CHAPTER 2 – SALT BALANCE IN CENTRAL ARIZONA

INTRODUCTION

In central Arizona, the natural cycle of salts returning to the sea has been interrupted by a series of human interventions, beginning with the completion of Roosevelt Dam in 1912. Other dams along the Salt, Verde, Agua Fria, and Gila Rivers followed, and in 1985 the CAP was opened, intercepting Colorado River water and delivering it to Phoenix, Tucson, and other areas. The rivers (particularly the Salt River) and CAP waters contain natural salts. The end repositories of these salts are now the groundwater basins in the central portion of the state.

This chapter examines the estimated salt loading in each CASS planning area shown in Figure 1-1. A salt balance was calculated for each study area by quantifying the amount of salt entering and leaving the study area. The difference represents an estimate of the quantity of salt that is accumulating in each area.

PHOENIX METRO STUDY AREA

The physiographic character of central Arizona began to form during the middle Tertiary Period 20 to 30 million years ago when tectonic forces stretched the crust and a series of faults formed the Basin and Range Province. Portions of the bedrock moved up relative to other portions, forming the mountain ranges presently seen throughout central Arizona. The basins formed from the blocks of bedrock that were not uplifted became the repositories of materials eroded from the mountains or transported from other areas by rivers (Turek, 2003).

The rivers have carried salts into the Phoenix metropolitan area for millions of years. The process began some 225 million years ago when marine formations of shale, sandstone, siltstone, and limestone were deposited during the Mesozoic Era over the northern and eastern sections of Arizona. The sodium, calcium, potassium, chloride, and carbonate ions trapped in these formations are the source of many of the salts that end up in central Arizona basins. As these formations erode, their salts are transported to central Arizona via the river systems. At on point in the past, the rivers were blocked from leaving the Phoenix area and a lake formed. As the lake evaporated, the salts accumulated. Evidence of this ancient activity is the salt dome located near Luke Air Force Base. Fifteen cubic miles of salt are buried in the middle unit of the aquifer. It is estimated (assuming similar conditions as the present) that the rivers would have had to carry salts into the Phoenix region for some 250,000 years for this quantity to accumulate (Turek, 2003).

The Salt River gets most of its salts from salt springs located at the confluence of the White and Black Rivers and another site further downstream of State Route 60 on the White Mountain Apache Indian Reservation at a location called the "Red Wall." These springs are highly saline, ranging from 3,000 to 8,000 milligrams per liter (mg/L) TDS, and are warm, about 84° Fahrenheit. The White River has a TDS of about 136 mg/L above the springs and a TDS of about 2,376 mg/L below the springs (U.S. Geological Survey, 1977).

The Salt and Gila Rivers have historically conveyed most of their load of salts through the Phoenix metropolitan area to the Gulf of California, though some salts accumulated in the groundwater in proximity to their channels. W.T. Lee of the U.S. Geological Survey observed in 1905, "In certain localities along the river the surface of the underground water is so near the land surface that evaporation takes place readily. Water from the river directly or from the underflow is continually finding its way into these localities, bearing its burden of soluble salts, and escaping from the surface by evaporation, leaving its load of salts behind" (Lee, 1905). The groundwater along the Salt and Gila Rivers had salinities in the range of 3,000 mg/L when western settlers began farming, but as one moved away from the river the groundwater was of progressively better quality.

As noted, the first major environmental change caused by human activities with respect to salinity was the damming of the rivers. The rivers no longer flowed to the sea, but the water, with its salts, was diverted across the Phoenix metropolitan area for irrigation. This irrigation water from the Salt and Verde Rivers would be depositing 500,000 tons of salts annually (assuming typical year values of 460 mg/L TDS and 770,000 AF), although some of the salts would be carried out of the area through agricultural return waters via the Gila River, flood events, and groundwater movement. This accumulation of salts still constituted a significant change from the pre-development environment. Agricultural areas in the southwestern and southeastern portions of the Phoenix metropolitan area became waterlogged, and groundwater quality declined due to farm practices that concentrated the salts in the groundwater.

