treatment (Smith, 1987). Finally, there would be social and opportunity costs associated with not utilizing CAP water.

For the purpose of this study, the costs associated with water quality, land subsidence, and not utilizing CAP water will be excluded from this study's analyses for the following reasons: (1) it is not known how recharging CAP water will affect water quality when it is recovered, hence water quality may decline with and without recharging, (2) the annual cost of the CAP capital charge will be paid whether CAP water is used or not, and (3) there is no cost estimation of land subsidence in Tucson. Therefore, this analysis focuses on the other costs associated with the baseline scenario and with the recharging scenarios. The costs associated with the recharging scenarios are presented in the following sections.

6.2. Costs Associated with the Baseline Scenario

There are two major costs associated with the baseline scenario: (1) the costs associated with the expansion of the wellfield by 2015, and (2) the extra pumping cost as a result of continued groundwater decline. Table 6.2 summarizes the capital and O&M discounted at 4 percent.

Table 6.2. Summary of Capital and O&M-Baseline Scenario

	Capital Costs		O&M
	Conveyance	Wells	
	($000)	($000)	($000)
Baseline	14,436	4,331	56,282

Source: Adapted from Appendix A

6.2.1. Capital Cost Estimation of the Baseline Scenario

Based on the baseline scenario's assumptions, the long term demand for potable water in the city of Tucson would be satisfied only by pumping additional groundwater, which would increase from 117,378 af in 1998 to 169,612 af/yr by 2025 (Appendix A). Such an increase in groundwater use would require not only the improvement of the pumping and distribution systems, but also the extension of their capacities. The infrastructure for the TWD potable water system consists of reservoirs, booster pumping stations, pressure relief valves, and distribution and transmission pipelines.

Since such infrastructures would be needed regardless of the source of water, only the costs of new wells are included in the baseline scenario. Dames and Moore (1995) estimated that in order for Tucson Water to meet projected water demand, it would need to construct at least 52 additional new wells during the next 50 years. Given the projection that groundwater pumping increase would stabilize or decline over the next 27 years due to an increase in reclaimed water usage, and the impact of conservation policies, this study assumes that 25 new wells would be sufficient to meet the expected increase in water demand. It assumes that by year 2015, at least 25 new wells will be required.

At the current construction cost of $300,000 per well, the total cost for 25 wells would be $7.5 million. Since the construction would take place by 2015, the present value of the construction cost, discounted at 4 percent per year, would be $4.3 million, as demonstrated in Table 6.2. Further, given that pumping in the CWF already exceeds the capacity of the existing wellfield, a new wellfield would have to be utilized, either in the Santa Cruz Wellfield, or in the Avra Valley area, or in both locations (Malcolm Pirnie, 1994).

In the short run, the most likely possibility for new wells is in the Avra Valley area, due to the fact that the TWD already owns land and the rights to water in Avra Valley. Such a wellfield would require the construction of a collection system, including a booster, reservoir, and pipelines from Avra Valley to Tucson. Since the distribution and transmission systems for a recharging project are equivalent to planned capacity expansion for adding new wells, this study assumes that the capital costs for the construction of a collection system would be equal to the same costs for the recharge system. Therefore, the conveyance system cost for new wellfield in Avra Valley has been estimated to be about $25 million (TWD, 1996). The present value of this cost incurred in the year 2015 (the year by which it is estimated this wellfield will need to be constructed) would be $14.4 million, based upon a 4% discount rate, as shown in Table 6.2. Consequently, the total present value of the capital costs needed for continued groundwater pumping to cover water demand up to year 2025 would be $18.8 million, as shown in Table 6.2.

6.2.2. Operation and Maintenance Costs (O&M) of the Baseline Scenario

Using equation 5.3, the groundwater level decline in the CWF is estimated to be 4 to 6 feet per year over the planning period (1998-2025) (see Appendix A). This result is relatively consistent with the estimates of groundwater level decline provided by several consulting firms for the TWD (Black and Veach, 1988; Malcolm Pirnie, 1994, and R. Beck, 1996), and it is also consistent with the estimate of the Arizona Department of Water Resources (ADWR, 1996) and the USGS (Hanson, 1994). Thus, as the groundwater level declines in the CWF, not only the pumping, but also the well deepening costs would increase on an annual basis.

6.2.2.1. Pumping, Deepening and Well Maintenance Cost Estimation

While the current average groundwater level (GWL) within the CWF area is 250 feet, the estimates of the pumping costs in the CWF area are usually based on the current average pumping head of 490 ft (Dames & Moore, 1995). At this GWL of 490 feet, and with the unit pumping cost of $0. 137 per acre-foot per foot of lift, the total pumping cost per acre foot is $67. The average pumping cost is much lower than this figure. Therefore, this study estimates pumping costs based on an average GWL of 250 feet, because 250 feet is more reasonable and a good reference point, according to Sandy Elder, Hydrologist with the TWD (Personal communication, 1997).

As shown in Chapter 5, the most important factor that impacts on future pumping costs is the rate of water table decline. This study projects groundwater level decline to be 4 feet in 1998 and would gradually increase further until it reaches 6 feet in 2025 (Appendix A). Historically, the maintenance cost of groundwater pumping facilities in the Tucson basin has been 13 percent of power costs. Furthermore, given the assumption in the baseline scenario that groundwater withdrawal will continue, the necessity for deepening wells would be inevitable in order to reach water at lower depths. At the above groundwater level decline over the planning period, the GWL would reach 386 feet by the end of the planning period (2025) (Appendix A). There are costs associated with pumping and well deepening to such depths. In the case of deepening wells[15], the added costs would be the result of more piping, tubing, bowls, and larger motors. Bush and Martin (1986) estimated that the average deepening cost in the Tucson basin was $0.016 per af per additional foot of lift. In 1996 dollars, the cost is about $0.02 per af per foot based upon the *producer price index*. Adding this amount to the pumping cost yields an increased cost of $0.137 per af per foot of additional lift.

Since the pumping cost would increase as the well depth increases, the expected pumping cost would grow from $34 per af in 1998 to $52 per af in 2025. The total present value of the pumping, deepening and maintenance costs over the planning period, discounted at 4 percent, would be $56.3 million (Appendix A, Table 6.2).

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[15] Deepening cost is represented as a capital cost because it is annualized. Given the lack of data and since well deepening is a periodic investment, this study uses the estimate of deepening cost developed by Bush and Martin (1986) and includes it in the O&M costs as they did.

6.2.3. Quality and Social Costs

6.2.3.1. Quality Cost Estimation

The groundwater quality in the Tucson basin meets EPA enforceable drinking water standards currently in effect, without treatment (PAG, 1994). Most of the highest quality water occurs throughout the basin to depths of 700 feet (Dames & Moore, 1995). However, as groundwater levels get closer to the deep aquifer, the quality of the groundwater may not be suitable for potable purposes, due to high concentrations of total dissolved solids (TDS) and fluoride levels (Davidson, 1973).

Bush and Martin (1986, P. 17) indicated that "while declining pumping lifts are expected to cause some reduction in water quality over the coming years, the substitution of CAP water for groundwater will not lead to any improvement". Therefore, the replacement of groundwater with CAP water will not improve water quality, due to high salinity and TDS level of current CAP water. In addition, groundwater level decline under the baseline assumption would only reach to 386 ft by 2025. Therefore, since the predicated groundwater level decline is higher than the lower groundwater quality level as well as CAP water quality being worse than current groundwater, the costs associated with groundwater quality changes will be excluded from this study.

6.2.3.2. Social and Opportunity Costs

The assumption of total dependence by the TWD on groundwater in the baseline scenario indicates that it would preclude the utilization of Tucson's CAP allocation and the CAP infrastructures that have been built to deliver and treat CAP water. Therefore, there would be a social cost as a result of not using these facilities. Actually, while it is true that they are not being utilized by TWD at the present time, it is highly likely that they will be used by either the TWD or by other water providers within the Tucson AMA. If the TWD does not utilize its allocation of CAP water, some other water providers within the Tucson AMA are interested in utilizing the CAP water allocation (Jacob, 1998).

Consequently, CAP water will not be underutilized in the long run; rather its use will be simply reallocated within the Tucson AMA. As a result, there will not be a social loss, just a transfer of economic activity from one entity to another or one location to another. The "accounting stance" adopted for this study is restricted to the Tucson AMA. An accounting stance refers to the geographic area in which benefits and costs are measured (Loomis, 1993). It does not include potential economic incentives outside the area. In the case of CAP water, this study only accounts for the benefits and costs that are incurred by Tucson AMA residents.

There are opportunity costs associated with not utilizing CAP water that can be determined by quantifying the construction costs of the Tucson CAP water aqueduct and the CAP treatment facility. However, as discussed earlier, the costs associated with the CAP capital charge and treatment plant will only be discussed in this study, but will be excluded from this analysis due to the fact that it is obligatory for the TWD to pay the capital charge whether CAP water is used or not. The construction cost of the treatment plant is considered a sunk cost. Moreover, as the cost is a common to all scenarios, it is irrelevant to comparative analysis.

The capital charge paid by the TWD is derived from the entitlement of 148,420 af of CAP water annually for municipal and industrial (M&I) uses, as set by the Central Arizona Water Conservation District (CAWED) and the Secretary of the Interior. It is not obligatory for the TWD to use CAP water; however, it is required to pay the annual capital charges on its entire allocation regardless of whether it is used or not. Based on current charges set by CAWCD, which range from $21 per af in 1995 to $54 per af in 2000, Tucson was obligated to pay $5.8 million in 1997.

6.3. Costs associated with Recharging Scenarios

The capital cost for each recharge scenario primarily reflects the construction of the necessary facilities for basin and stream bed recharge sites, as well as the construction of transmission systems to transport CAP water to those sites and then to recover it into the distribution system. It does not include the costs of CWF's distribution system expansion. The O&M costs for each recharge scenario are for pumping, maintaining infrastructure and treating CAP water. The operation cost is represented by the cost of pumping. The maintenance cost is estimated to be 13 percent of the pumping cost for all three scenarios.

For the CAV and RWS schemes, which are represented by scenario 2 and scenario 3 when combined, the operational cost represents only the incremental costs which are in addition to the pumping cost from the CWF. However, for the DMAFB scheme, which is part of scenario 4, the operational cost is the total pumping cost. The summaries of the capital and O&M costs associated with each recharging scenario are demonstrated in Table 6.3.

Table 6.3. TPV of Capital and O&M costs for Recharging Scenarios

Scenarios	Capital Cost	CAP Water Purchase	O & M Costs
	($000)	($000)	($000)
Scenario 2	58,000	107,117	89,296
Scenario 3	78,627	160,676	145,341
Scenario 4	145,000	214,235	104,488

Source: Appendix N TPV= Total Present Value

The O&M costs demonstrated in Table 6.3 consists of pumping, maintenance, and CAP water purchase costs. The purchase costs of CAP water is different from the CAP system capital cost as discussed in section 6.2.3.2., because the commodity charge is based on the volume of CAP water actually used. The current charge for CAP water is $67 per acre-foot and it will vary over time. It is projected to increase to $103 by 2005 (Malcolm Pirnie, 1996). This cost represents the operation, maintenance, and repair costs for delivering CAP water to the Tucson AMA. For the purpose of this study, the CAP water price is assumed to increase by 1 percent over the planning period (1998-2025). Furthermore, the O&M costs for each scenario are assumed to be constant over the entire planning period because of the technological improvement. The capital and O&M costs associated with each scenario will be described in the following sections.

6.3.1. Costs Associated with Scenario 2

6.3.1.1. Capital and O&M Costs

In scenario 2, the recharging of CAP water in the CAV is used in conjunction with a reduction in groundwater pumpage within the CWF. This could be achieved by shifting pumping from the Tucson Basin to the CAV. The estimated capital cost associated with implementing this scenario is broken down by construction components as shown in Table 6.4.

Table 6.4. Estimated Capital Cost for Scenario 2

Description	**Estimated Cost $**
Recharge and Recovery Facilities	17,700,000
Pipelines, Booster, Reservoir,	34,000,000
Engineering Service	6,300,000
Total	**58,000,000**

Source: Adapted from (TWD,1996; Malcolm Pirnie, 1996)

As discussed above, the pumping cost represents the operational cost. The maintenance cost is estimated to be 13 percent of the pumping cost. Appendix B demonstrates the O&M costs for recharging CAP. The O&M costs are computed as follows: given the pumping cost per foot of lift per acre-foot pumped of $0.1024, the pumping cost from the CAV Wellfield to the Snyder Hill pump station (750 feet) is $76.8 per af ($0.1024 * 750 feet). Finding the maintenance cost in the CAV requires multiplying the pumping cost ($76.8 per af for 750 feet) by the total amount of recharge, then multiplying that by 13 percent to get the maintenance cost as shown in Appendix B. Since the planning period of this scenario is 27 years, the O&M costs need to be discounted at a 4 percent discount rate which gives $89 million. CAP water purchase cost for 60,000 af/yr is also shown in Appendix B of $107 millions. However, since the capital cost is a "front-loaded" investment, it is already a "present value" and is not discounted. Table 6.3 shows the total present value of O&M and CAP water costs over the planning period (1998-2025).

6.3.1.2. Groundwater Pumping Costs Associated with Scenario 2

Although scenario 2 would reduce groundwater pumpage within the CWF to prevent land subsidence by shifting pumping from the Tucson basin to the CAV, there is no direct artificial recharge in the CWF. Therefore, the groundwater level in the CWF would only be stabilized at 250 feet between the years 1998 and 2016 from natural recharge. After that, another source of water will need to be found to meet water demand, otherwise groundwater levels will decline again, causing the TWD to violate the provisions of the CPA and SY. Since groundwater withdrawal will continue over the planning period, there are O&M costs associated with continued pumping. The total present value of the O&M costs would be $9.3 million, discounted at 4 percent over the 27-year period (see Appendix C).

6.3.2. Costs associated with Scenario 3

6.3.2.1. Capital and O&M Costs

Scenario 3 is the combination of scenario 2 and the RWS scheme, where CAP water recharge and recovery from the CAV would take place simultaneously with the recharging of 17,000 af/yr in the CWF and the use of 13,000 af/yr of CAP water to substitute for reclaimed water usage. The capital and O&M costs of scenario 2 have already been described above as $58 million, and the capital and O&M costs associated with scenario 3 are a combination of the costs of scenario 2 and the costs of the RWS scheme. The total combined present value of capital, pumping, maintenance and purchasing costs of CAP water at a 4 percent discount rate over the 27-year period for the combined schemes of the CAV and RWS is shown in Table 6.5.

Table 6.5. TPV of Capital and O&M costs for Scenarios 3

Recharge Scheme	Capital Cost ($000)	O&M Costs ($000)	CAP Purchase cost ($000)
CAV scheme	58,000	89,296	-
RWS scheme	20,627	56,045	-
Total	**78,627**	**145,341**	**160,676**[16]

Source: Adapted from Appendix D; TPV = Total Present Value

The cost components in Table 6.5 are described as follows: For the RWS scheme, the capital costs are the costs of constructing 48 and 36 inch diameter pipes, and a booster at the CAP canal at Tangerine Road. The TWD estimated that the total capital cost for RWS is $20,627,000. This cost is based on delivering 30,000 af/yr of untreated CAP water. However, since this capital cost is a "front-loaded" investment, it will not be discounted.

The operational cost, which is the pumping cost from Tangerine Road to the reclaimed water system, is estimated to be $1.4 million per year. Assuming it is constant over the planning period, the present value of the pumping and Maintainance costs discounted at 4 percent, would be $56 million (Table 6.5). With the annual purchase cost for 90,000 af/yr of untreated CAP water, the total cost for CAP water acquisition

[16] This total amount of purchase cost of 90,000 af/yr for 27 years. It is discounted at 4 percent.

discounted at 4 percent over the planning period would be $161 million (For more details, please see Appendix D).

6.3.2.2. Groundwater Pumping Costs Associated with Scenario 3

Scenario 3 assumes that 60,000 af would be recharged in CAV, 17,000 af/yr of CAP water would be recharged in the CWF area, and 13,000 af/yr would be used instead of reclaimed water. In general, the total amount of CAP water recharge and use in scenario 3 would be 90,000 af per year over the planning period (1998-2025). As a consequence of recharging CAP water in the CWF, the groundwater level in the CWF would be increased from 250 ft in 1998 to 223 ft in 2025. This would qualify TWD to meet CPA and SY provisions. However, there are pumping costs associated with continue pumping groundwater from CWF to meet expected increase of water demand. As shown in Appendix E, the total present value of the O&M costs would be $8.6 million, discounted at 4 percent over the 27-year period.

