Central Arizona Salinity Study

Phase I Report

December 2003

The study partners: City of Glendale, City of Mesa, City of Phoenix, City of Scottsdale, City of Tempe, Arizona-American Water Company, City of Chandler, City of Goodyear, City of Peoria, City of Surprise, City of Tucson, Town of Buckeye, Town of Gilbert, Queen Creek Water Company, Brown and Caldwell, and the Bureau of Reclamation.

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Acronyms and Abbreviations

ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
af	acre-feet
af/yr	acre-feet per year
AMA	Active Management Area
BLM	Bureau of Land Management
BID	Buckeye Irrigation District
CAGRD	Central Arizona Groundwater Replenishment District
CAP	Central Arizona Project
CASS	Central Arizona Salinity Study
CAWCD	Central Arizona Water Conservation District
cfs	cubic feet per second
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
Forum	Colorado River Basin Salinity Control Forum
FY	fiscal year
GDP	Gross Domestic Product
gpcd	gallons per capita per day
GRIC	Gila River Indian Community
GRUSP	Granite Reef Underground Storage Project
GSF	Groundwater Savings Facility
MAG	Maricopa Association of Governments
MDWID	Metropolitan Domestic Water Improvement District
MCL	maximum contaminant level
mg/L	milligrams per liter
model	salinity economic model
msl	mean sea level
MWD	Maricopa Water District (Arizona)
MWD	Metropolitan Water District (California)
O&M	Operation and Maintenance

PL	Public Law
RID	Roosevelt Irrigation District
RO	Reverse Osmosis
SCIIP	San Carlos Irrigation Improvement Project
SDWA	Safe Drinking Water Act
SROG	Sub-Regional Operating Group
SRP	Salt River Project
SRPMIC	Salt River Pima-Maricopa Indian Community
TC	CASS Technical Committee
TDS	total dissolved solids
USBR	U.S. Bureau of Reclamation
USDA	U.S. Department of Agriculture
USF	Underground Storage Facility
USGS	U.S. Geological Survey

CENTRAL ARIZONA SALINITY STUDY

PHASE I EXECUTIVE SUMMARY

Salinity is increasingly becoming a key consideration in municipal water supply and infrastructure planning. Higher concentrations of salinity - also referred to as salts or "total dissolved solids"(TDS) - are progressively accumulating in the soils and water supplies of regions throughout the United States. This is particularly evident in portions of the arid Southwest where the collective impact of irrigation, urban growth, low rainfall and the high mineral content of geologic features exacerbate the problem. It is important to note that traditional water treatment practices do not remove salinity.

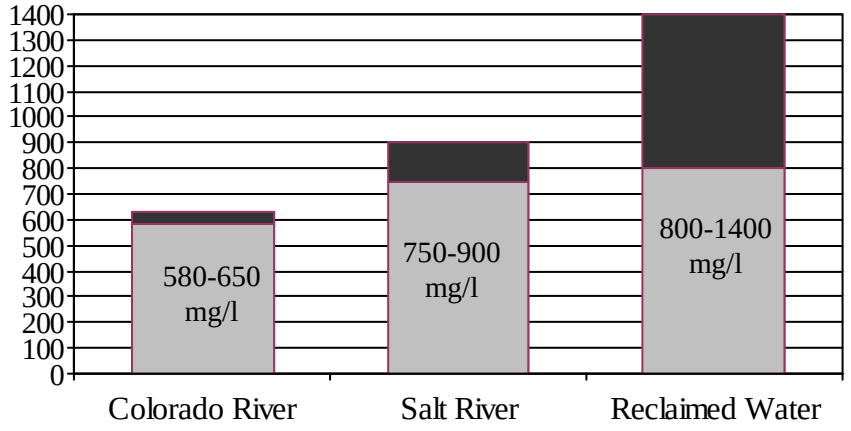
For decades, it has been acknowledged that the importation of high-salinity source waters for urban and agricultural uses could pose significant consequences. A 1948 planning report for the Central Arizona Project (CAP) indicated that *"…eventually it will become necessary to release salt-laden water from the Maricopa and Pinal units to maintain a salt balance in those areas"*(U.S. Bureau of Reclamation, 1948). With the CAP now delivering its full 1.5 million acre-feet capacity annually to central Arizona, along with 1.35 million tons of salt, it was felt that a comprehensive study of the impacts of those salts, and salts from other sources, was both timely and necessary. The "Central Arizona Salinity Study" was thus initiated in late 2001 as a means to evaluate these impacts, and to identify potential mitigation opportunities.