The second major human-caused change to the environment with respect to salinity was the completion in 1985 of the CAP canal and the subsequent diversion of Colorado River water to the Phoenix metropolitan area. In a typical year, the CAP transports 750,000 AF of water carrying 660,000 tons of salts into the Phoenix area, effectively doubling the area's salt load from pre-CAP completion. The addition of the CAP salts, coupled with salts introduced by humans via the sewer system and through the use of fertilizers, equates to approximately 1.45 million tons of salt entering the Phoenix metropolitan area each year. The Gila River, whose flows presently consist primarily of agricultural tail water and effluent, averages approximately 2,370 mg/L TDS and carries about 320,000 tons of salts out of the Phoenix area annually. Also, about 42,000 tons of salts are carried out via the groundwater, however, nearly 1.1 million tons of salts accumulate in the Phoenix Metro area annually. behind. Figure 2-1 illustrates the salt load currently entering and exiting the Phoenix metropolitan area each year.

Figure 2-1. Salt Balance in the Phoenix Metro Area (Typical Year)

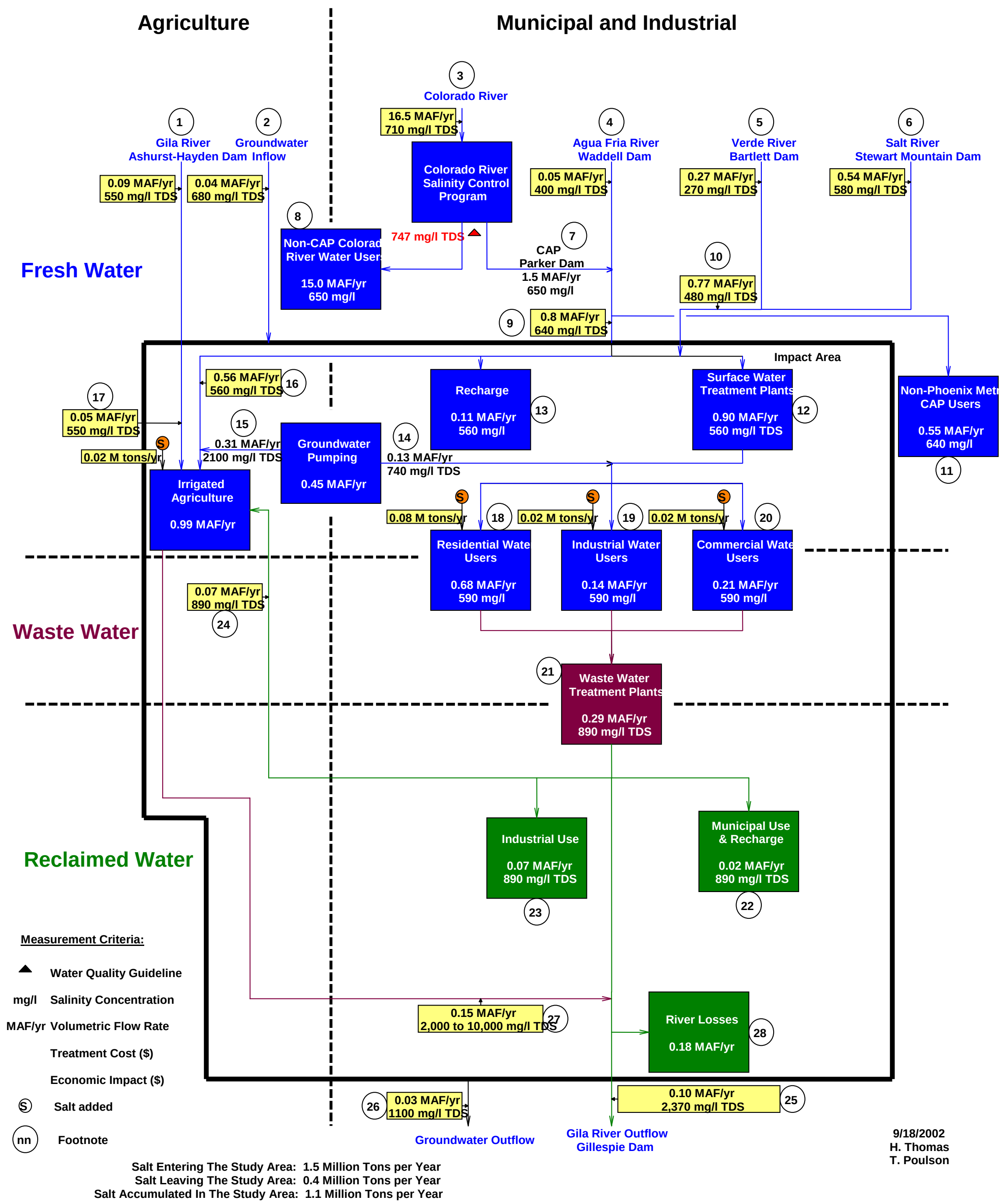

Table 2-1 summarizes the current annual salt flux for the Phoenix metropolitan area. The first row below the headings, "Groundwater," represents the flux of groundwater moving into the Phoenix area, generally from the north, and the salt load it transports. The sixth row, "Society," lists the quantity of water returned to the system on an annual basis through wastewater, yielding an additional 300 mg/L TDS. The seventh and eighth rows represent the tons of salts remaining after crops and other plants have consumed their nutrient needs (Appendix R).

Table 2-1. Estimated Annual Salt Balance in Phoenix Metropolitan Area

Entering Phoenix Metro	Volume (ac-ft)	TDS (mg/L)	Salt (tons)
Groundwater	37,000	680	34,218
SRP	810,000	480	528,768
CAP	752,000	650	664,768
Gila River	90,000	550	67,320
Agua Fria River	50,000	400	27,200
Society	290,000	300	118,320
Agricultural fertilizer			17,800