6.3.3. Costs associated with Scenario 4

6.3.3.1. Capital and O&M Costs

Scenario 4 consists of the CAV scheme (scenario 2) and the DMAFB scheme. As shown in Table 6.6, the estimated capital cost for the CAV scheme (scenario 2) is $58 million. For the DMAFB scheme, the estimated capital cost is $86.7 million. Adding these two capital costs, yields the total capital for scenario 4 of $144.7 million. Since capital cost is a "front-loaded" investment, it will not be discounted. However, O&M

costs will be discounted at a 4 percent discount rate, since they are future annual costs. As discussed in the previous scenarios, the annual purchase cost for untreated CAP water would increase by 1 percent over the planning period. Given the total volume of CAP water of 120,000 af/yr used in this scenario, the total present value of the CAP water purchase would be $214.2 million (Table 6.6).

Table 6.6. TPV of Capital and O&M costs for Scenarios 4

Recharge Scheme	Capital Cost ($000)	O&M Cost ($000)	CAP Purchase cost ($000)
CAV scheme	58,000	89,296	-
DMAFB scheme	86,700	15,192	-
Total	**145,700**	**104,488**	**214,235**

Source: Adapted from Appendix F

The operational cost, which is the pumping cost from CAP terminus to DMAFB is estimated to be $877,000 per year. It appears that the DMAFB scheme's pumping cost is less than CAV scheme even though the amount of CAP water pumped in the DMAFB scheme and CAV scheme are equal. This low pumping cost is due to the fact that whereas CAP water delivered from the CAV to the Snyder Hill pumping station is pumped over 750 vertical feet, CAP water is delivered by gravity from the CAP Terminus to DMAFB, and there is no additional pumping cost. By assuming DMAFB scheme's pumping cost is constant over the planning period, the present value of the pumping and maintainance costs discounted at 4 percent, would be $15 million (Table

6.6). Therefore, the total present value of pumping, maintenance costs of scenario 4, at a 4 percent discount rate over the 27-year period would be $104 million.

6.3.3.2. Groundwater Pumping Costs Associated with Scenario 4

Due to the capability of scenario 4 to utilize the total allocation of CAP water to the TWD, it meets CPA and SY provisions. Further, given that there is a high amount of groundwater saved in the CWF and in DMAFB, there is high possibility to utilize the groundwater saved in the CWF during the period 1998-2025 to meet projected water demand. However, while there are no capital costs associated with continued groundwater pumping from CWF and even though the groundwater level would rise from 250 ft in 1998 to 204 ft in 2025, there are O&M costs to continue groundwater pumping. As shown in Appendix G, the total present value of the O&M costs would be $8.2 million, discounted at 4 percent over the 27-year period.

6.4. Summary

Relying solely on groundwater for current and future drinking water supplies would result in a high quality water supply for at least the next three decades. In the long term, however, the physical availability and continued high quality of the water supply is uncertain. Recharging CAP water would not only provide long-term groundwater storage credit, but would also replenish the aquifer, reducing the potential for land subsidence. One unknown factor is how it would impact future groundwater quality. This chapter describes the capital and O&M costs associated the four scenarios designed for the purpose of this study. The first scenario is a baseline scenario which represents the conditions of not using or recharging CAP water. The other three scenarios represent different alternatives for recharging and using CAP water.

The total costs associated with the baseline scenarios are the costs that result from increasing pumping lift and the construction of new wellfieds. The total costs associated with the recharging scenarios, are mostly dependent on the amount of CAP water used for recharge and where the recharge occurs. Table 6.7 demonstrates the total costs associated with each alternative scenario.

Table 6.7. The Total Costs Associated with each Recharge Scenario

Scenario	Baseline	Scenario 2	Scenario 3	Scenario 4
($000)	75,048	263,707	393,253	471,969

Source: Adapted from Appendix N

As shown in Table 6.7, the range of total costs is between $76 and $472 million. This indicates that the total cost of the baseline scenario is much lower than the total cost of the recharge scenarios. The baseline scenario cost is low because it does not include the cost of water; it only represents the O&M costs of groundwater pumping and the extra costs of adding new wells. Further, it does not include (1) the environmental damage costs of the predicted water table decline, and (2) the financial obligations cost of violating the Safe-Yield goal of the Groundwater Management Act, and of not meeting the provisions of the Consumer Protection Act.

On the other hand, the total costs of the recharging scenarios represent the following: (1) the purchase costs of CAP water used for recharge, (2) the O&M costs of recharging and recovering CAP water for usage, and (3) the capital costs of constructing recharge sites and conveyance systems to deliver CAP water from the CAP canal to the recharge sites. In general, the present value of costs of recharge scenarios varies substantially from one recharge scenario to the other. Such variation is due to the differences in size, location, the configuration of each recharge scenario, and the total use of CAP water. Since this study is concerned with costs and benefits of CAP water recharge, chapter 7 describes the economic benefits of each recharge scenario, and chapter 8 will analyze which scenario is most beneficial to Tucsonans economically and institutionally.

Chapter 7: CAP Water Recharge Benefits

7.1. Introduction

Recharge has the capability to stop, or at least to slow, the rate of groundwater level decline. However, such capability depends upon the hydrogeologic parameters of each recharging site, such as specific yield, infiltration rate, and the existence of impermeable zones. In the Tucson basin, these parameters have been extensively examined in several studies, including CH2M Hill (1988); Anderson (1988); and Hanson, (1990) and (1994). The infiltration rate in Pantano Wash is between 800 and 1,000 af per mile per year (af/m/y), in Rillito Creek, it is 700 to 1800 af/m/yr, and the infiltration rate in Tanque Verde wash is about 1,100 af/m/yr (TWD, 1996). The infiltration rate in the CAV area and in the recharge basin near DMAFB is 0.5 feet (ft) [17] per day, and an average rate of specific yield for the Tucson basin is about 0.10 (Elder, 1997).

In compliance with the provisions of the Consumer Protection Act (CPA) of 1995 relating to the use of CAP water for preventing subsidence and to augment Tucson's groundwater supply through recharge, the Tucson Water Department (TWD) plans to recharge as much water as is withdrawn from the Central Wellfield (CWF), utilizing suitable areas within and outside the CWF area. There are costs and benefits associated with any recharge scheme. The costs associated with the recharge scenarios of this study have been discussed in Chapter 6. The purpose of this chapter is to discuss the benefits associated with each recharge scenario in the Tucson AMA.

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[17] At 0.5 ft per day, it is estimated that a 660 acres basin would be acquired to recharge 60,000 af/yr.

7.2. Economic and Institutional Benefits Associated with Recharging Scenarios

Most recharge projects are justified on the basis of groundwater augmentation benefits related to enhancing resource management efficiency by the conjunctive use of surface and groundwater, avoiding the depletion of aquifers, extending their life, and promoting or maintaining an economic development objective. Furthermore, other important benefits that can be realized from recharge include flood control, and protecting or improving water quality.

Given the difficulty of measuring all recharge benefits quantitatively, this chapter will (1) estimate the economic benefits relating to reducing pumping lift and groundwater saved in the Tucson basin and (2) assess CAP water recharge institutionally in terms of its effectiveness in meeting the legal requirements of the CPA, and in meeting the SY goal. The methodology of estimating these benefits will be discussed in the following sections.

7.2.1. Economic Benefits

The primary purpose of groundwater recharge is either to maintain the groundwater level (GWL) or even possibly recover it. There are economic and institutional benefits of groundwater recharge associated with any reduction in GWL decline or groundwater recovery. The economic benefit associated with reduction in GWL decline could be quantified in terms of reduced pumping costs, specifically energy costs, and in avoiding well deepening costs. The benefits of reduced pumping lifts are calculated in terms of savings in energy costs. In general terms, energy cost saving is equal to the difference in the amount spent on pumping with the recharge project versus what would have been spent without it.

The economic benefits associated with groundwater recovery could be measured in terms of saving groundwater. However, there is no general economic measure for water in situ underground. This study approximates the value of the groundwater saved to be $30 per af for the initial analysis in this chapter as discussed in section 5.4.3.3. There are further economic benefits from recharging CAP water, for example, the foregone cost of not having to extend the capacity of the pumping wellfield. For convenient reference, Table 7.1 summarizes the estimated economic benefits for each recharge scenario discounted at 4 percent. Detailed description of the economic benefits will be discussed later.

Table 7.1. Economic Benefits from Recharge Scenarios

	Present Value of Benefits						
	Pumping Cost Saving	Saving GW Overdraft	Not constructing New Wellfield	GW Saved from Recharge in the CWF	Saved GW in DMAFB	Using CAP Instead of Reclaimed Water	Not Treating Effluent
	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Scenario 2	46,987		18,768	1,035			
Scenario 3	47,672	32,100	18,768	7,931		104,081	50,689
Scenario 4	48,035	32,100	18,768	12,610	17,676		

Source: Adapted from Appendix O

7.2.2. Institutional Benefits

As discussed earlier, it is mandatory for TWD to achieve safe-yield status (SY) and to meet the provisions of CPA. Meeting these institutional requirements depends very much on the availability of water supply and projected water demand. The TWD projected its total water demand for the next 27 years to be 4 maf. However, given the limited groundwater resources within Pima County, the TWD has been authorized through various institutional arrangements to withdraw only 5 maf of groundwater over 100 years. Plus, the TWD has contracted for 148,000 af per year of CAP water. The total accumulated volume of the CAP water available for TWD during the planning period (1998-2025) would be 4.14 maf. While there is enough groundwater supply to meet projected water demand for the next 27 years, it is necessary to use CAP water as soon as possible in order to distribute the use of groundwater over the next 100 years.

However, since the 1995 Consumer Protection Act prohibits the use of CAP water directly for potable and well injection purposes, the only way to use CAP water for potable purposes is through surface recharge. Recharging CAP water in Tucson AMA is not a new idea; it has been under consideration for the last 20 years, that it would primarily within the CWF, where severe groundwater pumping has been occurring since the early years of the 20th century. However, as explained in Chapter 5, the maximum volume of CAP water that could be recharged within the CWF area is only 26,000 af/yr (TWD, 1996). Therefore, it becomes necessary to recharge and recover CAP water in areas outside the CWF in order to enhance water resource management efficiency and to prevent further water level declines. Table 7.2 summarizes the estimated institutional benefits of recharging CAP water within the Tucson AMA. Detailed description of the institutional benefits will be discussed later.

Table 7.2. Institutional Benefits from Recharge Scenarios

Scenarios	Consumer Protection Act	Safe-Yield Goal
Baseline	No	No
Scenario 2	No	No
Scenario 3	Yes	Yes
Scenario 4	Yes	Yes

Source: summarized from the following sections

The following sections include several tables. The figures in those tables are based on annual data for 27 years, however, for the sake of simplicity, the tables are summarized with a few selected years. For more details, please consult the attached Appendices for each table.

7.2. Benefits of Groundwater Recharge under Scenario 2

7.2.1. Assumptions

It is true that recharging CAP water in scenario 2 would not be conducted in the most severe area of groundwater level decline - that of the CWF - yet it is expected that groundwater recovery would occur, at least in part because of natural recharge. It has been estimated that the groundwater level in the CWF would increase from 1 to 2 ft per year (Malcolm Pirnie, 1994). This estimate was deduced from groundwater recovery during 1993 and 1994, when CAP water replaced groundwater use in the CWF area. As shown in Figure 7.1, the rate of groundwater level decline was not only slowed, but actually reversed in 1993.

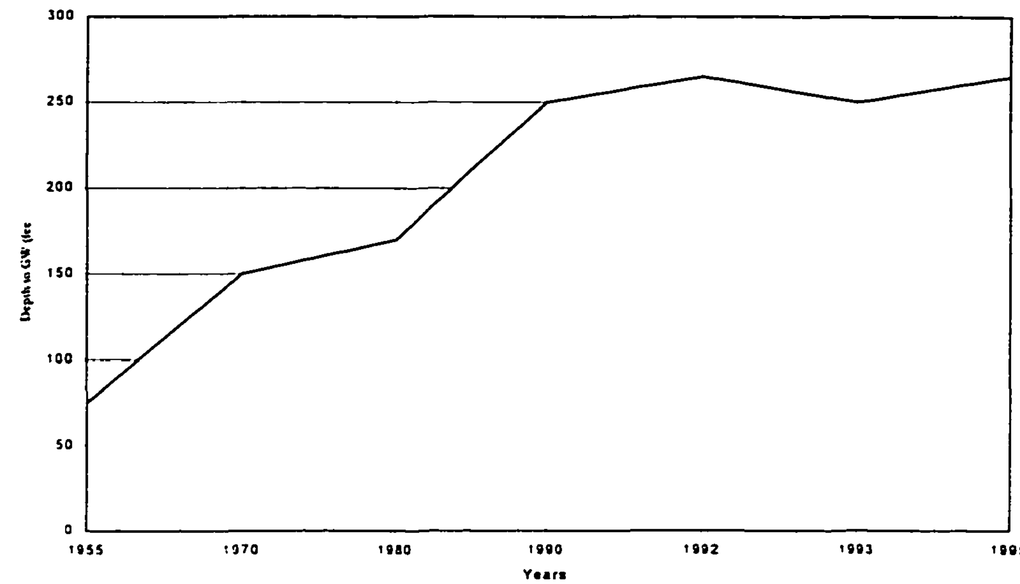

Figure 7.1. CWF Pumpage of Well B-052A for 1955-1995 (TWD,1996)

Given a CWF area of 127,894 acres and average specific yield of 10 percent, utilizing equation 5.4 we find the annual lift change from 16,750 af/yr of natural recharge would be 1.31 ft per year. However, this scenario assumes that the continuous pumping of groundwater from the CWF to meet expected increases in water demand, while less than the amount of natural recharge between 1998 and 2006, would slowly reduce groundwater recovery. The rate of increase in groundwater level would shrink from the expected 1.31 ft to just 0.6 ft in 1998, and would decrease further as the amount of groundwater pumping increases, until it reaches 0.1 ft in 2006, as shown in Table 7.3.

Table 7.3. Natural Recharge Impact in CWF's GWL-Scenario 2

Year	Expected Water Supply from CWF	Natural Recharge	Net GW Saved Through Natural Recharge	Average GWL Decrease	Ground Water Level
	af/yr		*af/yr*	*ft/yr*	*feet*
1998	8827	16,750	**7923**	-0.6	250.00
2000	10677	16,750	**6073**	-0.5	248.97
2002	12545	16,750	**4205**	-0.3	248.25
2004	14413	16,750	**2337**	-0.2	247.80
2006	16097	16,750	**653**	-0.1	247.64
Total			**36,896**		

Source: Adapted from Appendix C

Table 7.3 demonstrates that, due to 16,750 af/yr of natural recharge in the CWF, the expected amount of groundwater pumpage from CWF in 1998 would be 8,827 af and the net amount of groundwater saved from natural recharge would be 7,923 af (16,750 af - 8,827 af). In 2006, the amount of pumpage would be 16,097 af, which is slightly less than the natural recharge, and the amount saved would be only 653 af. At this level of savings, the groundwater table would only increase from 250 ft to 247 ft.

If there is no other source of water to meet the expected annual increases in water demand after year 2006, this scenario assumes that it is economically efficient to pump the amount of groundwater saved in the CWF between 1998 and 2006 to meet water demand after 2006.

However, pumping saved groundwater between 2007 until 2016 would make the rate of groundwater withdrawal greater than natural recharge, as shown in Table 7.4, and, therefore, the groundwater level would decline to 250 ft by year 2016.

Table 7.4. The Impact of Pumping GW saved on GWL-Scenario 2

Year	**Expected Water Supply from CWF**	**Natural Recharge**	**Overdraft of saved GW**	**Avg. GWL Decrease**	**GW level**
	af/yr	*af/yr*	*af/yr*	*ft/yr*	*feet*
2007	16846	16750	**-96**	0.0	**247.7**
2009	18345	16750	**-1595**	0.1	*247.8*
2011	19945	16750	**-3195**	0.2	247.3
2013	21648	16750	**-4898**	0.4	247.0
2015	23350	16750	**-6600**	0.5	247.9
2016	24276	16750	**-7526**	0.6	250.5
Total			**36,896**		

Source: Adapted from Appendix C

For long-term planning, this scenario assumes that, in addition to CAP water recovery from the CAV, it will continue pumping groundwater from CWF to meet expected increases in water demand after year 2016, even if groundwater withdrawal is greater than natural recharge. The amount of groundwater withdrawal in Scenario 2 would be, of course, less than the amount of pumpage in the baseline scenario. The estimates of the amount of groundwater overdraft from the CWF are 8,452 af in 2017, and it would increase to 16,526 af in 2025. This would cause the GWL to decrease from 250 ft in 2017 to 259 ft in 2025, as shown in Table 7.5.