Study Background

The primary sponsors of the Central Arizona Salinity Study (CASS) are the five cities comprising the Sub-Regional Operating Group (SROG) in partnership with the Bureau of Reclamation. SROG consists of the Cities of Phoenix, Tempe, Mesa, Glendale and Scottsdale, who jointly own the 91st Avenue Wastewater Treatment Plant. In recent years, SROG has noted an upward trend in the salinity of effluent generated at that plant – a supply which is currently used for agricultural and industrial purposes. CASS was envisioned as a means to broadly evaluate and eventually curtail the impacts of high-salinity source waters on consumers, industry, infrastructure, water resources and the environment in a geographic area roughly approximating the CAP service area. A similar study in Southern California, conducted by the Bureau of Reclamation and the Metropolitan Water District in 1999, served as a model for CASS (Bookman-Edmonston, 1999)

The TDS content of surface water sources and reclaimed water is indicated in Figure 1. TDS in area groundwater ranges widely from as little as 200 milligrams per liter (mg/L) to well over 2,500 mg/L in

Figure 1. Comparison of Recent TDS Levels in Select Phoenix-Area Sources (Top bar reflects typical range)



the West Salt River Valley. The Environmental Protection Agency has established a secondary (non-enforceable) standard for salinity at 500 mg/L. This standard generally reflects a threshold associated with aesthetics.

CASS was envisioned as a two-part process with each phase comprising two years. The first phase (the subject of this report), focuses on characterizing the nature of the salinity problem (i.e. where the salts come from, where they end up, and both short and long term impacts). Phase 2 is expected to identify and evaluate solutions for managing salinity contributions from a variety of sources, and managing the brine "concentrate" from treatment processes. It is expected that the results of Phase 2 will then be utilized by area utilities (individually or through collaborative efforts) to assess the feasibility of constructing facilities or participating in other salinity management efforts.

A key objective of the Phase 1 process has been to engage other municipalities, private water companies, government agencies and other entities impacted by salinity. To date, the cities of Chandler, Goodyear, Peoria, Surprise, and Tucson, the towns of Buckeye and Gilbert, the Arizona-American Water Company, Arizona Water Company, and the Queen Creek Water Company have all joined the CASS study and financially contribute to the effort. Several other entities participate in CASS discussions. The project is funded on a 50/50 cost share basis between the participating entities and the Bureau.

A "Train Wreck in Slow Motion"

A regional "salt balance" developed as part of Phase 1 concludes that the Phoenix region imports approximately 1.5 million tons of salt per year. Most of this salt arrives via two major surface water supplies - the Colorado River and the Salt River. The Colorado River picks up its salts from several sources including agricultural return flows, salt springs, natural run off from range land and effluent from communities located along the river. Salinity in the Salt River is primarily due to natural salt springs in the watershed. Salt contributions to wastewater systems (for example from food waste and water softeners) and from fertilizers used in agriculture are also included in the 1.5 million tons of imported salt. Since only about 400,000 tons leave the area, approximately 1.1 million tons (almost three-fourths) remain.

Preliminary estimates indicate that about 39 percent of the salts entering the Phoenix metropolitan area end up in the groundwater through recharge and agricultural irrigation. Approximately 22 percent of the salts become trapped in the vadose zone through urban irrigation of parks, golf courses and other landscaping. Over a long period, it is possible that some of these salts residing in the vadose zone will migrate to the groundwater table. About 8 percent of the salts end up in sinks such as evaporation ponds, golf course lakes and other water bodies. The evaporation ponds associated with Arizona Public Service's Palo Verde Nuclear Generation Facility (which uses effluent from the 91st Avenue Plant for cooling) are the largest salt sinks in the region. The remaining 31 percent of the salts end up in consumer and industrial appliances, water supply infrastructure, evaporative coolers, cooling towers and wherever water evaporation is taking place.