Turf fertilizer			4,700
Total			**1,463,094**

Exiting Phoenix Metro	Volume (ac-ft)	TDS (mg/L)	Salt (tons)
Groundwater	28,000	1,100	41,888
Gila River	100,000	2,370	322,320
Total			**364,208**

Residual Salt Load			**1,098,886**

As shown, nearly 1.1 million tons of salts remain in the Phoenix metropolitan area each year. Of that amount, it is estimated that approximately 39 percent accumulate in the groundwater basin through agriculture irrigation and groundwater recharge projects. Approximately 22 percent of the salts are ending up in the vadose zone through residential, commercial, and industrial urban irrigation of parks, lawns, and common green areas. The salts are thought to accumulate in the vadose zone at present, but depending on depth to the groundwater and irrigation practices, they may at some point reach groundwater. About 8 percent of the inflow of salts is ending up in evaporative ponds or sinks. The largest single sink in the region consists of the evaporative ponds at the Palo Verde Nuclear Generating Station. Other evaporative ponds and artificial lakes are also functioning as salt sinks. This leaves 31 percent of the salts that end up in the "other" category, which includes water heaters, evaporative coolers, household water appliances, cooling towers, and any other place that evaporation occurs (Figure 2-2). Swimming pools functionally act as temporary salt sinks that are eventually emptied either into the sewer system or onto the ground.

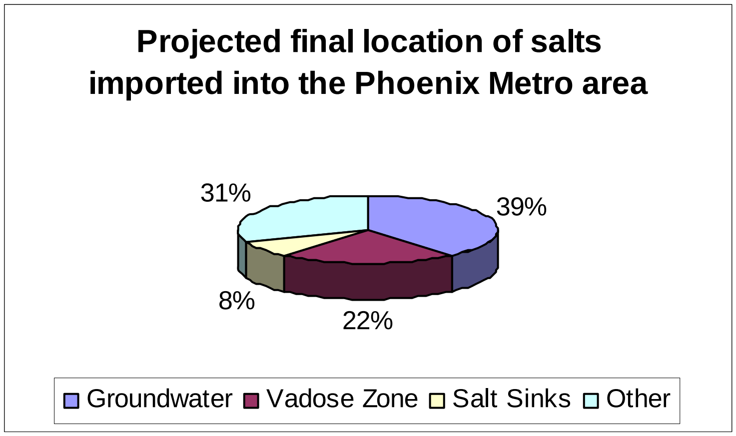

Figure 2-2. Where the Salts Accumulate

The distribution of salts throughout the Phoenix metropolitan area is a relatively new problem. While the Salt River has carried salts for millions of years, it has been fewer than 100 years since the damming of the rivers resulted in the salt load being distributed in the Phoenix area rather than being transported to the Gulf of California. Only 20 years have elapsed since the CAP began delivering Colorado River water and its inherent salt load into the Phoenix area. The impacts resulting from these changes have not yet fully developed.