Table 7.5. GW Overdraft Impact on GWL-Scenario 2

Year	Pumpage of Natural Recharge	GW Overdraft from CWF	Avg. GWL Decrease	Ground Water level
		af/yr	feet/yr	feet
2017	16,750	-8452	0.7	251.2
2019	16,750	-10304	0.8	252.7
2021	16,750	-12290	1.0	254.6
2023	16,750	-14408	1.1	256.7
2025	16,750	-16526	1.3	259.2

Source: Adapted from Appendix C

There are economic benefits associated with Scenario 2, including: (1) decreasing groundwater overdraft from the CWF by more than 50 percent, and the resulting pumping cost savings relative to the baseline scenario, (2) the relative maintenance of the groundwater level at 250 ft and the concomitant benefits of saving groundwater in the CWF; and (3) the usage of 60,000 af of CAP water out of its full allocation 148,000 af/yr. However, more than half of the CAP water allocation is still not consumed in scenario 2.

7.2.2. Benefits from Reducing Pumping Lift

Two of the benefits that can be measured from groundwater recovery in the CWF are: (1) the savings in capital costs that would no longer need to be invested to extend the capacity of the wellfield, and (2) the pumping savings that would be realized from reducing pumping lift.

Since the capital cost expenses for continued pumping of groundwater (Baseline Scenario) were estimated in Chapter 6 as costs, they would be accounted for in this scenario as avoided costs. Without CAP water recharge, the TWD would need to construct at least 25 wells by 2015 to meet projected water demand between 2015-2025. As discussed in section 6.2.1 (chapter 6) and demonstrated in Table 6.2, the total present value of the total avoided capital costs for not constructing wells and a conveyance system at a 4 percent discount rate over the planning period of this scenario (1998-2025) would be $18.8 million.

As shown in Tables 7.3, when groundwater withdrawal from the CWF is less than the natural recharge, the pumping lift would only decrease by 3 ft between 1998 and 2006. When groundwater withdrawal exceeds natural recharge as a result of pumping the saved groundwater, as shown in Table 7.4, the groundwater level would return to its starting point of 250 ft by 2016. Therefore, after year 2016, while CAP water recharge and recovery from the CAV would continue, groundwater pumping would also continue from the CWF to meet projected water demand. Since continue groundwater pumping from the CWF would exceed natural recharge, the groundwater level would increase from 250 ft in 2017 to 259 ft in 2025. This in turn would increase pumping lift costs from $28.9 per af in 2017 to $30.47 per af in 2025 (see Appendix C).

However, as a result of not totally depending on groundwater pumping from the CWF, and the recharging and recovering of CAP water from the CAV in scenario 2, there would be a pumping cost saving in comparison to the baseline scenario. For example, without recharging and recovering CAP water in the CAV, the total groundwater withdrawal from the CWF would be 2.3 maf over the planning period. However, because of the CAP water recharge and recovery from CAV, the total groundwater withdrawal from the CWF would be only 0.6 maf over the same period. Therefore, taking the difference between the expected pumping costs from the CWF and the expected pumping costs without CAP water recharge in the CAV, the present value of the total avoided pumping discounted at 4 percent would be $46.9 million over the planning period (see Table 7.1 and Appendix A and C).

7.2.3. Benefits from Saved Groundwater

As discussed in Chapter 5, recharge may extend aquifer life in terms of maintaining groundwater levels, and the economic benefits would be in terms of the value of the groundwater saved at the end of the planning period. In this scenario, recharging CAP water would not occur in the CWF area, therefore, the expected benefit would be in terms of recovering the groundwater level within the CWF through natural recharge due to the slowing of the mining of groundwater.

Since the GMA requires water users to achieve SY and the CPA requires augmentation of the Tucson aquifer. and in particular the CWF aquifer, the estimates of the value of the saved groundwater will only reflect the maximum quantity of groundwater that could be withdrawn in compliance with the legal and operational requirements of the GMA and CPA, which in this case is less than the natural recharge. Therefore, the saved groundwater from the CWF would vary from one year to the next, based on the amount pumped from the CWF.

In scenario 2, the groundwater savings in the CWF would be 7,923 af in 1998, and then it would decrease as groundwater pumpage increases, as shown in Table 7.3. This study estimates that the groundwater saved from this scenario would continue to accumulate up to 36,896 af in year 2006; after that, increased groundwater withdrawal from the CWF would begin to deplete the groundwater saved, as indicated in Table 7.4.

Since groundwater saved will be used between the years 2007 and 2016, there is a benefit from utilizing the CWF aquifer as water storage. As discussed in Chapter 5, for the initial analysis of this study, the groundwater saved will be valued at $30 per af. The total present value of using the saved groundwater, at a 4 percent discount rate over the 18-year period, would be over $1 million (see Table 7.1 and Appendix H).

7.2.4. Institutional Benefits

The institutional benefits from utilizing the full allocation of CAP water would be in terms of qualifying TWD to meet the SY and CPA provisions. However, scenario 2 assumes that only 60,000 af/yr of CAP water would be recharged and recovered from the Central Avra Valley (CAV) and groundwater withdrawal from the CWF would be greater than the natural recharge. Therefore, the SY and CPA provisions would be violated in scenario 2.

7.3. Benefits of Groundwater Recharge under Scenario 3

7.3.1. Assumptions

As described in Chapter 5, scenario 3 consists of a combination of the CAV and RWS schemes. The total amount of CAP water recharged would be 77,000 af/yr, of which 60,000 af/yr would be recharged and recovered from the CAV and 17,000 af would be recharged in the CWF. The total amount of recharge in the CWF in this scenario would be 33,750 af/yr, which includes 17,000 af/yr as artificial recharge and 16,750 af/yr as natural recharge.

Using equation 5.4, we find the impact of natural and artificial recharge of 33,750 af/yr on the CWF's groundwater level would be about 2.65 ft per year. However, since scenario 3 assumes groundwater pumping would continue from the CWF in order to meet water demand, the rate of groundwater level increase would slow from 2.65 ft/yr to 1.9 ft/yr in the early years of the project, and then gradually decline until reaching zero by year 2025, as shown in Table 7.6 for selected years.

Table 7.6. The Impact of Pumping GW saved on GWL-Scenario 3

Year	**Expected Water supply from CWF**	**Pumpage of Natural Recharge**	**CAP water recharge in CWF**	**GW saved in CWF**	**The Rate of GWL decrease**	**GW level**
	af/yr	*af/yr*	*af/yr*	*af/yr*	*feet/yr*	*feet*
1998	8827	16750	17000	**24,923**	-1.9	250
2015	23350	16750	17000	**10,400**	-0.8	227.3
2020	27980	16750	17000	**5,770**	-0.5	224.4
2025	33276	16750	17000	**474**	0.0	223.3

This table is selected years adapted from Appendix E

As Table 7.6 indicates, since the groundwater pumpage would be less than the amount of natural recharge, the groundwater level would increase from 250 ft to 223.5 ft due to the amount of groundwater saved within the CWF. For example, in Table 7.6, the amount of groundwater withdrawal in 1998 would be 8,827 af, while the amount saved would be 24,923 af. In 2025, the amount of pumpage would be 33,276 af, which is slightly less than the amount of artificial and natural recharge, therefore, the amount groundwater saved in 2025 would be only 474 af (Table 7.6 and Appendix E).

The economic and the institutional benefits from scenario 3 would be: (1) halting groundwater overdraft from the CWF, (2) halting groundwater level decline and the resulting pumping cost savings relative to the baseline scenario, and (3) utilizing 90,000 af of CAP water through recharge, and substituting reclaimed water for groundwater, which would give TWD the reliability and resiliency of water supply.

7.3.2. Benefits from Reducing Pumping Lift

In scenario 3, as a result of the recharging of CAP water in the CWF as well as in the CAV, groundwater level depth in the CWF would increase from 250 ft to 223.3 ft by year 2025 (Table 7.6). Since the pumping cost decreases when pumping lift decreases, there would be a small pumping cost saving per acre-foot as shown in Appendix E. For example, pumping cost would decrease from $28.9 per af in 1998 to $25.8 per acre-foot in 2025. There is also a pumping cost saving in terms of decreasing groundwater withdrawal from the CWF and not being totally dependent upon groundwater from the CWF. The present value of total avoided pumping costs relative to the baseline scenario would be $47.672 million by year 2025, discounted at 4 percent (Table 7.1).

Furthermore, there is a benefit associated with this scenario in terms of the saving of capital cost that would no longer need to be invested to extend the capacity of the wellfield. Since the capital expenses for continued groundwater pumping were estimated in Chapter 6 as costs, they would be accounted in this scenario as avoided costs. The present value of the total avoided capital costs for constructing wells and a conveyance system, at a 4 percent discount rate over the planning period of this scenario (1998-2025), would be $18.8 million (see Table 6.2 in Chapter 6 and Table 7.1).

7.3.3. Benefits from Saved Groundwater

As mentioned in Chapter 5, an estimate of the value of saved groundwater could be obtained by multiplying the total amount of water recharged by the approximated prices of an acre-foot of in situ groundwater. Since scenario 3 is, a combination of the CAV scheme (scenario 2) and RWS scheme, the economic benefits from scenario 3 will be a combination of benefits from the CAV and RWS recharge schemes. In this case, the combined volume of the net saved groundwater obtained from recharging CAP water under both schemes will be 365,705 af (see Table 7.1 and Appendix E). This represents the volume of saved groundwater due to artificial and natural recharge within the CAV, under the restriction of the SY, up to year 2025.

This scenario assumes that these groundwater savings would be pumped eventually to meet future water demand, so they have been consider as saved resources or assets. Therefore, the present value of the saved groundwater from scenario 3 at $30 per af and 4 percent discount rate would be about $7.9 million (see Appendix I).

Furthermore, since scenario 3 achieves the goal of SY and meets the provisions of CPA, there is a benefit associated with this scenario in terms of the saving of groundwater in CWF that otherwise would be pumped without recharging and recovering

CAP water in the CAV and in the CWF. The present value of the saved groundwater from scenario 3 would be about $32 million at $30 per af and 4 percent discount rate (see Table 7.1).

In addition, since scenario 3 includes the RWS scheme, there is also a benefit associated with utilizing 13,000 af of CAP water for non-potable purposes within the CWF. As explained in Chapter 5, there are two major benefits: First, using CAP water instead of reclaimed water generates the benefits of avoiding the cost of treating effluent to be used in CWF. The current O&M cost for treating effluent is $225 per af. Considering this cost as saving cost, the present value of not treating reclaimed water to be used in CWF during the 27-year period at a 4 percent discount rate would be about $51 million (Table 7.1 and Appendix K).

Second, substituting CAP water for the reclaimed water could result in: (1) cheaper and good quality water for the turf industries, (2) better utilization of the existing reclaimed delivery system, and (3) a reduction of the subsidy that other TWD customers pay to keep the price of reclaimed water affordable. Further, reclaimed water plant could remain in use to provide reclaimed water for other users outside CWF area. The present value of using CAP water instead of reclaimed water in the CWF would be in terms of selling CAP water at $462 per af relative to the current cost of producing reclaimed water of $607 per af. The net present total value, discounted at 4 percent during a 27-year period, would be $104 million (see Table 7.1 and Appendix J).

7.3.4. Institutional Benefits

One of the assumptions of scenario 3 was that 17,000 af of CAP water would be recharged within the Tucson CWF. Because of the limitations on the volume of water available for recharge through the reclaimed water system, the RWS scheme by itself would not have institutional benefits because it could not augment the CWF, or even partially offset the groundwater withdrawal from the CWF. Therefore, it is reasonable to combine the RWS scheme with the CAV scheme in order to use CAP water economically and efficiently. Regardless of whether CAP water is recharged in the CWF area or not, recharging CAP water in the CAV is a necessary condition for the city of Tucson to augment the CWF's aquifer to meet the CPA's provisions, at least for the short term. Therefore, the institutional benefits of scenario 3 would be a combination of benefits from recharging CAP water through the CAV and RWS schemes.

The use of the 77,000 af of CAP water through recharge and 13,000 af of CAP water for non-potable usage over the planning period (1998-2025), would qualify TWD to meet the SY and CPA provisions.

7.4. Benefits from Groundwater Recharge under Scenario *4*

7.4.1. Assumptions

As discussed in Chapter 5, scenario 4 consists of the CAV and Davis-Monthan Air Force Base (DMAFB) schemes. The total amount of CAP water recharge in scenario 4 would be 120,000 af/yr, where 60,000 af/yr of CAP water would be recharged in the

DMAFB scheme, 26,000 af/yr would be recharged in the CWF and 34,000 af would be recharged in the recharge basin near DMAFB. Since the DMAFB scheme takes place simultaneously with the CAV scheme, the total amount of natural and artificial recharge in the CWF would be 42,750 af/yr, which would increase the groundwater level by 3.35 ft per year at zero pumping from the CWF. However, as indicated in scenario 2, groundwater would continue to be withdrawn from the CWF in order to meet projected increases in water demand in the Tucson basin, therefore, the rate of groundwater level increase in 1998 would be 2.7 af/yr rather than 3.35, as shown in Table 7.7 for selected years.

Table 7.7. The Impact of GW Recharge on GWL-Scenario 4

Year	**GW saved in CWF from Artificial and natural Recharge**	**Rate of GW level decrease**	**GW level**
	af/yr	*feet/yr*	*feet*
1998	33923	-2.7	250
2005	27043	-2.1	233.5
2015	19400	-1.5	215.4
2025	9474	-0.7	204.3

Source: Adapted from Appendix G

Table 7.7 indicates that groundwater level increases would slowly decline until reaching 0.7 ft by year 2025. This decline which would be the result of pumping groundwater by less than the amount of natural and artificial recharge, allows the groundwater level to increase from 250 ft in 1998 to 204.3 ft in 2025. For example, in 1998, the amount of groundwater pumpage would be 8,827 af, while the amount saved would be 33,923 af. In 2025, the amount of pumpage from the CWF would be 33,276 af, which is less than the sum of the artificial and natural recharge. The amount saved in 2025 would be 9,474 af, thereby increasing the groundwater level by only 0.7 ft (Table 7.7).

In general, there are three economic benefits in scenario 4; (1) the groundwater value level would increase from 250 ft to 204.3 ft by 2025; (2) there are pumping cost savings relative to the baseline scenario; (3) there is the value of the groundwater saved within the CWF and the DMAFB.

7.4.2. Benefits from Reducing Pumping Lift

Since the groundwater level would increase and the pumping lift would decrease, the unit O&M cost per acre-foot would decrease from $28.9 per af in 1998 to $23.6 per af by 2025. Therefore, the total present value of pumping cost savings from scenario 4 relative to the baseline scenario would be $48 million (Table 7.1). An additional benefit in this scenario is the savings in capital costs that would no longer need to be invested to extend the capacity of the wellfield. Since the capital expenses for continued pumping were estimated in Chapter 6 as costs, they would be accounted in this scenario as avoided costs. The present value of the total avoided capital costs for constructing wells and a conveyance system at a 4 percent discount rate over the planning period of this scenario (1998-2025) would be $18.8 million (Table 6.2 and Table 7.1)

7.4.3. Benefits from Groundwater Saved

In scenario 4, there are two large increments of groundwater saved. At the prices determined in Chapter 5 of $30 per af and at 4 percent discount rate, the present value of the saved groundwater in CWF would be about $12.6 million (Table 7.1 and Appendix L) and for groundwater save in DMAFB would be $17.7 million (Table 7.1 and Appendix M). Furthermore, since scenario 4 achieves the goal of SY and meets the provisions of CPA, there is a foregone benefit associated with this scenario in terms of the saving of groundwater in CWF that otherwise would be pumped without recharging and recovering CAP water in the CAV and in the CWF. The total present value of the saved groundwater from scenario 4 would be about $32 million at $30 per af and 4 percent discount rate (see Table 7.1).

7.4.4. Institutional Benefits

The institutional benefits of scenario 4 would derive from the volume of CAP water recharged. Scenario 4 assumes the recharging of 120,000 af/yr of CAP water within the Tucson AMA. This amount is actually sufficient to offset the groundwater withdrawal from the CWF and to give TWD the capability to comply with the CAP contract and to meet the CPA's provisions. Achieving the Safe-Yield goal is attainable in scenario 4.

7.5. Summary

In this chapter, the economic and the institutional benefits of groundwater recharge through using CAP water in the Tucson AMA have been estimated. Specifically, groundwater recharge and its impact on decreasing pumping lift and saving groundwater as well as meeting requirements of the law were described thoroughly. Based on the costs associated with the baseline scenario, the value of recharging CAP water was estimated as avoided costs for the three scenarios. The total economic benefits from recharging CAP water in the Tucson AMA are summarized in Table 7.8.

Table 7.8. Total Benefits Associated with Recharging Scenario

Scenario	Total Benefits
	($000)
Baseline	0
Scenario 2	66,791
Scenario 3	261,242
Scenario 4	129,189

Source: Adapted from Appendix O

As shown in Table 7.8, the total economic benefits range from about $67 million to $261 million. From these estimates, it is difficult to reach any conclusion, or to determine which scenario is most beneficial to the City of Tucson, because these benefits need to be compared with the total amount of CAP water recharged, and the costs associated with each recharge scenario need to be subtracted in order to derive a conclusive result. These analyses will be the focus of Chapter 8.