A similar salt balance for the Tucson area indicates a net accumulation of 100,000 tons per year – a figure that is expected to double in the near term as the importation of CAP supplies increases to replace the lower-TDS groundwater currently used in the area. The predominately agricultural areas of Pinal County and the Harquahala Basin have over the past decade supplemented local water sources with CAP. Aquifers in these agricultural areas are continuing to degrade both due to the high-TDS source water and from fertilizer applications.

Economic and Other Impacts

Water with a high TDS concentration impacts virtually all sectors of society - residential, commercial, industrial, and agricultural. For the homeowner, salinity reduces the useful life of household appliances, such as water heaters, evaporative coolers, faucets, garbage disposals, clothes washers and dishwashers. Homeowners also incur salinity "avoidance costs" such as buying bottled drinking water and installing water softening systems. The commercial sector (schools, hospitals, retail stores, etc.) encounters impacts similar to homeowners with water-intensive operations bearing higher costs. Some industries in central Arizona (such as food and beverage manufacturers and semiconductor manufacturing) require de-mineralized water, other industries require water softening. In such cases, relative costs are directly tied to the TDS content of the water they receive from potable systems.

The effect of salinity on crops has been well documented. Worldwide, millions of acres of land - in some cases dating back to ancient civilizations - have been rendered unproductive due to salt loading. The present day agricultural sector experiences economic losses as high TDS water reduces crop yields, requires additional fertilizers and soil additives, and results in a need to apply supplemental water to flush salts downward away from the root zone. Increasing salinity content of groundwater has left supplies in certain areas unusable for expanding urban growth without some form of treatment.

The overall impact is even more significant when considering increased urban and agricultural reliance on reclaimed wastewater. Because wastewater streams include significant salt contributions from commercial, residential and industrial uses, this added salt can render reclaimed water less desirable or even unusable for certain purposes. Furthermore, irrigation with reclaimed water amplifies the salt-loading problem in groundwater.

Though economic impact of high-TDS water in central Arizona is significant, it has not yet substantively affected economic development of the region. The economic impacts of salinity are very subtle, and are widely spread among the sectors previously indicated. CASS Phase I economic modeling equated a 100 mg/L TDS variation of the two primary surface water sources (the Salt River and Colorado River) with approximately $30 million in damages. About 93 percent of those damages are associated with the Phoenix Metropolitan area. However, given that the gross domestic product (GDP) for Maricopa County is about $93.6 billion, the relative impact at present is minor. However, the economic impacts are expected to increase substantially in the future with the compound affects of continued salt importation via the rivers and additional salt loading as the population grows.

Next Steps

CASS Phase 2 will evaluate a wide range of potential solutions to address the continued buildup of salts in the study area, and will describe the consequences of a "no action" alternative. The key focus areas are likely to include: 1) removal of salt (or prevention of entry) in watersheds; 2) salt removal at water and wastewater plants; 3) limiting salt contributions to wastewater systems through regulations or incentives; 4) concentrate management; and 5) preventing further salt loading of soils and aquifers. Phase 2 will also explore the feasibility of developing brackish groundwater in the area as a supplemental source. The results of Phase 2 will form a basis for future funding decisions with regard to salinity management practices and infrastructure needs to both protect and enhance our water supplies.

CHAPTER 1 – INTRODUCTION

BACKGROUND

Salinity has been recognized as a problem for agriculture in the western United States for many years. City managers and others have recently begun to recognize that elevated salinity levels in groundwater and surface water also pose potentially serious challenges for the urban environment. Central Arizona, which includes Arizona's largest metropolitan areas, is just one western region where the issue of high salinity levels may soon need to be addressed.