TUCSON METRO STUDY AREA

The hydrogeologic system of the Tucson Active Management Area (AMA) is characterized by periodic natural recharge in the ephemeral stream channels of the Santa Cruz River, Brawley Wash, and their tributaries; groundwater flow to the north-northwest through basin-fill deposits; underflow to the Picacho Basin to the northwest; and discharge to water supply wells. Some perennial reaches occur near the mountain fronts. Periodic streamflow in the ephemeral drainages occurs in response to precipitation and snowmelt from the surrounding mountains. Infiltration occurs through the highly permeable stream-channel deposits and flows downgradient through moderately to highly permeable basin-fill deposits.

Based on Osterkamp (1973), rates of groundwater recharge at the mountain fronts and stream channels in the Tucson AMA range from 0 to 850 acre-feet (af) per mile of mountain front or stream-channel. Average annual natural recharge in the Tucson AMA is approximately 76,600 acre-feet per year (af/yr) (Arizona Department of Water Resource, 1999). TDS concentrations in groundwater in the Tucson AMA range from 101 mg/L to 752 mg/L, and average approximately 259 mg/L (Pima Association of Governments, 1994). In most areas of the Tucson AMA, groundwater is below the EPA's secondary maximum contaminant level (MCL).

The groundwater table in the Upper Santa Cruz Valley Subbasin has declined as much as 200 feet since 1940 (Arizona Department of Water Resources, 2003). Cones of depression are evident within Tucson Water's central well field as a result of municipal pumping and within the Green Valley/Sahuarita area as a result of agricultural and mining-related pumping. Typical annual declines have been on the order of 3–4 feet (Arizona Department of Water Resources, 2003). Since the late 1970s and early 1980s, approximately 80 feet of water table recovery has occurred in southern portions of the Upper Santa Cruz Valley Subbasin due to effluent flows in the Santa Cruz River.

The CAP was completed to the Tucson area in the early 1990s to deliver a renewable supply of water from the Colorado River. For the purpose of this study, a TDS concentration of 650 mg/L was used to characterize CAP water typically received in the Tucson area (Tucson Water, 2003). In 2000, 24,289 af of CAP water was delivered and used for agricultural irrigation in lieu of groundwater (Arizona Department of Water Resources, 2003).

The CAP water allocation for the Tucson Basin's water providers and users is 215,333 af/yr, devoted primarily to municipal contracts (Arizona Department of Water Resources, 1999). The City of Tucson has an allocation of 135,966 af of this total (Arizona Department of Water Resources, 1999). Direct delivery of Colorado River water was rejected by the public when the delivered water caused problems with the older piping of the distribution system. In response, the City of Tucson elected not to serve their CAP allotment directly but to recharge it in the Avra Valley Subbasin at the Clearwater Renewable Resource Facility (Tucson Water, 2001).

The Clearwater facility consists of a series of recharge basins and recovery wells; the facility is currently permitted to recharge and recover 60,000 af/yr. The recovery wells produce a blend of groundwater and CAP water and convey it to a central pumping station for delivery to customers (Tucson Water, 2001).

Other recharge basins, such as the Pima Mine Road Recharge Project, the Avra Valley Recharge Project, and the Lower Santa Cruz Recharge Project are each recharging CAP water. Future recharge projects are under consideration and will allow more CAP water to be recharged.

Tucson Water developed two generalized salt balances for the Tucson AMA. The salt balance for the year 2000 reflects current conditions and is presented on the following page (Figure 2-3). The salt balance for 2015 was developed to reflect conditions when the full allotment of CAP water will be utilized. The 2015 projections are presented and discussed in detail in Chapter 5, *Future Trends Analysis*.