Chapter 8: The Results of the Economic and Institutional Assessments

8.1. Introduction

The costs and benefits of CAP water recharge in the Tucson AMA have been identified by TWD (1996) and ADWR (1996), but they have not been quantified thoroughly. This study attempts to quantify some of the financial costs and benefits that can be measured with reasonable accuracy for four recharging scenarios. The costs quantified in Chapter 6 are the financial costs of the recharge scenarios. The benefits from CAP water recharge discussed in Chapter 7 are only those benefits that are measurable and attributable to the net decrease in groundwater overdraft. The first objective of this chapter is to compare the results of the total benefits and costs of the three recharge scenarios and contrast them with the result of the baseline scenario. The second goal is to analyze the costs and benefits of each recharge scenario in terms of achieving the goal of utilizing CAP water. Finally, sensitivity analyses are conducted on key variables

8.2. Cost-Benefit Analysis

In the initial analysis (or base case analysis) of Chapter 6 and 7, the recharge costs and benefits were estimated at 4 percent discount rate and on minimum values of recharge benefits, as demonstrated in Table 8.1. The present value of costs and benefits are called Costs and Benefits in Table 8.1. Net Present Value (NPV) which is the difference between costs and benefits is also calculated.

Table 8.1. TPV of Recharging Scenarios-Base Case

US$ (000)	Cost	Benefit	NPV
Baseline	75,049	0.0	-75,049
Scenario 2	263,708	66,791	-196,917
Scenario 3	393,253	261,242	-132,011
Scenario 4	471,970	129,189	-342,780

Source: Adapted from Appendix P

Table 8.1 indicates that the total cost of the baseline scenario is much lower than the total cost of the recharge scenarios. The baseline scenario cost is low because, as discussed in Chapter 6, it does not include the cost of water; it only represents the O&M costs of groundwater pumping and the extra costs of adding new wells. Further, it does not include (1) the environmental damage costs of the predicted water table decline from 250 ft in 1998 to 386 ft in 2025, and (2) the financial obligations cost of violating the Safe-Yield goal of the Groundwater Management Act, and of not meeting the provisions of the Consumer Protection Act.

On the other hand, the total costs of the recharging scenarios represent the following: (1) the purchase costs of CAP water used for recharge, (2) the O&M costs of recharging and recovering CAP water for usage, and (3) the capital costs of constructing recharge sites and conveyance systems to deliver CAP water from the CAP canal to the recharge sites. In general, the present value of costs and benefits varies substantially from one recharge scenario to the other. Such variation is due to the differences in size, location, the configuration of each recharge scenario, and the total use of CAP water.

8.2.1. Cost Analysis

The results in Table 8.1 indicate that the total costs increase as the volume of CAP water use increases. For example, when the annual amount of CAP water use in scenarios 2 and 3 increases from 60,000 af/yr to 90,000 af/yr, the total costs increases from $264 million to $393 million and when it increases to 120,000 af/yr, as in scenario 4, the total costs increases to $472 million. Such proportional increases are due to the fact that capital and CAP water purchase costs represent a high proportion of costs components. Consequently, when the total amount of CAP water use increases for a particular scenario, the total costs increase as shown in Table 8.2.

For the O&M costs component, however, the results in Table 8.2 indicate that the total O&M does not increase proportionally with the volume of CAP water used for recharge. For example, while the amount of CAP water used in scenario 3 is less than the amount used in scenario 4 by 25 percent, its total O&M costs is $145 million which is higher than the total cost of scenario 4 ($104 million).

It is important to note that the total cost of each recharge scenario is associated with its objective. For example, while the main objective of the CAV scheme is to recharge and recover CAP water simultaneously, the objective of DMAFB scheme is only to recharge CAP water and the purpose of the RWS scheme is to recharge and use CAP water instead of reclaimed water. Therefore, their costs are substantially different.

Table 8.2. Costs Components

US$ (000)	Capital Cost	CAP Water Purchase	O & M Costs of CAP	CAP Water Use (af/yr)
Baseline	18,767		56,282	0
Scenario 2	58,000	107,117	89,296	60,000
Scenario 3	78,627	160,676	145,341	90,000
Scenario 4	145,000	214,235	104,488	120,000

Source: Adapted from Appendix N

Further, as shown in Table 8.2, even though the ratio of CAP water use between scenario 2 and 4 is 1:2, the O&M costs of scenario 2 is less than scenario 4 by only 17 percent. This higher O&M costs of scenario 2 are associated with the extra costs involving recovering and pumping CAP water to CWF for domestic use. In addition, the O&M costs of scenario 4 is low because no pumping cost are needed to pump CAP water from CAP terminus to DMAFB and CWF recharge sites since it flows by gravity. Therefore, combining the CAV and DMAFB schemes results in low total costs relative to the amount of CAP water use.

8.2.2. Benefit Analysis

The present value of the major benefits of recharge scenarios consist of several components that include: (1) pumping cost savings, (2) value of groundwater saved, (3) value of selling CAP water, and (4) value of not constructing new wells and not treating effluent. Since there are no economic benefits associated with the baseline scenario, it has been omitted from this section. Table 8.3. presents only the recharge benefits associated with each recharge scenario under the 4 percent discount rate and minimum values of recharge benefits. The results in Table 8.3 indicate that the total benefits do not increase proportionally with the volume of CAP water use. As explained in the previous section, while the amount of CAP water used in scenario 3 is less than the amount used in scenarios 4 by 25 percent, its total benefits are $261 million which are double the total benefits of scenario 4 ($129 million).

Table 8.3. Major Recharge Benefits

US$ (000)	Pumping Cost Saving	GW Saved	Not Constructing Wells	Value of CAP water Use	Not Treating Effluent	Total Benefits
Scenario 2	46,987	1,035	18,767			**66,791**
Scenario 3	47,672	40,031	18,767	104,081	50,689	**261,242**
Scenario 4	48,035	62,387	18,767			**129,189**

Source: Adapted from Appendix O

It is important to note that the total benefits of each recharge scenario are represented by the project accomplishment rather than by the total amount of CAP water use. For example, since much of the CAP water recharged in scenario 2 is recovered simultaneously, scenario 2 does not generate enough benefits in terms of reducing pumping lift and saving groundwater, so that its total benefits are only $67 million over the planning period. However, when it is combined with DMAFB scheme to form scenario 4, the total benefits increased to $129 million. This does not mean that DMAFB scheme generates greater benefits than scenario 2, but when they are combined they do; by itself, the DMAFB scheme cannot generate enough benefits to cover even its costs. The total benefits of scenario 4 are derived from pumping cost saving and from the value of groundwater saved. When scenario 2 is combined with the RWS scheme to form scenario 3, the total benefits increase to $261 million. As shown in Table 8.3, the major benefit of scenario 3 is derived from the use of 13,000 af/yr of CAP water instead of reclaimed water.

8.2.3. Summary Analysis of the Base Case

The above results seem to indicate that adding the RWS and DMAFB schemes to scenario 2 generates large benefits. However, such a conclusion is misleading. It is very important to note that the volume of water available for recharge through the RWS and DMAFB schemes by themselves could not augment the CWF, or even partially offset the groundwater withdrawal from the CWF. Therefore, it is necessary to combine one of them with the CAV scheme (scenario 2) in order to use CAP water more economically.

Regardless of whether CAP water is recharged in the CWF area or not, or whether CAP water is used instead of reclaimed water, recharging CAP water in the CAV is a necessary condition to offset groundwater overdraft from CWF, at least for the short term. Without recharging and recovering CAP water in the CAV, the total groundwater withdrawal from the CWF would be 2.3 maf over the planning period. However, because of the CAP water recharge and recovery from CAV, the total groundwater withdrawal from the CWF would be only 0.6 maf over the same period.

Finally, combining the CAV scheme (scenario 2) and RWS scheme or DMAFB scheme is a sufficient condition to augment CWF's aquifer. The major benefits actually derive from scenario 2, which decreases groundwater overdraft from the CWF by more than 75 percent, and stabilizes groundwater level at 259 ft. Given scenario 2's benefits. the total benefits of scenario 3 and 4 are increased.

8.3. Net Present Value

Since the recharge scenarios are the means by which it is hoped to achieve the maximum utilization of CAP water, the present value of costs and benefits are calculated in the following section in per acre-foot (af) of CAP water used rather than in total, because it is easier to formulate the costs and benefits in terms of CAP water use. This is done by dividing the total costs and benefits by the total amount of groundwater withdrawal from the CWF in the baseline scenario and total CAP water use in scenarios 2, 3, and 4 throughout the entire planning period (1998-2025) as shown in Table 8.4.

Table 8.4. Net Present Value for the Base Case

US$/af	Cost	Benefit	NPV	Total Water Use (000) (af)
Baseline	33.2	0.0	-33.2	2,259
Scenario 2	162.8	41.2	-121.6	1,620
Scenario 3	161.8	107.5	-54.3	2,430
Scenario 4	145.7	39.9	-105.8	3,240

Source: Adapted from Appendix Q

This study utilizes two criteria for determining which scenario is preferable economically: the first criteria is the lowest cost project and highest volume of CAP water usage. By this criteria, scenario 4 would be the best choice from Table 8.4. The second criteria is reached by determining the minimum benefits that are necessary to make each recharge scenario economically viable relative to the baseline scenario. This is be done by comparing the present value of benefits relative to CAP water use.

Strictly speaking, the NPV per acre foot of CAP water use for all the scenarios are negative at the minimum values of $30/af for water saved, $225/af for avoiding O&M cost of treating effluent, and $462/af for using CAP water instead of reclaimed water as described in Chapter 5. As shown in Table 8.4, the baseline scenario has the highest estimated NPV under the base case assumption of a 4 percent discount rate and minimum benefit values. As explained earlier, the low baseline cost compared to the recharge scenarios is due to the fact that major costs associated with the baseline scenario are not included.

Therefore, the analysis in this section will concentrate on the NPV of recharge scenarios. The highest NPV among the recharge scenarios is for scenario 3. This is because the value from using CAP water instead of reclaimed water is relatively high. The smallest estimated NPV is negative \$121.6 per af in scenario 2, because CAP water is recharged and recovered simultaneously. It is true that scenario 2 also is part of scenario 3, but the benefits generated from using CAP water instead of reclaimed water outweigh some of the costs.

The estimates of the above total costs and total benefits are based on the estimation of major economic factors that include the O&M costs of the recharge scenarios, the cost of CAP water purchase, the energy cost, the selling price of CAP water, the value of groundwater saved, the cost and life of each recharge project, and the cost of producing reclaimed water. Many of these factors are subject to substantial uncertainty. In the above initial analysis or base case analysis the total costs and benefits are calculated with a single estimate for each of the uncertain factors; the results, as shown above, are negative NPVs. Since it is difficult to estimate the cash flow of each project accurately, this study considers a range of possible values for each cost and benefit component which are generally considered as uncertain. This can be achieved by conducting simulation analyses of the major factors that impact the costs and benefits of each recharge scenario.

8.4. Simulation Framework and Results

One way to study the possible outcomes of the recharge scenarios is to perform a sensitivity analysis on each of them. This analysis reveals how the NPV will change in response to a given change in the costs and benefits components. It is conducted based on variations in the following variables: (1) discount rates, (2) value of groundwater saved, (3) values of avoiding having to treat effluent to reclaimed water standards, and (4) the values of using CAP water instead of reclaimed water. As explained in Chapter 5, the initial analysis was conducted at a 4 percent discount rate and with minimum values of the recharge benefits components. Table 8.5 shows the variations of each economic variable for each scenario.

As shown in Table 8.5, the discount rate is changed by 25 percent above and below the base case discount rate of 4 percent. As explained in Chapter 5, the value of groundwater saved would increase from \$30 per af to \$58 per af between the low and the mid range, and then from \$58 per af to \$103 per af between the mid to the high range to reflect different prices of groundwater saved. The savings from not treating effluent would increase over the base case of \$225 per af by 1 percent per year in the mid value, then by 2 percent per year in high value to reflect a range of expected average costs of treating effluent. The sale price of CAP water for golf courses is allowed to increase from $462 per af to $607 per af between the low and the mid range, and then from $607 per af to $758 per af between the mid to the high range as explained in Chapter 5.

Table 8.5. Alternative Values for Simulation Analysis

	Baseline			Scenario 2			Scenario 3			Scenario 4		
	Low	Mid	High	Low	Mid	High	Low	Mid	High	Low	Mid	High
Discount Rate (%)	3	4	5	3	4	5	3	4	5	3	4	5
Value of Groundwater Save ($)				30	58	103	30	58	103	30	58	103
Value of Not Treating Effluent ($)							225	1%[18]	2%			
Value from selling CAP water ($)							462	607	758			

Source: Obtained from Chapter 5

[18] The O&M costs per af of reclaimed water is $225. For this simulation analysis, the future cost of treating effluent increases by 1 percent per year, and at the maximum by 2 percent per year.

8.4.1. Discount Rate Simulation

Using the base case with minimum values of recharge benefits and a 4 percent discount rate, the discount rate will be changed by 25% above and below the base case. Table 8.6. summarizes the results of varying the discount rates.

Table 8.6. The Results of Varying Values of Discount Rates

	3%			4%			5 %		
US$/af	Cost	Benefit	NPV	Cost	Benefit	NPV	Cost	Benefit	NPV
Baseline	36.6	0.0	**-36.6**	33.2	0.0	**-33.2**	30.4	0.0	**-30.4**
Scenario 2	178.3	45.1	**-133.2**	162.8	41.2	**-121.6**	149.7	38.0	**-111.7**
Scenario 3	177.5	119.3	**-58.2**	161.8	107.5	**-54.3**	148.6	97.5	**-51.1**
Scenario 4	158.1	44.1	**-114.0**	145.7	39.9	**-105.8**	135.2	36.4	**-98.9**

Source: Adapted from Appendix Q

As shown in Table 8.6, the effect of the discount rate on recharge benefits is essentially in inverse proportion. Decreasing the discount rate from 4 percent to 3 percent, results in increasing the costs and benefits. For example, the benefits of scenario 3 increases from $107 per af to $119 per af. On the other hand, when the discount rate increases from 4 percent to 5 percent, the benefits decrease for all scenarios. The benefits of scenario 3 decrease from $107 per af to $98 per af.

It is apparent from the discounting equations that as the discount rate gets larger, the benefits get smaller and smaller, and NPV also gets larger. For example, with a change from 4 percent to 5 percent for Scenario 3, the NPV would change from negative $54 to negative $51.1. The reason that the NPV increases rather than decreases is because since the total costs are greater than total benefits, the costs get penalized proportionally more as the discount rate increases, while the total benefits are penalized proportionally less. Therefore, the NPV gets larger.

In general, simulation of the discount rate only has a small effect on the results (Table 8.6). Therefore, since the discount rate is not a major concern, the rest of the simulations will be with a 4 percent rate.

8.4.2. Simulation 1: Mid Value of Recharge Benefits

This simulation is different from the previous one is that it will examine whether changing of the value of recharge benefits would significantly influence the NPV of each recharge scenario. The value of the recharge benefits in the first analysis was assumed to be a minimum value, with the result, as noted, of a negative NPV. However, when those scenarios are examined relative to each other, scenario 3 is more economically viable than the baseline or the other two recharge scenarios. At mid value, the future recharge benefits were estimated assuming a \$58/af for water saved, a 1 percent increase per year of the \$225 per af O&M costs of treating reclaimed water, and \$607/af for using CAP water instead of reclaimed water.

The effect of changing the values of benefits, as shown in Table 8.7, is proportional to the component of recharge benefits. It is clear from Table 8.7 that the most economically favorable scenario under the mid value conditions is still scenario 3, which generates a negative NPV of \$23 per af. The other NPVs are still highly negative, but they increase proportionally with increasing the values of recharge benefits. There is a possibility that the results of NPV would be improved increasing the value of recharge benefits by even higher.

Table 8.7. Net Present Value for Mid Value Simulation

US$/af	Cost	Benefit	NPV
Baseline	33.2	0.0	-33.2
Scenario 2	162.8	41.8	-121.0
Scenario 3	161.8	138.8	-23.0
Scenario 4	145.7	57.8	-87.8

Source: Adapted from Appendix Q

8.4.3. Simulation 2: High Value of Recharge Benefits

Under the high value simulation, the value of groundwater saved would increase from $58 per af to $103 per af, the value of not treating effluent would increase by 2 percent per year, and the sale price of CAP water to be used for golf courses would increase from $607 per af to $758 per af. The results are presented in Table 8.8.