Since the mid-1980s, it is estimated that in a typical year nearly 1.3 million tons of waterborne salts are transported into the Phoenix metropolitan area, primarily via the Salt River and the Central Arizona Project (CAP) canal. An additional 140,000 tons of salts are added to the water system from humans through fertilizers, water softeners, industrial waste, commercial waste, and other wastes disposed into the sewer system. Only about 320,000 tons of these salts are carried out of the region via the Gila River each year. Thus, more than 1 million tons of salts build up in the Phoenix metropolitan area every year. CAP officials had recognized this problem and in December 1947 prophetically noted, "Eventually it will become necessary for the users to release enough water from the area to carry out the same amount of salt as introduced annually" (Central Arizona Project, 1947).

Salinity, which for practical purposes is defined as total dissolved solids (TDS), is a measure of the total ionic concentration of dissolved minerals in water. TDS is principally composed of the cations (or positively charged ions) sodium, calcium, potassium, and magnesium, and the anions (or negatively charged ions) chloride, sulfate, carbonate, and bicarbonate (Appendix A). The problems created by salinity are a complex series of interrelated impacts to society that affect virtually everyone in central Arizona.

How much salt is coming into central Arizona? Where are the salts accumulating? What is the economic impact of these salts? What will the future impacts to society be because of this constant inflow of salts? This report atempts to answer these and other questions about the impacts of salinity to central Arizona.

PROGRAM SUMMARY

The Central Arizona Salinity Study (CASS) is a 4-year study of the salinity problems in central Arizona and a concerted effort to identify possible solutions to those problems. The study was originally initiated through a cooperative partnership between the U.S. Bureau of Reclamation (USBR) and the Sub-Regional Operating Group (SROG), which is a partnership between the cities of Phoenix, Mesa, Scottsdale, Glendale, and Tempe to jointly operate the 91st Avenue Waste Water Treatment Plant, located in Phoenix Arizona. After the first year, the following entities joined and financially contributed to the study: Arizona-American Water Company, City of Chandler, City of Goodyear, City of Peoria, City of Surprise, City of Tucson, Town of Buckeye, Town of Gilbert, and Queen Creek Water Company.

MISSION STATEMENT

CASS is a coalition of water and wastewater agencies evaluating salinity issues in central Arizona. The mission of CASS is to provide its members with workable alternatives for a quality, cost-effective, sustainable, and reliable water supply through partnerships and cooperative efforts in regional salinity planning and management.

GOALS

The process goal is to develop a common base of understanding of the issues and options, and develop a consensus plan to address salinity issues in central Arizona.

The outcome goal is to define the salinity problem, identify appropriate uses and reuses of water and associated guidelines for managing TDS, determine where mitigation efforts should be focused, and develop a Central Arizona Salinity Master Plan.

CASS

The study is organized into two phases. Phase I is a 2-year study (Fiscal Year [FY] 2002 and FY 2003) to identify the problems and potential future problems related to importing and retaining large quantities of salts in central Arizona. This report summarizes Phase I research.

Phase II will develop and assess solutions to the problems identified in Phase I. Phase II is also a 2-year study (FY 2004 and FY 2005); a final report will be issued at the conclusion of Phase II.

In October 2001, a cost-share agreement was signed between the City of Phoenix, representing SROG, and USBR. USBR contributes $300,000 per year in labor, research and direct costs towards the CASS, and SROG matches that amount with similar expenditures.

The study is led by joint project managers, one from USBR and one from SROG. Guidance during the study comes from the Project Management Team (PMT), which consists of one representative from each of the financial contributing partners. The PMT meets on a quarterly basis.

A technical committee (TC), consisting of stakeholders, meets on a monthly basis. TC members contribute to the study by writing papers, contributing personal knowledge and pertinent information, and giving presentations. In addition, the TC critiques the progress and data gathered for the study and reviews written papers and reports. Many other entities, such as Arizona Department of Water Resources (ADWR), Arizona Department of Environmental Quality (ADEQ), consultants, private citizens, and various central Arizona communities have representatives attending the technical meetings. Their collective involvement will ensure that a comprehensive study will be conducted to assess potential salinity issues in central Arizona.