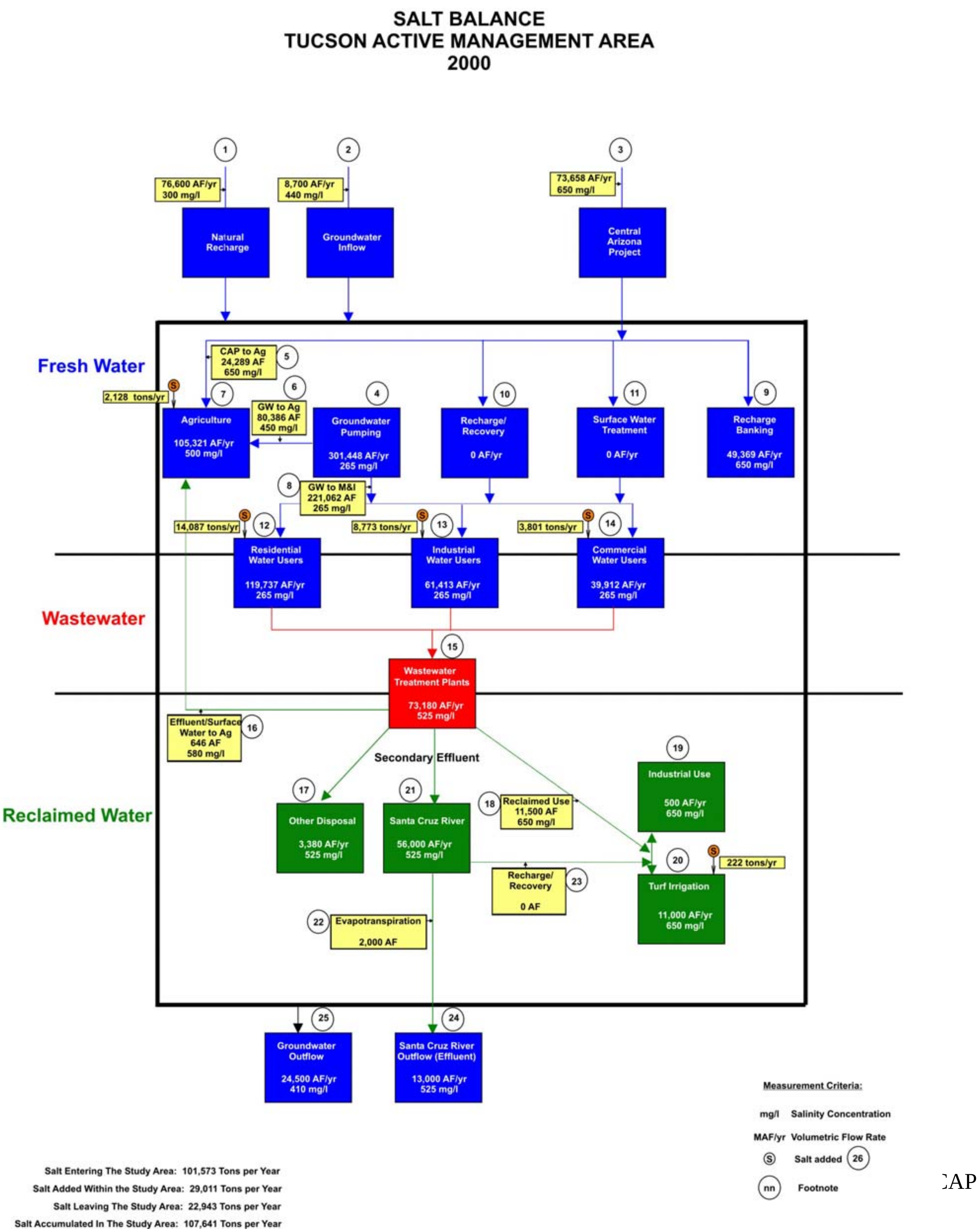

Figure 2-3. Salt Balance in the Tucson Active Management Area (2000)

In 2000, approximately 107,500 tons of salt accumulated in the Tucson AMA. Utilization of the CAP accounted for approximately 50 percent of the salt entering the Tucson AMA, while natural recharge accounted for approximately 24 percent. Additional salt sources from human activities such as the application of fertilizers and municipal and industrial uses accounted for approximately 22 percent. The amount of additional salt sources was based on estimated values utilized in a salt balance for the Phoenix AMA (Central Arizona Salinity Study, 2002). Approximately 4 percent of the salt that entered the Tucson AMA was from groundwater inflow. Table 2.2 summarizes the salt balance flowcharts.