Table 8.8. Net Present Value for High Value Simulation

US$/af	Cost	Benefit	NPV
Baseline	33.2	0.0	-33.2
Scenario 2	162.8	42.8	-120.0
Scenario 3	161.8	180.4	18.6
Scenario 4	145.7	86.7	-58.9

Source: Adapted from Appendix Q

Table 8.8 shows an increase in the NPV of the recharge scenarios as a result of increasing the value of recharge benefits. However, with higher values, the NPVs of recharge scenarios 2 and 4 are still negative. Relatively, scenario 3 accrues more benefit with the increase in value of recharge benefits. The NPV of scenario 3 increases from negative $23 in the previous simulation to positive $18.6 per af. The major factors that serve to increase the NPV of scenario 3 are: (1) the utilization of CAP water instead of reclaimed water and (2) the utilization of the reclaimed water system. The total amount of CAP water used for recharge and for replacing reclaimed water is 90,000 af/yr., of which 60,000 af/yr., and 17,000 af/yr., would be recharged in the CAV and CWF, respectively; the other 13,000 af/yr., being used instead of reclaimed water in the CWF area.

Even though scenario 3 demonstrates a positive NPV, it is very is sensitive to the price and quantity of CAP water that can be sold for non-potable purposes. Therefore, six additional simulation analyses for scenario 3 are conducted to demonstrate the sensitivity of this scenario's NPV (Table 8.9). The alternative values are categorized in Table 8.9 as follows: the price of groundwater saved, the value of the cost savings of treating effluent and the price of CAP water sold for non-potable purposes.

As shown in Table 8.9, at $103 per af for groundwater saved and with a 2 percent annual increase in O&M costs of reclaimed water ($225 per af), and at the selling price of CAP water for non-potable purposes, the NPV is positive $18.59 per af. When the value of the O&M cost of treating effluent decreases from 2 percent to 1 percent, keeping the other variables constant, the NPV decreases from $18.59 per af to $15.69 per af. Further, when the O&M costs of treating effluent are kept constant at $225 per af, the NPV decreases further to $13.20.

In addition, when the value of groundwater saved and the price of CAP water sold for non-potable purposes is kept constant for scenario 3 at $103 per af and $607 per af, respectively, while the value of the O&M costs of treating effluent changes from 2 percent to 1 percent, the NPV decreases from $4.60 per af, to $1.69 per af. When the value of treating effluent is kept constant at $225 per af along with the other values, the NPV becomes negative. Furthermore, when the value of groundwater saved decreases from $103 per af to $58 per af, while keeping the value of cost savings and sales of CAP water at the highest level, the NPV becomes more negative. Simulation results indicate that magnitude of the NPV is related to the range of assumed values of recharge scenario benefits.

Table 8.9. Additional Simulation Analysis of Scenario 3

Alternatives Values	Total NPV ($000)	NPV ($/af)
$103,2% and $758	45,186	18.59
$103,1% and $758	38,115	15.69
$103, $225 and $758	32,083	13.20
$103,2% and $607	11,168	4.60
$103,1% and $607	4,097	1.69
$103, $225 and $607	(1,935)	-0.80
$58,2% and $758	(14,861)	-6.12

8.5. Institutional Assessment Results

It is also important to note that the major benefits achieved by scenario 3 are as follow: (1) halting the groundwater overdraft from the CWF, (2) recovering enough groundwater in the CWF to increase groundwater levels from 250 feet in 1998 to 223 feet in 2025, (3) savings from decreasing pumping cost relative to the pumping cost of the baseline scenario, and (4) utilizing 90,000 af of CAP water through recharge. While it has potential economic benefits, it also meets the institutional requirement of achieving Safe-Yield goal (SY) and the augmentation policy of Consumer Protection Act as shown in Table 8.10. It is important to note that while scenario 4 has a negative NPV, it raises the groundwater table to a higher level than that of scenario 3, and it meets the goal of SY and CPA provisions.

Table 8.10. Institutional Benefits of Scenarios

	GW Level	CPA	SY
Baseline	386	No	No
Scenario 2	259	No	No
Scenario 3	223	Yes	Yes
Scenario 4	204	Yes	Yes

8.6. Benefit-Cost Ratio

The results obtained from the previous section indicate that scenario 3 is the most feasible institutionally and economically. However, such results do not indicate how the project is economically feasible relative to costs and available budget. Pearce (1983) stated that at given budget constraint, the NPV is, in fact, only a necessary condition for choosing a project, but it is not sufficient, because it does not reflect the cost of the project relative to the budget available. To consider the budget constraint in the economic analysis of a project, Pearce (1983) suggests the use of a Cost-Benefit Ratio, which is the outcome of dividing the present value of benefits by the present value of costs (Table 8.11).

Table 8.11. Benefit-Cost Ratio

US$	Cost	Benefit	BCR
Scenario 2	162.8	42.8	0.26
Scenario 3	161.8	180.4	1.11
Scenario 4	145.7	86.7	0.60

Source: Adapted from Appendix Q

Examining the Benefit-Cost ratio (BCR) in Table 8.11 indicates that scenario 3 is also the most preferable economically. The baseline scenario is not included because there are no benefits.

8.7. Land Subsidence

The above analyses use the Central Wellfield area as a case study for examining the economic benefits to artificial recharge in the Tucson AMA. In general, there are several possible economic benefits from groundwater recharge that include: (1) reduction of pumping lift, (2) preventing land subsidence, (3) using the aquifer for storage, treatment, and conveyance, and (4) using recharge facilities for recreational purposes (Reichard, 1984). Due to the lack of data to measure all of these potential benefits, this study quantified only the economic benefits from (1) reducing pumping lift in terms of pumping cost savings, (2) using the aquifer fcr storage in terms of groundwater saved, (3) the value of replacing reclaimed water with CAP water, and (4) cost savings from not treating effluent and not constructing new wells. The general results of this analysis indicate that the discounted benefits derived from these elements are less than the discounted costs of CAP water recharge, except for scenario 3 at the higher and mid values of recharge benefits.

A simple comparison of the results leads one to conclude that recharge projects are almost certainly economically unfeasible. Such a simple conclusion is due to the fact that other potential benefits of CAP water recharge are not measured, such as land subsidence avoided. There are two professional studies conducted by U.S. Geological

Survey which indicate that the Tucson AMA is highly vulnerable to land subsidence by the year 2024, if groundwater overdraft continues at the 1986 pumpage rate.

Hanson and Benedict (1994) concluded in their *Simulation of Groundwater Flow and Potential Subsidence*, that a maximum potential subsidence for 1987-2024 ranges from 1.2 feet for an inelastic specific storage of 1.0×10^{-5} per foot, to 12 feet for an inelastic specific storage of 1.5×10^{-4} per foot. The land subsidence simulations were based on the pumpage and recharge rates from 1986 and a preconsolidation stress threshold of 100 feet. Further, a maximum potential subsidence in the Avra Valley basin for the period 1985 through 2024 ranges from 0.9 feet for an inelastic specific storage of 1.0×10^{-5} per foot to 14.7 feet for an inelastic specific storage of 1.5×10^{-4} per foot, on the basis of pumpage and recharge rates from 1973 through 1977 and a preconsolidation stress threshold of 100 feet (Hanson et al, 1990).

Given such vulnerability to land subsidence and because there are no cost estimations of land subsidence in the Tucson AMA, it is important to consider how large the potential cost savings of preventing land subsidence must be to justify recharge scenarios that otherwise seem to be a poor use of scarce funds. To obtain such a rough estimate, a technique used in cost-benefit analysis to address missing information on benefits and costs is utilized.

8.7.1. Technique to Estimate Unmeasurable Costs and Benefits

This technique is explained in Kahn (1998) for application to an incomplete cost-benefit analysis. It is conducted by taking the difference between the measured benefits and measured costs and then examining whether unmeasured benefits or costs are likely to fall in the range of the difference between measured costs and benefits. Since the difference between costs and benefits in this study is just simply the NPV, the first step to apply this technique is to convert the NPV of each recharging scenario into an equivalent stream of annual NPVs. This is done by utilizing a geometric series formula of:

$$\text{Total NPVs} = X + X\left[\frac{1}{1+r}\right]^1 + X\left[\frac{1}{1+r}\right]^2 + X\left[\frac{1}{1+r}\right]^3 + \ldots\ldots X\left[\frac{1}{1+r}\right]^n +$$

Where X= unknown annual benefits for which one solves the equation, r = a decimal fraction. When "*n*" approaches infinity and $0<[\frac{1}{1+r}]<1$, then annual NPV (X in the above equation) will be approximated as follows:

$$\text{Annual NPV} = \text{Total NPV}\ [1/(1-[\frac{1}{1+r}])]$$

Given the base case estimation of total costs, benefits, and NPVs as reported in Appendix P (Low Value of Benefits at 4 Percent Discount Rate), and r = 0.04 and n approaching infinity, the convergence of the geometric series would be 0.03846[19]. Multiplying this figure by the total NPVs, yields the approximated annual NPV as shown in Table 8.12.

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[19] This decimal is calculated from $\{1/(1-[\frac{1}{1+0.04}])\}$.

Table 8.12. The Annual Net Present Values of Recharge Scenarios

US$ (000)	Total Costs	Total benefits	Total NPV	Annual NPV
Scenario 2	263,708	66,791	196,917	7,574
Scenario 3	393,253	261,242	132,011	5,077
Scenario 4	471,970	129,189	342,780	13,184

Source: Adapted from Appendix P

Table 8.12 indicates that the annual NPV for scenario 2 is $7.6 million per year (mpy), for scenario 3 is $5 mpy and for scenario 4, it is $13 mpy. Now, If the benefits of avoiding subsidence damage are greater than or equal to the annual NPV, then the recharge scenarios would have a positive NPV. The question is, "Are the expected annual range of land subsidence costs likely to exceed the range between $5 mpy and $13 mpy within Tucson AMA?

In general, the consequences from the projected subsidence in Tucson aquifer could include permanent reduction of aquifer storage, as well as damage to highways, railroads, building, aqueduct, irrigation system, wells, and sewage systems (Hanson and Benedict, 1994). In fact, subsidence of as much as 12.5 ft, water level-decline of 300 ft (Laney, and others, 1978), and related earth fissures have already occurred in the adjacent Picacho basin just north of Tucson (Carpenter, 1991).

Reichard and Bredehoeft (1984) stated that the actual subsidence damage depends on geographic location and the type of structure. For a particular structure, incremental damage after the first several feet of subsidence is likely to be small. As subsidence occurs over time, however, different structures are affected. Therefore, the total costs of subsidence damage to all affected structure may be close to linear. For this study, the assumption is that the damages will be linear over the entire Tucson AMA and the average present cost are distributed equally among households. The following section elaborates the possibility of the cost saving from preventing land subsidence.

8.7.2. The Average Annual Cost Saving

One of the ways to evaluate the annual level of benefits or cost savings that are required to make the NPVs of the recharge scenarios is equal to zero is to find the annual average value per household. As shown in Table 8.12, the range of the annual NPV is from \$5 mpy to \$13 mpy. Dividing the annual values by the number of households, yields an average unit of needed benefits or cost savings per household. This could be done in two ways: the first is to divide the annual NPV by the total number of households in the Tucson AMA; the second is to divide it only by the households in the CWF area because it is the most vulnerable for future land subsidence.

Using the 1994 Tucson AMA population of 712,888 and the average number of people per household in Pima County at 2.49, the number of households in Tucson AMA is 286,300. Dividing the range of annual NPVs by the total number of households in the Tucson AMA, yields the annual amount of benefits or cost savings of recharge to avoid land subsidence or to make NPV equal zero as shown in Table 8.13.

Table 8.13. Annual NPV per Household in the Tucson AMA.

Scenarios	Annual NPV	Annual NPV per Household
	$/yrs	*$/yr/household*
Scenario 2	7,573,733	26.45
Scenario 3	5,077,363	17.73
Scenario 4	13,183,865	46.05

However, since the projected land subsidence is expected to occur within the central area of the city of Tucson, it is reasonable to estimate the annual average cost per household within the central area rather than within the whole Tucson AMA. By using the 1994 central area population of 496,083 and the average number of people per household in Pima County at 2.49, the number of households in central area is 199,230. Dividing the range of annual NPVs by the total number of households in the central area, yields the annual average cost saving per household as shown in Table 8.14.

Table 8.14. Annual NPV per Household in the Central Area.

Scenarios	Annual NPV	Annual NPV per Household
	$/yr	*$/yr/household*
Scenario 2	7,573,733	38.01
Scenario 3	5,077,363	25.48
Scenario 4	13,183,865	66.17

Given the fact that most of the city of Tucson residential areas are located in the central area, this study will use the average construction costs for new homes in Tucson, which is $70 per square foot, for comparisons to land subsidence damage of homes (Mneimneh, 1998). Ideally, data on home repair costs would be useful but since such data are unavailable, new construction costs give a context for considering how much subsidence related costs might be on a per household basis. For example, if land subsidence damages one square foot of a home per year, the economic feasibility of recharge scenarios would pass the cost benefit test, because the annual benefits or cost savings from avoiding land subsidence that are required to make NPV = 0 are less than $70 as shown in Table 8.13 and 8.14.

8.8. Summary

From the previous simulations, it is clear that none of the measurable economic benefits associated with recharge scenarios 2 and 4, would be large enough to make them cost-effective for long-term planning. Therefore, any justification for a recharge option will come not from an economic point of view, but from a political viewpoint, the purpose being to find ways to keep CAP water in the area. For those who support the maximum use of CAP water for recharge purposes only, scenario 4 will give a better solution, even though the NPV of scenario 4 is negative. Its value is still higher than scenario 2 and even higher than the baseline scenario. For those who are in favor of utilizing CAP water for non-potable purposes, scenario 3 is the best alternative.

Conducting additional sensitivity analyses of scenario 3 by changing the recharge benefits between mid and high values, gives several choices of utilizing CAP water for recharge and for non-potable purposes. Finally, since NPVs are negative for recharge scenarios at low benefit values and 4 percent discount rates, this study uses a technique to examine how large unmeasurable benefits such as land subsidence would need to be to justify a recharge scenario. This technique estimates the average benefits or cost savings that are required to make NPV equal zero. The results indicate that the additional benefits or cost savings required to make the NPVs equal to zero appear to be small. This suggests that when unmeasured but potentially important benefits of avoiding land subsidence are considered, recharge scenarios become economically feasible.

Chapter 9: Summary and Conclusions

9.1. Summary

The Tucson Basin, located in a semi-arid region, faces escalating pressure on its groundwater resources associated with rapid urbanization and population growth. Since the city of Tucson is the second largest metropolitan area in the state and because of fears that the declining water table will threaten the city's development, groundwater overdraft has been a growing concern among city planners, industry, mining companies and agricultural interests over the past 50 years. For these reasons, bringing water from Colorado River via the Central Arizona Project (CAP) was perceived as the sole solution for Tucson's water shortage problem. As soon as CAP water arrived in Tucson in 1992, its quality provoked a quarrel over its use for potable purposes. The most significant outcome of that quarrel was the enactment of the 1995 Consumer Protection Act (CPA).

The primary objective of the CPA is to preclude the use of CAP water for potable purposes unless it is treated to achieve the same quality as the groundwater previously supplied. The CPA has prohibited the use of CAP water for potable purposes until at least the year 2000, and it encourages its use for non-potable purposes and for replenishing the Tucson aquifer through recharge. Even though the CPA recommended several alternatives for utilizing CAP water, the recharge alternative has gained priority over all others due to the fact that artificial recharge has been perceived to offer a number of benefits. One of the major benefits of recharge is the prevention of further decline in the groundwater level, thereby reducing the threat of land subsidence and saving energy costs that would be necessary for pumping at greater depths.

The major goal of this dissertation was to assess the economic and the institutional aspects of recharging CAP water in the Tucson AMA. The purpose of the economic assessment was to test the hypothesis that the economic benefits realized from reduced pumping lifts and saved groundwater exceed their costs. The aim of the institutional assessment was to examines how effective the use of CAP water through recharge would be in terms of qualifying the TWD to meet the Safe-Yield goal and CPA provisions. These assessment were conducted by developing four planning scenarios to measure and compare the costs and benefits with and without CAP water recharge.

The first scenario is a baseline scenario which it is a benchmark from which to measure the costs and benefits associated with the other three recharge scenarios. The baseline scenario assumes no CAP water use and groundwater withdrawal will be continued from CWF throughout the planning period (1998-2025). The other three scenarios incorporated different volumes of CAP water recharge within the Tucson and Avra Valley basins. The first recharge scenario assumes 60,000 af/yr of CAP water would be recharged and recovered simultaneously from Central Avra Valley (CAV). The second recharge scenario assumes that in addition to the 60,000 af/yr of CAP water recharge in the CAV, an extra 30,000 af/yr of CAP water would be delivered through Reclaimed Water System to CWF area. Of the 30,000 af/yr, 17,000 af/yr would be recharged in the CWF stream channel and 13,000 af/yr would be used for irrigating turf grass.

The third recharge scenario assumes that in addition to the 60,000 af/yr of CAP water recharge in the CAV, an extra 60,000 af/yr of CAP water would be delivered from CAP Terminus to a location south of the Davis-Monthan Air Force Base (DMAFB), where 26,000 af/yr would be conveyed to CWF area for recharge in the streamchannel and the remaining 34,000 af/yr would be recharged within DMAFB area.