Table 2.2. Generalized Salt Balance in the Tucson AMA, 2000 and 2015

	(million tons per year)	
Description	**2000**	**2015**
Average salt inflow from the CAP Aqueduct	0.065	0.191
Average salt inflow from groundwater	0.005	0.005
Average salt inflow due to natural recharge	0.031	0.031
Additional salt sources	0.029	0.034
Total amount of salt entering the Tucson AMA	**0.130**	**0.261**
Average salt outflow in groundwater	0.014	0.014
Average salt outflow in the Santa Cruz River	0.009	0.041
Total amount of salt leaving the Tucson AMA	**0.023**	**0.055**
Net salt accumulation in the Tucson AMA	**0.107**	**0.205**

It is estimated that by 2015, salt accumulation in the Tucson AMA will almost double from current (2000) levels. This is primarily due to utilization of the full CAP allotment. While in 2000, utilization of CAP accounted for approximately 50 percent of the salt entering the Tucson AMA, by 2015 (when the full allotment is utilized) the CAP will account for approximately 73 percent of the salt entering the Tucson AMA, or approximately 200,000 tons. Additional salt sources from human activities, such as the application of fertilizers and municipal and industrial uses, will account for approximately 13 percent of the salt entering the Tucson AMA. As with the 2000 salt balance, the amount of additional salt sources was based on values utilized in the salt balance for the Phoenix AMA. Natural recharge will account for approximately 12 percent of salt entering the Tucson AMA, and approximately 2 percent of the salt entering the Tucson AMA will be from groundwater inflow. Approximately 21 percent of the salt entering the Tucson AMA will leave as groundwater underflow and Santa Cruz River outflow.

PINAL STUDY AREA

Prior to the introduction of CAP water in the mid 1980's, the primary source of salt contribution in the principal subbasins of the Pinal study area was from utilization of Gila River water (approximately 69 percent), followed by groundwater inflow (approximately 26 percent), and agricultural practices (approximately 8 percent). The Santa Cruz River acted as a salt sink, removing approximately 2 percent of the salt accumulated in the principal subbasins.

CAP utilization dominates salt accumulation and accounts for approximately 50 percent of the salt accumulation in the Pinal study area between 1988 and 2000. In this period, Gila River utilization accounted for approximately 35 percent of salt accumulation, followed by interbasin groundwater inflow (approximately 12 percent), and agricultural practices (approximately 3 percent). Removal of salt in surface water outflow was negligible during this time.

Pinal County's economy is predominantly agricultural. In 1995, 75 percent of the water used in Pinal County was for agriculture. In the past, the agricultural water supplies were primarily groundwater, supplemented by the Gila River, and the groundwater table was declining rapidly. With the introduction of CAP water for agriculture, the groundwater table recovered in the areas receiving a CAP allocation.

Importation of salts into Pinal County comes from the Gila River, Santa Cruz River, CAP water and human activities such as the application of fertilizers and municipal uses. Currently, approximately 600,000 tons of salts are imported into the basin, with roughly half this amount entering into the basin from the CAP.

Based on available surface and groundwater information, a generalized salt balance was calculated for the principal subbasins of the Pinal AMA. Results of the salt balance are presented in Table 2-3.

Table 2-3. Generalized Salt Balance in the Principal Subbasins of the Pinal AMA

	(million tons per year)	
Description	**1950 to 1987**	**1988 to 2000**
Average salt inflow from the Gila River	0.1937	0.2578
Average salt outflow from the Gila River	0.0121	0.0486
Average salt inflow from the Santa Cruz River	0.0017	0.0044
Average salt outflow from the Santa Cruz River	0.0077	0.0051
Average salt inflow from the CAP Aqueduct	0	0.2984
Average salt inflow from groundwater inflow	0.0683	0.0683
Average salt inflow from agricultural practices	0.0200	0.0200
Average salt accumulation in the principal subbasins	**0.2639**	**0.5952**

HARQUAHALA STUDY AREA

Based on ADWR groundwater pumping data and CAP water deliveries, a generalized salt balance was calculated for the Harquahala Basin (Table 2-4). The salt balance is divided into three distinct timeframes based on irrigation water sources and CAP water usage. The period from 1951 to 1985 represents extensive groundwater development and pumping, almost exclusively for agricultural irrigation. The period from 1986 to 2002 represents the introduction of CAP water for irrigation, and consequent significant reductions in groundwater pumping. The final column, representing future conditions, is based on continued utilization of the Vidler Recharge Facility and irrigation with CAP water.