After developing a cash flow and estimating the net present value for each scenario, a simulation analysis was conducted on parameters of the base case analysis, including the discount rate, the value of CAP water recharged, the price of CAP water used for non-potable purposes, and the cost saving from not treating effluent. The results of these simulations indicate that utilizing CAP water through groundwater recharge is not economically justified. However, combining the use of CAP water for groundwater recharge and for non-potable purposes, as demonstrated by the results of scenario 3, would not only augment the water table, but also result in savings of groundwater as well as decreasing pumping costs. Given the assumptions of this study, scenario 3 demonstrated potentially positive net benefits over the baseline scenario. When conducting additional sensitivity analyses of scenario 3 with various combinations of mid and high values, scenario 3 demonstrated positive and negative NPVs.

Finally, a simple comparison between the baseline scenario and recharge scenarios leads one to conclude that recharge projects are almost certainly economically unfeasible. However, this conclusion is due to the fact that other potential benefits of CAP water recharge are not measured, such as avoided land subsidence. This study examined the sensitivity of NPV to such unmeasurable benefits. This technique estimates the average benefits or cost savings that are required to make NPV equal zero. The results indicate that the additional benefits or cost savings required to make the NPVs equal to zero appear to be small on a per household basis. This suggests that the recharge scenarios are economically feasible if subsidence damage represents a genuine economic concern.

9.2. Credibility of the Economic Assessment Methods

As shown in the previous section, the aim of the economic assessment is to determine whether artificial recharge is the most economic way of handling CAP water. It might be true that these results represent what will truly happen with the recharge scenarios. However, nobody knows for sure because quantifying the economic benefits from groundwater recharge depends very much upon hydrogeologic parameters, such as storage coefficients, transmissivity values, and the existence of impermeable zones (Supalla et al, 1982).

To establish these parameters would require not only an extensive data collection and modeling effort, but also require long term investigation. Since this study is only an exploration effort to measure the economic benefits from groundwater recharge as a result of the enactment of CPA in 1995, with the available data of the hydrological characteristics of the Tucson aquifers, it approximates the effect of groundwater recharge with simplifying models, like those discussed in Chapter 5. However, it is important to note that measuring the impact of groundwater recharge with high accuracy would also require a detailed specification of how recharge water influences the water quality and water table configuration, which by itself would require intimate knowledge of each recharging site.

In either case using simplifying models or highly sophisticated models, the goal of recharging CAP water in Tucson AMA is to maximize its use and to augment Tucson aquifer. In recognition of that, this study used a simplified models with secondary data to measure the expected benefit of groundwater recharge. Yet, this study is a pioneer in quantifying some of the physical and economic benefits from CAP water recharge in Tucson AMA.

9.3. Limitations of the Analysis

There are several limitation of the approach used in this study: First, because no economic studies were available regarding the demand for water, the water demand data were taken from a secondary source and its projection was based on population growth and on the assumption of reducing per capita water consumption due to conservation efforts and greater use of reclaimed water. This projection does not take into consideration the impact of the major economic and weather factors on water demand such as price, income, and seasonal changes. Specifically, it does not reflect the impact of relative price and income changes on water use and the impact of seasonal changes on water demand by different categories of users such as residential, commercial, and industrial.

Second, measuring the impacts of groundwater recharge with high accuracy would require a detailed specification of how recharge water influences the water quality and water table configuration which by itself would require intimate knowledge of each recharging site. In recognition of the lack of reliable data regarding the impact of CAP water recharge on water quality and the water table, the recharge benefits of the recharge scenarios were estimated using simplified models incorporating hydrogeological parameters such as specific yield. For example, this study assumes a 10 percent specific yield throughout the study area and the planning period.

Third, the baseline scenario of this study assumed that no CAP water will be used and groundwater withdrawal will continue from CWF throughout the planning period. Barring major institutional changes, however, this scenario is not feasible because of the GMA's 100 year assured water supply requirement. In addition, the costs associated with the baseline scenario that may result from land subsidence or from fines imposed as a result of failure to meet the Safe-Yield goal and Assured Water Supply requirement were omitted from this analysis.

Finally, scenario 3 (which demonstrates the greatest economic potential for positive net present value) is very sensitive to assumptions about the price and quantity of CAP water that can be sold for non-potable purposes, mainly golf courses and other turf grass uses. The inability to sell the assumed quantities at the assumed prices would potentially reduce the expected benefits of this scenario.

9.4. Future Research

As mentioned previously, this study used secondary data for water demand and simplified models to measure the expected benefits of groundwater recharge. Comprehensive and interdisciplinary research is recommended to evaluate the economic and hydrologic impacts of CAP water recharge in the Tucson AMA. An urgent need exists for an economic analysis of the demand of water by the different categories of users in the Tucson AMA that includes residential, industrial, agricultural, and Indian communities.

Artificial recharge in the Tucson Basin is a relatively a new idea and there is a continuing debate on the long-term hydrologic impacts of CAP water recharge on water table elevation, infiltration rate, and water quality. To answer some of the technical questions, hydrologic studies have been initiated in a pilot-study phase for the last two years. These studies will help to specify the spatial and quality responses of CAP water recharge in potential recharge sites in the CAV and near the Pima Mine Road. The availability of a more sophisticated the hydrologic model to better estimate hydrologic impact of CAP water recharge on water quality is critical because it is the main reason of not using CAP water directly.

Further, Hanson (1994) stated that if groundwater withdrawal continues at the current rate of pumping, a land subsidence of 12 feet will occur in the CWF area by year

2025. Comprehensive engineering and economic studies of the impact of land subsidence on the City of Tucson's infrastructure are needed to more thoroughly evaluate the potential economic benefits of groundwater recharge. Finally, since using CAP water for agriculture is a reasonable match of water quality with type of use and allows groundwater use by municipal users that can not use CAP water directly, it is desirable to conduct research on how much subsidy would it take to make the use of CAP water economically attractive for agriculture and the mining industry located south of Tucson.

APPENDIXES

Appendix A: GWL Decline and O&M Costs of the Baseline Scenario

Year	Projected Water demand	Projected GW demand	GW Pumpage from CWF[1]	GW Overdraft from CWF	Average GWL Decline	GWL	O&M Cost[2]	Total O&M Costs	O&M costs discounted		
	af/yr	af/yr	af/yr	af/yr	feet/yr	feet	$/af	$/yr	3%	4%	5%
		0.000	0.000	0.000				0.000	0.000	0.000	0.000
1998	117,378	105.89	69	52	4.07	250	33.9	2336	2,336	2,336	2,336
1999	119,347	107.31	70	53	4.15	254	34.5	2406	2,336	2,314	2,292
2000	121,316	108.73	71	54	4.22	258	35.1	2479	2,336	2,292	2,248
2001	123,294	110.17	72	55	4.29	263	35.7	2553	2,336	2,270	2,205
2002	125,272	111.61	73	56	4.36	267	36.2	2629	2,336	2,248	2,163
2003	127,251	113.05	73	57	4.44	271	36.8	2707	2,335	2,225	2,121
2004	129,229	114.48	74	58	4.51	276	37.5	2787	2,334	2,203	2,080
2005	131,207	115.92	75	59	4.58	281	38.1	2869	2,333	2,180	2,039
2006	132,901	117.07	76	59	4.64	285	38.7	2946	2,325	2,152	1,994
2007	134,595	118.23	77	60	4.70	290	39.3	3024	2,317	2,124	1,949
2008	136,289	119.38	78	61	4.76	295	40.0	3103	2,309	2,097	1,905
2009	137,983	120.53	78	62	4.82	299	40.6	3185	2,301	2,069	1,862
2010	139,677	121.68	79	62	4.88	304	41.3	3267	2,292	2,041	1,819

[1] Estimated at 65% of groundwater withdrawal by Tucson Water Department

[2] For 100 % pumping efficiency, it would require 1.024 kWh. With a cost per kWh of $0.06 and pumping efficiency of 60%, plus $0.02 deepening cost, the pumping cost per acre-feet (af) in Tucson AMA is $0.1357

Appendix A: *Continued*

Year	Projected Water demand	Projected GW demand	GW Pumpage from CWF	GW Overdraft from CWF	Average GWL Decline	GWL	O&M Cost	Total O&M Costs	O&M costs discounted		
	af/yr	af/yr	af/yr	af/yr	feet/yr	feet	$/af	$/yr	3%	4%	5%
		0.000	0.000	0.000				0.000	0.000	0.000	0.000
2011	141,528	122.99	80	63	4.94	309	42.0	3356	2,285	2,016	1,780
2012	143,378	124.30	81	64	5.01	314	42.7	3447	2,279	1,990	1,741
2013	145,229	125.61	82	65	5.08	319	43.4	3539	2,272	1,965	1,703
2014	147,079	126.92	82	66	5.14	325	44.0	3634	2,265	1,940	1,665
2015	148,930	128.23	83	67	5.21	330	44.8	3730	2,257	1,915	1,628
2016	150,896	129.66	84	68	5.28	335	45.5	3832	2,251	1,892	1,592
2017	152,861	131.08	85	68	5.35	340	46.2	3936	2,245	1,868	1,558
2018	154,827	132.51	86	69	5.43	346	46.9	4042	2,238	1,845	1,524
2019	156,793	133.93	87	70	5.50	351	47.7	4151	2,231	1,822	1,490
2020	158,759	135.35	88	71	5.57	357	48.4	4262	2,224	1,798	1,457
2021	160,930	136.98	89	72	5.65	363	49.2	4381	2,220	1,778	1,426
2022	163,100	138.61	90	73	5.74	368	50.0	4504	2,215	1,757	1,396
2023	165,271	140.24	91	74	5.82	374	50.8	4628	2,211	1,736	1,367
2024	167,441	141.87	92	75	5.90	380	51.6	4756	2,205	1,715	1,338
2025	169,612	143.50	93	77	5.99	386	52.4	4887	2,200	1,695	1,309
Total	**4,002,373**								**63,826**	**56,282**	**49,986**

Appendix B: O&M Costs for Scenario 2

Year	CAP water Cost ($/af)	Total CAP water cost	Total CAP Water discounted			Total O&M Costs in CAV	O&M cost discounted		
	Increase by 1%/yr	$/yr (000)	3%	4%	5%	$/yr (000)	3%	4%	5%
1998	71	4260	4260	4260	4260	4560	5152.8	5152.8	5152.8
1999	82	4920	4777	4731	4686	4560	5002.7	4954.6	4907.4
2000	87	5220	4920	4826	4735	4560	4857.0	4764.1	4673.7
2001	91	5460	4997	4854	4717	4560	4715.5	4580.8	4451.2
2002	93	5580	4958	4770	4591	4560	4578.2	4404.6	4239.2
2003	94	5640	4865	4636	4419	4560	4444.9	4235.2	4037.4
2004	104	6240	5226	4932	4656	4560	4315.4	4072.3	3845.1
2005	104	6240	5074	4742	4435	4560	4189.7	3915.7	3662.0
2006	103	6180	4879	4516	4183	4560	4067.7	3765.1	3487.6
2007	104	6242	4784	4385	4024	4560	3949.2	3620.3	3321.5
2008	105	6304	4691	4259	3870	4560	3834.2	3481.0	3163.4
2009	106	6367	4600	4136	3723	4560	3722.5	3347.2	3012.7
2010	107	6431	4511	4017	3581	4560	3614.1	3218.4	2869.3
2011	108	6495	4423	3901	3445	4560	3508.8	3094.6	2732.6
2012	109	6560	4337	3788	3313	4560	3406.6	2975.6	2602.5
2013	110	6626	4253	3679	3187	4560	3307.4	2861.2	2478.6
2014	112	6692	4170	3573	3066	4560	3211.1	2751.1	2360.6
2015	113	6759	4089	3470	2949	4560	3117.5	2645.3	2248.1
2016	114	6827	4010	3370	2837	4560	3026.7	2543.6	2141.1
2017	115	6895	3932	3273	2729	4560	2938.6	2445.7	2039.1
2018	116	6964	3856	3178	2625	4560	2853.0	2351.7	1942.0
2019	117	7033	3781	3086	2525	4560	2769.9	2261.2	1849.6
2020	118	7104	3707	2997	2428	4560	2689.2	2174.3	1761.5
2021	120	7175	3635	2911	2336	4560	2610.9	2090.6	1677.6
2022	121	7247	3565	2827	2247	4560	2534.8	2010.2	1597.7
2023	122	7319	3496	2745	2161	4560	2461.0	1932.9	1521.6
2024	123	7392	3428	2666	2079	4560	2389.3	1858.6	1449.2
2025	124	7466	3361	2589	2000	4560	2319.7	1787.1	1380.2
Total			**120,583**	**107,117**	**95,803**		**99,588**	**89,296**	**80,605**

Appendix C: GWL Decline and O&M Costs of the Scenario 2

	Expected Water supply from CWF	GW Saved and Overdraft from CWF	Avg. GWL Decrease & Increase	Ground Water level	Total O&M cost	Discounted O&M costs in CWF		
	af/yr	*af/yr*	*Feet/yr*	*Feet*	*$/af*	*3%*	*4%*	*5%*
1998	8827	7923	-0.6	250.000	28.9	255	255	255
1999	9749	7001	-0.5	249.452	28.9	273	271	268
2000	10677	6073	-0.5	248.977	28.8	290	284	279
2001	11611	5139	-0.4	248.575	28.8	306	297	288
2002	12545	4205	-0.3	248.247	28.7	320	308	296
2003	13479	3271	-0.3	247.991	28.7	334	318	303
2004	14413	2337	-0.2	247.808	28.7	346	327	308
2005	15347	1403	-0.1	247.698	28.7	358	334	313
2006	16097	653	-0.1	247.647	28.7	364	337	312
2007	16846	-96	0.0	247.655	28.7	370	339	311
2008	17596	-846	0.1	247.721	28.7	375	341	310
2009	18345	-1595	0.1	247.846	28.7	380	342	308
2010	19095	-2345	0.2	248.029	28.7	384	342	305
2011	19945	-3195	0.2	248.279	28.7	390	344	304
2012	20796	-4046	0.3	248.595	28.8	395	345	302
2013	21648	-4898	0.4	248.979	28.8	400	346	300
2014	22499	-5749	0.4	249.428	28.9	405	347	297
2015	23350	-6600	0.5	249.94	28.9	409	347	295
2016	24276	-7526	0.6	250.53	29.0	413	347	292
2017	25202	-8452	0.7	251.19	29.1	418	348	290
2018	26128	-9378	0.7	251.93	29.1	422	348	287
2019	27054	-10304	0.8	252.73	29.2	425	347	284
2020	27980	-11230	0.9	253.61	29.3	428	346	281
2021	29040	-12290	1.0	254.57	29.5	433	347	278
2022	30098	-13348	1.0	255.62	29.6	438	347	276
2023	31158	-14408	1.1	256.74	29.7	442	347	273
2024	32217	-15467	1.2	257.95	29.8	446	347	270
2025	33276	-16526	1.3	259.25	30.0	449	346	267
Total						10,669	9,294	8,154

Appendix D: O&M Costs for Scenario 3

Year	CAP water Cost ($/af)	Total CAP water cost	Total CAP Water discounted			Total O&M Costs in RWS	O&M cost discounted		
	Increase by 1%/yr	$/yr (000)	3%	4%	5%	$/yr (000)	3%	4%	5%
1998	71	6390	6390	6390	6390	2862	3234	3282	3289
1999	82	7380	7165	7096	7029	2862	3140	3144	3115
2000	87	7830	7381	7239	7102	2862	3048	3012	2951
2001	91	8190	7495	7281	7075	2862	2960	2886	2796
2002	93	8370	7437	7155	6886	2862	2873	2766	2650
2003	94	8460	7298	6954	6629	2862	2790	2650	2512
2004	104	9360	7839	7397	6985	2862	2708	2540	2382
2005	104	9360	7611	7113	6652	2862	2630	2435	2259
2006	103	9270	7318	6773	6274	2862	2553	2334	2142
2007	104	9363	7176	6578	6035	2862	2479	2237	2032
2008	105	9456	7036	6388	5805	2862	2406	2145	1928
2009	106	9551	6900	6204	5584	2862	2336	2056	1830
2010	107	9646	6766	6025	5371	2862	2268	1972	1736
2011	108	9743	6634	5851	5167	2862	2202	1891	1648
2012	109	9840	6506	5683	4970	2862	2138	1813	1565
2013	110	9939	6379	5519	4781	2862	2076	1739	1485
2014	112	10038	6255	5359	4599	2862	2015	1668	1410
2015	113	10138	6134	5205	4423	2862	1957	1600	1339
2016	114	10240	6015	5055	4255	2862	1900	1535	1272
2017	115	10342	5898	4909	4093	2862	1844	1472	1208
2018	116	10446	5784	4767	3937	2862	1791	1412	1148
2019	117	10550	5671	4630	3787	2862	1738	1355	1091
2020	118	10656	5561	4496	3643	2862	1688	1300	1036
2021	120	10762	5453	4367	3504	2862	1639	1248	985
2022	121	10870	5347	4241	3370	2862	1591	1197	936
2023	122	10979	5243	4118	3242	2862	1545	1149	889
2024	123	11088	5142	3999	3118	2862	1500	1103	845
2025	124	11199	5042	3884	3000	2862	1456	1058	803
Total			180,874	160,676	143,705		62,505	55,001	49,285

Appendix E: GWL Decline and O&M Costs of the Scenario 3

Year	Expected Water supply from CWF	GW Saved in CWF	Average GWL Decrease	Ground Water level	Total O&M cost	Discounted O&M costs in CWF		
	af/yr	af/yr	Feet/yr	Feet	$/af	3%	4%	5%
1998	8,827	24,923	-1.9	250.0	28.9	255	255	255
1999	9,749	24,001	-1.9	248.1	28.7	272	269	267
2000	10,677	23,073	-1.8	246.3	28.5	287	281	276
2001	11,611	22,139	-1.7	244.6	28.3	301	292	284
2002	12,545	21,205	-1.7	242.9	28.1	313	301	290
2003	13,479	20,271	-1.6	241.3	27.9	325	309	295
2004	14,413	19,337	-1.5	239.8	27.7	335	316	298
2005	15,347	18,403	-1.4	238.4	27.6	344	322	301
2006	16,097	17,653	-1.4	237.0	27.4	348	323	299
2007	16,846	16,904	-1.3	235.7	27.3	352	323	296
2008	17,596	16,154	-1.3	234.4	27.1	355	322	293
2009	18,345	15,405	-1.2	233.2	27.0	358	322	289
2010	19,095	14,655	-1.1	232.1	26.9	360	320	285
2011	19,945	13,805	-1.1	231.0	26.7	363	320	283
2012	20,796	12,954	-1.0	230.0	26.6	366	320	279
2013	21,648	12,102	-0.9	229.0	26.5	368	319	276
2014	22,499	11,251	-0.9	228.2	26.4	370	317	272
2015	23,350	10,400	-0.8	227.3	26.3	372	315	268
2016	24,276	9,474	-0.7	226.6	26.2	374	314	264
2017	25,202	8,548	-0.7	225.9	26.1	376	313	261
2018	26,128	7,622	-0.6	225.3	26.1	377	311	257
2019	27,054	6,696	-0.5	224.8	26.0	378	309	253
2020	27,980	5,770	-0.5	224.4	26.0	379	306	248
2021	29,040	4,710	-0.4	224.0	25.9	381	305	245
2022	30,098	3,652	-0.3	223.7	25.9	383	304	242
2023	31,158	2,592	-0.2	223.5	25.9	385	302	238
2024	32,217	1,533	-0.1	223.4	25.8	386	300	234
2025	33,276	474	0.0	223.3	25.8	387	298	230
Total						9,850	8,610	7,579

Appendix F: O&M Costs for Scenario 4

Year	CAP water Cost ($/af)	Total CAP water cost	Total CAP Water discounted			Total O&M Costs in DMAFB	O&M cost discounted		
	Increase by 1%/yr	$/yr (000)	3%	4%	5%	$/yr (000)	3%	4%	5%
1998	71	8,520	8520	8520	8520	775.8	876.7	876.7	876.7
1999	82	9,840	9553	9462	9371	775.8	851.1	842.9	834.9
2000	87	10,440	9841	9652	9469	775.8	826.3	810.5	795.2
2001	91	10,920	9993	9708	9433	775.8	802.3	779.3	757.3
2002	93	11,160	9916	9540	9181	775.8	778.9	749.4	721.2
2003	94	11,280	9730	9271	8838	775.8	756.2	720.5	686.9
2004	104	12,480	10452	9863	9313	775.8	734.2	692.8	654.2
2005	104	12,480	10147	9484	8869	775.8	712.8	666.2	623.0
2006	103	12,360	9757	9031	8366	775.8	692.0	640.6	593.4
2007	104	12,484	9568	8771	8047	775.8	671.9	615.9	565.1
2008	105	12,608	9382	8518	7740	775.8	652.3	592.2	538.2
2009	106	12,735	9200	8272	7446	775.8	633.3	569.5	512.6
2010	107	12,862	9021	8033	7162	775.8	614.9	547.6	488.2
2011	108	12,990	8846	7802	6889	775.8	597.0	526.5	464.9
2012	109	13,120	8674	7577	6627	775.8	579.6	506.2	442.8
2013	110	13,252	8506	7358	6374	775.8	562.7	486.8	421.7
2014	112	13,384	8341	7146	6131	775.8	546.3	468.1	401.6
2015	113	13,518	8179	6940	5898	775.8	530.4	450.1	382.5
2016	114	13,653	8020	6740	5673	775.8	514.9	432.7	364.3
2017	115	13,790	7864	6545	5457	775.8	499.9	416.1	346.9
2018	116	13,928	7711	6356	5249	775.8	485.4	400.1	330.4
2019	117	14,067	7562	6173	5049	775.8	471.2	384.7	314.7
2020	118	14,208	7415	5995	4857	775.8	457.5	369.9	299.7
2021	120	14,350	7271	5822	4672	775.8	444.2	355.7	285.4
2022	121	14,493	7130	5654	4494	775.8	431.3	342.0	271.8
2023	122	14,638	6991	5491	4323	775.8	418.7	328.8	258.9
2024	123	14,784	6855	5333	4158	775.8	406.5	316.2	246.6
2025	124	14,932	6722	5179	4000	775.8	394.7	304.0	234.8
Total			241,166	214,235	191,607		16,943	15,192	13,714

Appendix G: GWL Decline and O&M Costs of the Scenario 4

Year	Expected Water supply from CWF	GW Saved in CWF	Average GWL Decrease	GWL	Total O&M cost	Discounted O&M costs in CWF		
	af/yr	af/yr	Feet/yr	Feet	$/af	3%	4%	5%
1998	8,827	33,923	-2.7	250.0	28.9	255	255	255
1999	9,749	33,001	-2.6	247.4	28.6	271	268	266
2000	10,677	32,073	-2.5	244.9	28.3	285	280	274
2001	11,611	31,139	-2.4	242.5	28.1	298	290	281
2002	12,545	30,205	-2.4	240.1	27.8	310	298	287
2003	13,479	29,271	-2.3	237.8	27.5	320	305	291
2004	14,413	28,337	-2.2	235.6	27.3	329	311	293
2005	15,347	27,403	-2.1	233.5	27.0	337	315	295
2006	16,097	26,653	-2.1	231.4	26.8	340	315	292
2007	16,846	25,904	-2.0	229.4	26.5	343	314	288
2008	17,596	25,154	-2.0	227.4	26.3	344	313	284
2009	18,345	24,405	-1.9	225.5	26.1	346	311	280
2010	19,095	23,655	-1.9	223.6	25.9	347	309	275
2011	19,945	22,805	-1.8	221.8	25.7	349	307	271
2012	20,796	21,954	-1.7	220.1	25.5	350	306	268
2013	21,648	21,102	-1.7	218.5	25.3	351	304	263
2014	22,499	20,251	-1.6	216.9	25.1	352	301	259
2015	23,350	19,400	-1.5	215.4	24.9	352	299	254
2016	24,276	18,474	-1.4	213.9	24.8	353	297	250
2017	25,202	17,548	-1.4	212.6	24.6	353	294	245
2018	26,128	16,622	-1.3	211.3	24.4	354	291	241
2019	27,054	15,696	-1.2	210.0	24.3	353	288	236
2020	27,980	14,770	-1.2	208.9	24.2	353	285	231
2021	29,040	13,710	-1.1	207.8	24.0	354	283	227
2022	30,098	12,652	-1.0	206.8	23.9	354	281	223
2023	31,158	11,592	-0.9	205.9	23.8	355	278	219
2024	32,217	10,533	-0.8	205.1	23.7	354	276	215
2025	33,276	9,474	-0.7	204.3	23.6	354	273	211
Total						9,416	8,247	7,274

Appendix H: The Value of GW Saved in CWF from Scenario 2

Year	GW Saved	$30/af			$58/af			$103/af		
	af/yr	3%	4%	5%	3%	4%	5%	3%	4%	5%
1998	7,923	238	238	238	460	460	460	816	816	816
1999	7,001	204	202	200	394	390	387	700	693	687
2000	6,073	172	168	165	332	326	319	590	578	567
2001	5,139	141	137	133	273	265	257	484	471	457
2002	4,205	112	108	104	217	208	201	385	370	356
2003	3,271	85	81	77	164	156	149	291	277	264
2004	2,337	59	55	52	114	107	101	202	190	180
2005	1,403	34	32	30	66	62	58	117	110	103
2006	653	15	14	13	30	28	26	53	49	46
Total		1,060	1,035	1,012	2,048	2,002	1,957	3,638	3,555	3,476

Appendix I: The Value of GW Saved in CWF from Scenario 3

Year	GW Saved	$30/af discounted			$58/af discounted			$103/af discounted		
	af/yr	3%	4%	5%	3%	4%	5%	3%	4%	5%
1998	24,923	748	748	748	1,446	1,446	1,446	2,567	2,567	2,567
1999	24,001	699	692	686	1,352	1,339	1,326	2,400	2,377	2,354
2000	23,073	652	640	628	1,261	1,237	1,214	2,240	2,197	2,156
2001	22,139	608	590	574	1,175	1,142	1,109	2,087	2,027	1,970
2002	21,205	565	544	523	1,093	1,051	1,012	1,941	1,867	1,797
2003	20,271	525	500	476	1,014	966	921	1,801	1,716	1,636
2004	19,337	486	458	433	939	886	837	1,668	1,574	1,486
2005	18,403	449	420	392	868	811	759	1,541	1,440	1,347
2006	17,653	418	387	358	808	748	693	1,435	1,329	1,231
2007	16,904	389	356	327	751	689	632	1,334	1,223	1,122
2008	16,154	361	327	298	697	633	575	1,238	1,124	1,021
2009	15,405	334	300	270	645	580	522	1,146	1,031	928
2010	14,655	308	275	245	596	531	473	1,059	943	841
2011	13,805	282	249	220	545	481	425	968	854	754
2012	12,954	257	224	196	497	434	379	882	770	674
2013	12,102	233	202	175	451	390	338	800	692	600
2014	11,251	210	180	155	407	348	299	722	619	531
2015	10,400	189	160	136	365	310	263	648	550	467
2016	9,474	167	140	118	323	271	228	573	482	405
2017	8,548	146	122	101	283	235	196	502	418	348
2018	7,622	127	104	86	245	202	167	435	358	296
2019	6,696	108	88	72	209	170	139	371	303	248
2020	5,770	90	73	59	175	141	114	310	251	203
2021	4,710	72	57	46	138	111	89	246	197	158
2022	3,652	54	43	34	104	83	66	185	147	117
2023	2,592	37	29	23	72	56	44	128	100	79
2024	1,533	21	17	13	41	32	25	73	57	44
2025	474	6	5	4	12	10	7	22	17	13
Total	365,705	8,541	7,931	7,396	16,512	15,333	14,299	29,323	27,230	25,393

Appendix J: CAP Water Sale instead of Reclaimed Water - Scenario 3

Year	CAP water Sold	$462/af discounted			$607/af discounted			$758/af discounted		
	af/yr	3%	4%	5%	3%	4%	5%	3%	4%	5%
1998	13,000	6,006	6,006	6,006	7,891	7,891	7,891	9,854	9,854	9,854
1999	13,000	5,831	5,775	5,720	7,661	7,588	7,515	9,567	9,475	9,385
2000	13,000	5,661	5,553	5,448	7,438	7,296	7,157	9,288	9,111	8,938
2001	13,000	5,496	5,339	5,188	7,221	7,015	6,817	9,018	8,760	8,512
2002	13,000	5,336	5,134	4,941	7,011	6,745	6,492	8,755	8,423	8,107
2003	13,000	5,181	4,936	4,706	6,807	6,486	6,183	8,500	8,099	7,721
2004	13,000	5,030	4,747	4,482	6,609	6,236	5,888	8,253	7,788	7,353
2005	13,000	4,883	4,564	4,268	6,416	5,997	5,608	8,012	7,488	7,003
2006	13,000	4,741	4,389	4,065	6,229	5,766	5,341	7,779	7,200	6,670
2007	13,000	4,603	4,220	3,872	6,048	5,544	5,087	7,552	6,923	6,352
2008	13,000	4,469	4,057	3,687	5,872	5,331	4,844	7,332	6,657	6,050
2009	13,000	4,339	3,901	3,512	5,701	5,126	4,614	7,119	6,401	5,761
2010	13,000	4,212	3,751	3,344	5,535	4,929	4,394	6,911	6,155	5,487
2011	13,000	4,090	3,607	3,185	5,373	4,739	4,185	6,710	5,918	5,226

Appendix J : *Continued*

Year	CAP water Sold	$462/af discounted			$607/af discounted			$758/af discounted		
	af/yr	3%	4%	5%	3%	4%	5%	3%	4%	5%
2012	13,000	3,971	3,468	3,033	5,217	4,557	3,985	6,515	5,690	4,977
2013	13,000	3,855	3,335	2,889	5,065	4,382	3,796	6,325	5,472	4,740
2014	13,000	3,743	3,207	2,751	4,917	4,213	3,615	6,141	5,261	4,514
2015	13,000	3,634	3,083	2,620	4,774	4,051	3,443	5,962	5,059	4,299
2016	13,000	3,528	2,965	2,496	4,635	3,895	3,279	5,788	4,864	4,095
2017	13,000	3,425	2,851	2,377	4,500	3,745	3,123	5,620	4,677	3,900
2018	13,000	3,325	2,741	2,264	4,369	3,601	2,974	5,456	4,497	3,714
2019	13,000	3,229	2,636	2,156	4,242	3,463	2,832	5,297	4,324	3,537
2020	13,000	3,134	2,534	2,053	4,118	3,330	2,698	5,143	4,158	3,369
2021	13,000	3,043	2,437	1,955	3,998	3,202	2,569	4,993	3,998	3,208
2022	13,000	2,955	2,343	1,862	3,882	3,078	2,447	4,848	3,844	3,055
2023	13,000	2,868	2,253	1,774	3,769	2,960	2,330	4,706	3,696	2,910
2024	13,000	2,785	2,166	1,689	3,659	2,846	2,219	4,569	3,554	2,771
2025	13,000	2,704	2,083	1,609	3,552	2,737	2,114	4,436	3,418	2,639
Total		116,078	104,081	93,952	152,510	136,748	123,439	190,449	170,766	154,146

Appendix K: The Value of Cost Saving of not Treating Effluent

Year	CAP Water Sold	$225/af discounted			O&M Cost Increase	$225/af with 1 % increase per year-discounted			O&M Cost Increase	$225/af with 2% increase per year-discounted		
	af/yr	3%	4%	5%	1%/yr	3%	4%	5%	2%/yr	3%	4%	5%
1998	13,000	2,925	2,925	2,925	225	2,925	2,925	2,925	225	2,925	2,925	2,925
1999	13,000	2,840	2,813	2,786	227	2,868	2,841	2,814	230	2,897	2,869	2,841
2000	13,000	2,757	2,704	2,653	230	2,813	2,759	2,706	234	2,868	2,814	2,760
2001	13,000	2,677	2,600	2,527	232	2,758	2,679	2,603	239	2,841	2,759	2,681
2002	13,000	2,599	2,500	2,406	234	2,704	2,602	2,504	244	2,813	2,706	2,605
2003	13,000	2,523	2,404	2,292	236	2,652	2,527	2,409	248	2,786	2,654	2,530
2004	13,000	2,450	2,312	2,183	239	2,600	2,454	2,317	253	2,759	2,603	2,458
2005	13,000	2,378	2,223	2,079	241	2,550	2,383	2,229	258	2,732	2,553	2,388
2006	13,000	2,309	2,137	1,980	244	2,500	2,314	2,144	264	2,705	2,504	2,320
2007	13,000	2,242	2,055	1,885	246	2,452	2,248	2,062	269	2,679	2,456	2,253
2008	13,000	2,176	1,976	1,796	249	2,404	2,183	1,984	274	2,653	2,409	2,189
2009	13,000	2,113	1,900	1,710	251	2,357	2,120	1,908	280	2,627	2,362	2,126
2010	13,000	2,052	1,827	1,629	254	2,312	2,059	1,835	285	2,602	2,317	2,066
2011	13,000	1,992	1,757	1,551	256	2,267	1,999	1,765	291	2,577	2,272	2,007