Table 2-4. Generalized Salt Balance in the Harquahala Basin

	(million tons per year)		
Description	**1951 to 1985**	**1986 to 2002**	**Future**
Average salt load from agricultural irrigation	0.002	0.002	0.002
Average salt load from CAP deliveries and canal seepage	0	0.066	0.066
Average salt load from recharge facilities	0	0.001	0.076
Average salt accumulation in the Harquahala Basin	**0.002**	**0.069**	**0.144**

Prior to the introduction of CAP water, the only reliable source of water in the Harquahala Basin was groundwater, and virtually all of the groundwater pumped was utilized for agricultural purposes (Graf, 1980). The groundwater was of good quality ranging from under 500 mg/L to 1000 mg/L for the most part. According to the ADWR, municipal and industrial water demands in the basin are essentially negligible (1,000 af/yr), and represent 1 percent of the average water pumping in the basin (104,000 af/yr from 1951 to 1985). Therefore, the only significant source of salt loading in the Harquahala Basin prior to CAP water was from agricultural irrigation practices. It is estimated that farming practices in the Harquahala Basin would contribute approximately 0.002 million tons of salt per year from the use of fertilizers.

Utilization of CAP water for irrigation purposes in the mid-1980s essentially replaced groundwater pumping in the basin. Compared to average pumping from 1951 to 1985 (104,000 af/yr), groundwater production from 1986 to 2002 decreased dramatically to approximately 8,500 af/yr. During this time, average CAP water deliveries were approximately 81,000 af/yr. Although CAP water essentially replaced groundwater, the total amount used for irrigation did not decrease dramatically, and the salt contribution from agricultural irrigation practices is essentially the same, averaging 2,000 tons per year. Furthermore, CAP water represents a new water source inflow for the basin, resulting in approximately 66,000 tons of additional salts per year (calculated based on the quantity of CAP deliveries, including seepage, and an average TDS concentration of 650 mg/l). Recharge facilities also represent additional inflow of CAP water into the basin. The Vidler Recharge Facility began pilot operations in 1998 and, based on reported water deliveries, had recharged approximately 17,000 ac-ft of water by 2002 (Central Arizona Project, 2002).

Future salt loading in the Harquahala Basin was estimated for comparative purposes only. The future salt loading assumed that average irrigation demands from 1986 to 2002 would continue into the future, and that the Vidler Recharge Facility would operate at the maximum permitted capacity of 100,000 af/yr of CAP water. Additional sources of future salt loading in the basin could result from new recharge facilities in the basin. Decreases in future sources of salt loading could result from significant declines in agriculture, as predicted in the 1993 ADWR assessment.

The annual salt accumulation in the Harquahala Basin is relatively low (0.069 million tons per year) compared to recently completed calculations of salt balances in nearby basins. By comparison, the Gila Bend Basin averages approximately 0.5 million tons per year of salt, while the Phoenix metropolitan area averages approximately 1.1 million tons per year. Although the accumulated salts in the Harquahala Basin are relatively small, they are generally restricted to the agricultural area in the southeast portion of the basin. This agricultural area encompasses approximately 40,000 acres, and the percolation of irrigation water in this area has produced a perched water system above the fine-grained unit (Graf, 1980). The perched water system has significantly increased TDS concentrations compared to the regional aquifer, and cross-contamination through wells has degraded water quality locally (Hedley, 1990; Graf, 1980). Therefore, although the annual salt accumulation is relatively small in the basin, the applied area is also relatively small, and groundwater salinity has been impacted locally due to salt loading from agricultural irrigation practices.

The Harquahala Basin exemplifies a classic example of a declining groundwater table, which recovers when an alternate water sources are found. Harquahala agriculture began by using groundwater in the early 1950s. Groundwater pumping from 1951 to 1985 produced an extreme groundwater table decline. With introduction of CAP water in the mid-1980s, groundwater pumping decreased dramatically and the groundwater table recovered. CAP water currently brings approximately 66,000 tons of salt a year into the Harquahala basin, far surpassing the salt load from fertilizer of about 2,000 tons annually.

GILA BEND STUDY AREA

Based on USGS stream flow and water quality data, a generalized salt balance was calculated for the Gila Bend Basin (Table 2-5).

Table 2-5. Generalized Salt Balance in the Gila Bend Basin

	(million tons per year)		
Description	**1960 to 1977**	**1978 to 1995**	**1996 to 2001**
Average salt inflow from Gillespie Dam inflows	0.40	2.67	0.46
Average salt outflow from Painted Rock Dam outflows	0.19	1.86	0.01
Average salt accumulation in the Gila Bend Basin	**0.21**	**0.81**	**0.45**

The primary source of TDS in the Gila Bend Basin is from surface flows of the Gila River. The Gila River below the 91st Avenue Wastewater Treatment Plant consists of effluent and drainage discharged from the Buckeye Irrigation District, Arlington Canal Company, and Roosevelt Irrigation District, and averages around 2,300 mg/L TDS. According to ADWR, municipal and industrial water demands in the basin were met entirely by groundwater, and no additional sources of surface water were utilized.

Rascona (1996) estimated that approximately 600 af/yr per year of groundwater entered the basin as underflow from the Lower Hassayampa Basin to the north. However, the amount of groundwater underflow is considerably less than 1 percent of the average surface flow at Gillespie Dam, and the difference between groundwater inflow and outflow from the basin is considered to be negligible for the purposes of salt balance in this study area. According to ADWR, groundwater pumpage for crop irrigation averaged approximately 233,000 af/yr between 1971 and 1990. Based on previous salt contribution calculations from irrigation in the Phoenix metropolitan area, crop irrigation in the Gila Bend Basin would result in approximately 5,000 tons of salt per year, and is thus considered to be negligible for the purposes of this balance.

The primary source of salt outflow from the Gila Bend Basin is from surface flows downstream of Painted Rock Dam during high flow (flood) events. Due to limited water quality data, the TDS concentration of surface water below Painted Rock Dam is assumed to be equal to the TDS concentration of surface water entering the basin at Gillespie Dam. This assumption is also based on the minimal residence time of the surface water in the basin during high flow events, which represents the majority of outflow and salt discharge from the basin. Painted Rock Dam is designed to retain non-flood flows, and the Gila Bend Basin is essentially a closed basin during normal flow on the Gila River. Therefore groundwater pumping, treated wastewater flow, and irrigation return flows are not considered in the salt balance, as they originate and terminate within the basin.

The Gila Bend area has poor quality groundwater. Concentrations of TDS within the majority of the basin are between 1,000 and 5,000 mg/L. The groundwater delivered to the citizens of Gila Bend was of such poor quality that for years it was used only for bathing and household purposes. For drinking, residents had relied on bottled water. In June 2003, however, the Town of Gila Bend opened a 1.2-million-gallon-a-day RO water treatment facility and the TDS of delivered water was reduced from between 1,200–1,800 mg/L to 75 mg/L. The facility includes two evaporation ponds for disposal of concentrate.

CONCLUSION

The Phoenix metropolitan area currently receives the majority of the salt load in central Arizona. Estimates indicate that approximately 1.1 million tons of salt are accumulating in the Phoenix metropolitan area each year. Approximately three-quarters of the salt load entering wastewater treatment plants in the Phoenix metropolitan area originates from the surface water supply, and one-quarter originates from industrial, commercial, and residential uses of the water supply.

The Tucson metropolitan area’s annual accumulation of salt is approximately 100,000 tons, but this will increase to approximately 200,000 tons with in the next 15 years as more CAP water is imported. The agricultural areas of Pinal County have doubled their salt load since CAP went on line, currently at 595,000 tons per year. The salt loading in Harquahala is primarily the result of CAP water and compared to the other study areas it is insignificant at 69,000 tons of salts annually. Gila Bend’s accumulation of salts, currently at about 460,000 tons per year, comes from the effluent and agriculture return flows which enter into the Gila River.