Appendix K: *Continued*

Year	CAP Water Sold	$225/af discounted			O&M Cost Increase	$225/af with 1 % increase per year-discounted			O&M Cost Increase	$225/af with 2% increase per year-discounted		
	af/yr	3%	4%	5%	1%/yr	3%	4%	5%	2%/yr	3%	4%	5%
2012	13,000	1,934	1,689	1,477	259	2,223	1,942	1,698	297	2,552	2,229	1,949
2013	13,000	1,877	1,624	1,407	261	2,180	1,886	1,633	303	2,527	2,186	1,894
2014	13,000	1,823	1,562	1,340	264	2,137	1,831	1,571	309	2,502	2,144	1,840
2015	13,000	1,770	1,502	1,276	266	2,096	1,778	1,511	315	2,478	2,103	1,787
2016	13,000	1,718	1,444	1,215	269	2,055	1,727	1,454	321	2,454	2,062	1,736
2017	13,000	1,668	1,388	1,158	272	2,015	1,677	1,398	328	2,430	2,023	1,686
2018	13,000	1,620	1,335	1,102	275	1,976	1,629	1,345	334	2,406	1,984	1,638
2019	13,000	1,572	1,284	1,050	277	1,938	1,582	1,294	341	2,383	1,945	1,591
2020	13,000	1,527	1,234	1,000	280	1,900	1,536	1,245	348	2,360	1,908	1,546
2021	13,000	1,482	1,187	952	283	1,863	1,492	1,197	355	2,337	1,871	1,502
2022	13,000	1,439	1,141	907	286	1,827	1,449	1,152	362	2,314	1,835	1,459
2023	13,000	1,397	1,097	864	289	1,792	1,407	1,108	369	2,292	1,800	1,417
2024	13,000	1,356	1,055	823	291	1,757	1,367	1,066	377	2,270	1,765	1,377
2025	13,000	1,317	1,014	783	294	1,723	1,327	1,025	384	2,248	1,732	1,337
Total		56,532	50,689	45,756		63,644	56,721	50,902		72,016	63,792	56,908

Appendix L: The Value of GW Saved in CWF-Scenario 4

Year	GW Saved	$30/af			$58/af			$103/af		
	af/yr	3%	4%	5%	3%	4%	5%	3%	4%	5%
1998	33,923	1,018	1,018	1,018	1,968	1,968	1,968	3,494	3,494	3,494
1999	33,001	961	952	943	1,858	1,840	1,823	3,300	3,268	3,237
2000	32,073	907	890	873	1,753	1,720	1,687	3,114	3,054	2,996
2001	31,139	855	830	807	1,653	1,606	1,560	2,935	2,851	2,771
2002	30,205	805	775	745	1,557	1,498	1,441	2,764	2,659	2,560
2003	29,271	757	722	688	1,464	1,395	1,330	2,601	2,478	2,362
2004	28,337	712	672	634	1,376	1,299	1,226	2,444	2,307	2,178
2005	27,403	668	625	584	1,292	1,208	1,130	2,295	2,145	2,006
2006	26,653	631	584	541	1,220	1,130	1,046	2,167	2,006	1,858
2007	25,904	596	546	501	1,151	1,056	968	2,045	1,875	1,720
2008	25,154	562	510	463	1,086	986	896	1,928	1,750	1,591
2009	24,405	529	476	428	1,023	919	828	1,816	1,633	1,470
2010	23,655	498	443	395	962	857	764	1,709	1,522	1,357
2011	22,805	466	411	363	901	794	701	1,599	1,411	1,246

Appendix L: *Continued*

Year	GW Saved	$30/af			$58/af			$103/af		
	af/yr	3%	4%	5%	3%	4%	5%	3%	4%	5%
2012	21,954	435	380	333	842	735	643	1,495	1,306	1,142
2013	21,102	406	352	305	786	680	589	1,395	1,207	1,046
2014	20,251	379	324	278	732	627	538	1,300	1,114	956
2015	19,400	352	299	254	681	578	491	1,209	1,026	872
2016	18,474	326	274	230	629	529	445	1,118	939	791
2017	17,548	300	250	208	580	483	403	1,031	858	715
2018	16,622	276	228	188	534	440	363	948	781	645
2019	15,696	253	207	169	489	400	327	869	709	580
2020	14,770	231	187	151	447	361	293	794	642	520
2021	13,710	208	167	134	403	323	259	716	573	460
2022	12,652	187	148	118	361	286	228	641	508	404
2023	11,592	166	130	103	321	252	199	570	448	353
2024	10,533	147	114	89	283	220	172	503	391	305
2025	9,474	128	99	76	247	191	147	439	338	261
Total		13,759	12,610	11,620	26,601	24,379	22,465	47,239	43,294	39,894

Appendix M: The Value of GW saved in DMAFB-Scenario 4

Year	GW Saved	$30/af			$58/af			$103/af		
	af/yr	3%	4%	5%	3%	4%	5%	3%	4%	5%
1998	34,000	1,020	1,020	1,020	1,972	1,972	1,972	3,502	3,502	3,502
1999	34,000	990	981	971	1,915	1,896	1,878	3,400	3,367	3,335
2000	34,000	961	943	925	1,859	1,823	1,789	3,301	3,238	3,176
2001	34,000	933	907	881	1,805	1,753	1,703	3,205	3,113	3,025
2002	34,000	906	872	839	1,752	1,686	1,622	3,111	2,994	2,881
2003	34,000	880	838	799	1,701	1,621	1,545	3,021	2,878	2,744
2004	34,000	854	806	761	1,652	1,559	1,472	2,933	2,768	2,613
2005	34,000	829	775	725	1,603	1,499	1,401	2,847	2,661	2,489
2006	34,000	805	745	690	1,557	1,441	1,335	2,765	2,559	2,370
2007	34,000	782	717	658	1,511	1,386	1,271	2,684	2,460	2,257
2008	34,000	759	689	626	1,467	1,332	1,211	2,606	2,366	2,150
2009	34,000	737	663	596	1,425	1,281	1,153	2,530	2,275	2,048
2010	34,000	715	637	568	1,383	1,232	1,098	2,456	2,187	1,950
2011	34,000	695	613	541	1,343	1,184	1,046	2,385	2,103	1,857

Appendix M: Continued

Year	GW Saved	$30/af			$58/af			$103/af		
	af/yr	3%	4%	5%	3%	4%	5%	3%	4%	5%
2012	34,000	674	589	515	1,304	1,139	996	2,315	2,022	1,769
2013	34,000	655	566	491	1,266	1,095	949	2,248	1,945	1,685
2014	34,000	636	545	467	1,229	1,053	903	2,182	1,870	1,604
2015	34,000	617	524	445	1,193	1,012	860	2,119	1,798	1,528
2016	34,000	599	504	424	1,158	973	819	2,057	1,729	1,455
2017	34,000	582	484	404	1,125	936	780	1,997	1,662	1,386
2018	34,000	565	466	384	1,092	900	743	1,939	1,598	1,320
2019	34,000	548	448	366	1,060	865	708	1,882	1,537	1,257
2020	34,000	532	430	349	1,029	832	674	1,828	1,478	1,197
2021	34,000	517	414	332	999	800	642	1,774	1,421	1,140
2022	34,000	502	398	316	970	769	611	1,723	1,366	1,086
2023	34,000	487	383	301	942	740	582	1,673	1,314	1,034
2024	34,000	473	368	287	914	711	555	1,624	1,263	985
2025	34,000	459	354	273	888	684	528	1,577	1,215	938
Total		19,714	17,676	15,956	38,113	34,174	30,848	67,683	60,688	54,782

Appendix N: The Cost Components of the Scenarios for the Base Case

	Present Value of Costs				
	Capital Cost	CAP Water Cost	O&M costs of		Total Costs
			CAP recharge	GW in CWF	
	$0.000	**$0.000**	**$0.000**	**$0.000**	**$0.000**
3%					
Baseline	18,767	$0		63,826	**82,593**
Scenario 2	58,000	120,583	99,588	10,669	**288,840**
Scenario 3	78,627	180,874	162,093	9,850	**431,444**
Scenario 4	145,000	241,166	116,531	9,416	**512,113**
4%					
Baseline	18,767	$0		56,282	**75,049**
Scenario 2	58,000	107,117	89,296	9,294	**263,708**
Scenario 3	78,627	160,676	145,341	8,610	**393,253**
Scenario 4	145,000	214,235	104,488	8,247	**471,970**
5%					
Baseline	18,767	$0		49,986	**68,753**
Scenario 2	58,000	95,803	80,605	8,154	**242,563**
Scenario 3	78,627	143,705	131,196	7,579	**361,107**
Scenario 4	145,000	191,607	94,319	7,274	**438,200**

Appendix O: The Benefits Components of the Scenarios for the Base Case

	Present Value of Benefits						
	Value of Saving			Value of Not			Total Benefits
	Reduced Pumping	From Eliminating GW Overdraft	from CAP water Recharge	*Constructing New Wells*	*Treating Effluent*	Value of Using CAP water	
	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
3%							
Scenario 2	53,156		1,060	18,768			**72,984**
Scenario 3	53,976	36,105	8,541	18,768	56,532	116,078	**289,999**
Scenario 4	54,410	36,105	33,472	18,768			**142,755**
4%							
Scenario 2	46,987		1,035	18,768			**66,791**
Scenario 3	47,672	32,100	7,931	18,768	50,689	104,081	**261,242**
Scenario 4	48,035	32,100	30,286	18,768			**129,189**
5%							
Scenario 2	41,831		1,012	18,768			**61,612**
Scenario 3	42,407	28,739	7,396	18,768	45,756	93,952	**237,018**
Scenario 4	42,712	28,739	27,575	18,768			**117,795**

Appendix P: TPVs at Selected Benefit Values and Discount Rates

Discount Rate	Low Value			Mid value			High Value		
R = 3%									
	Total Costs	Total Benefits	Net Benefits	Total Costs	Total Benefits	Net Benefits	Total Costs	Total Benefits	Net Benefits
	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
R = 3%									
Baseline	82,593		-82,593	82,593		-82,593	82,593		-82,593
Scenario 2	288,840	72,984	-215,856	288,840	73,973	-214,867	288,840	75,562	-213,278
Scenario 3	368,939	289,999	-78,940	431,444	375,211	-56,233	431,444	488,491	57,047
Scenario 4	512,113	142,755	-369,358	512,113	207,694	-304,419	512,113	312,060	-200,053
R =4%									
Baseline	75,049		-75,049	75,049		-75,049	75,049		-75,049
Scenario 2	263,708	66,791	-196,917	263,708	67,757	-195,951	263,708	69,310	-194,398
Scenario 3	393,253	261,242	-132,011	393,253	337,303	-55,951	393,253	438,439	45,185
Scenario 4	471,970	129,189	-342,780	471,970	187,417	-284,553	471,970	280,996	-190,973
R = 4%									
Baseline	68,753		-68,753	68,753		-68,753	68,753		-68,753
Scenario 2	242,563	61,612	-180,951	242,563	68,853	-173,711	242,563	64,075	-178,488
Scenario 3	361,107	237,018	-124,088	361,107	311,674	-49,433	361,107	396,294	35,187
Scenario 4	438,200	117,795	-320,405	439,678	176,651	-263,027	438,200	254,828	-183,372

TPV = Total Present Values

Appendix Q: TPVs per AF at Selected Benefit Values and Discount Rates

Low Value										
		3%			4%			5%		
US$/af	**Total CAP & GW water**	**PVc**	**PVb**	**NPV**	**PVc**	**PVb**	**NPV**	**PVc**	**PVb**	**NPV**
	Acre-feet	$	$	$	$	$	$	$	$	$
Baseline	2,259,295	36.6	0.0	**-36.6**	33.2	0.0	**-33.2**	30.4	0.0	**-30.4**
Scenario 2	1,620,000	178.3	45.1	**-133.2**	162.8	41.2	**-121.6**	149.7	38.0	**-111.7**
Scenario 3	2,430,000	177.5	119.3	**-58.2**	161.8	107.5	**-54.3**	148.6	97.5	**-51.1**
Scenario 4	3,240,000	158.1	44.1	**-114.0**	145.7	39.9	**-105.8**	135.2	36.4	**-98.9**
Mid Value										
		3%			4%			5%		
Baseline	2,259,295	36.6	0.0	**-36.6**	33.2	0.0	**-33.2**	30.4	0.0	**-30.4**
Scenario 2	1,620,000	178.3	45.7	**-132.6**	162.8	41.8	**-121.0**	149.7	42.5	**-107.2**
Scenario 3	2,430,000	177.5	154.4	**-23.1**	161.8	138.8	**-23.0**	148.6	128.3	**-20.3**
Scenario 4	3,240,000	158.1	64.1	**-94.0**	145.7	57.8	**-87.8**	135.7	54.5	**-81.2**
High Value										
		3%			4%			5%		
Baseline	2,259,295	36.6	0.0	**-36.6**	33.2	0.0	**-33.2**	30.4	0.0	**-30.4**
Scenario 2	1,620,000	178.3	46.6	**-131.7**	162.8	42.8	**-120.0**	149.7	39.6	**-110.2**
Scenario 3	2,430,000	177.5	201.0	**23.5**	161.8	180.4	**18.6**	148.6	163.1	**14.5**
Scenario 4	3,240,000	158.1	96.3	**-61.7**	145.7	86.7	**-58.9**	135.2	78.7	**-56.6**

TPV = Total Present Value
PVc= Present Value of Costs
Pvb= Present Value of Benefits

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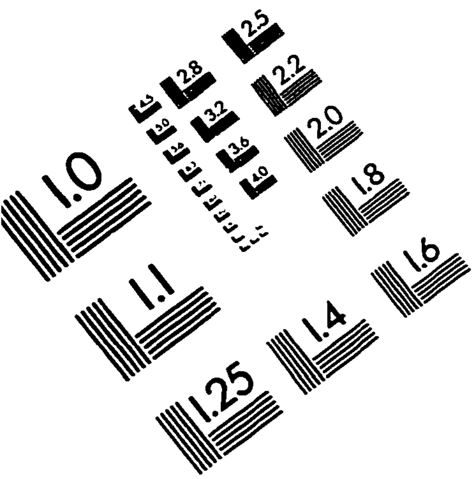
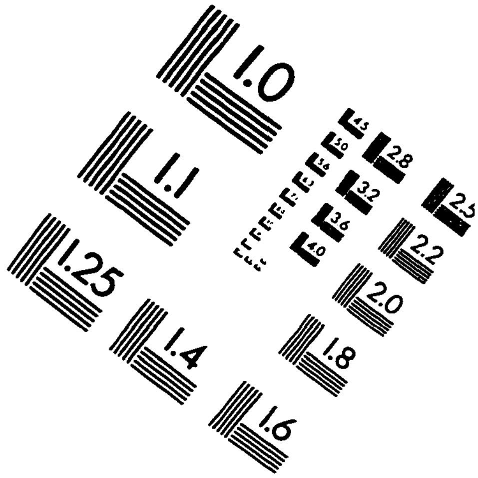
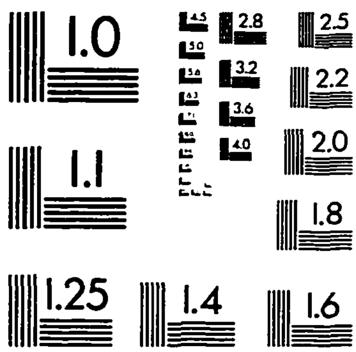
IMAGE EVALUATION TEST TARGET (QA-3)







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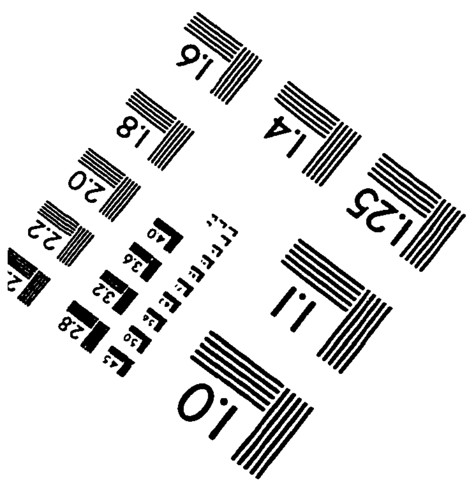

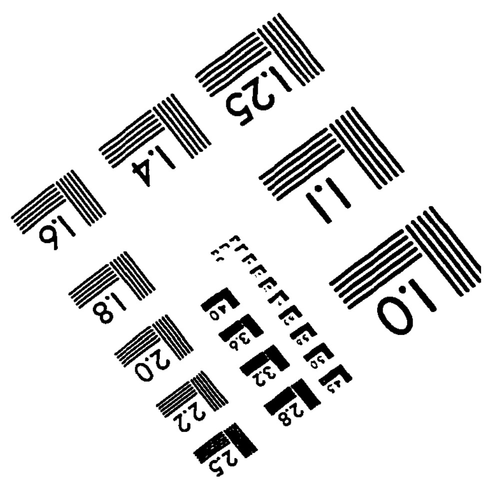

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