STUDY AREA

For the purposes of this study, central Arizona is defined as the portions of Arizona supplied by the CAP in Maricopa, Pinal, and Pima Counties. The primary focus areas of this study are the Phoenix and Tucson metropolitan areas. Deciding factors in maintaining this focus are: (1) the majority of the population of Arizona lives in these areas[1], (2) by far the greatest economic impacts and potential for future impacts from salinity fall in these areas, and (3) access to the necessary data to evaluate salinity trends and impacts is readily available for these communities.

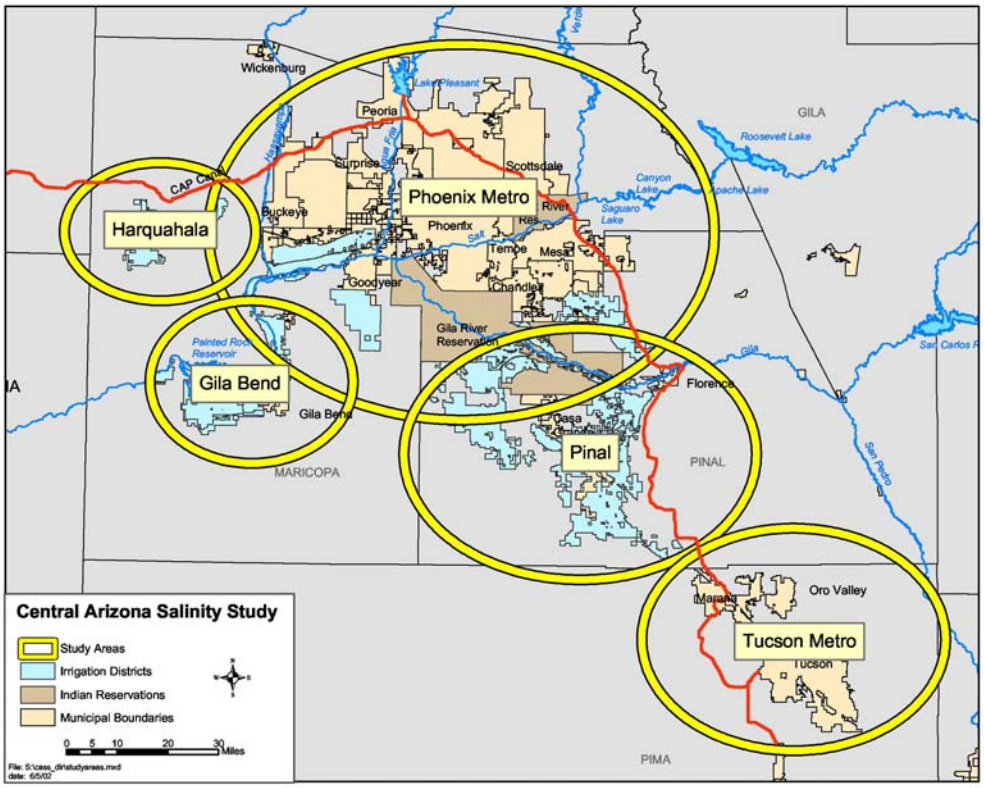
Secondary study areas include portions of the agricultural areas in Pinal County, the Harquahala Basin, the Gila Bend Basin, and on the Gila River Indian Community (GRIC). The thread which unifies these diverse areas is the CAP, which supplies water from the Colorado River to each area either directly or indirectly (Figure 1-1).

Central Arizona is located within the Basin and Range Physiographic Province, an area characterized by low, rugged mountain ranges separated by broad alluvial valleys. The alluvial valley deposits are shallow along the basin margins, but in the central portion of the basins may be several thousand feet thick. These alluvial deposits contain vast aquifers which hold significant quantities of groundwater, a vital source for the communities and farmers in central Arizona. Water quality in these aquifers is variable, ranging from excellent to poor.

The climate in central Arizona is hot and dry, with lowland desert vegetation dominating the region. The most abundant species of plants include creosote bush, palo verde, saguaro, cholla, prickly pear, ocotillo, lotebush, desert hackberry, and mesquite. Rainfall is relatively meager, typically 7 to 8 inches annually in Maricopa and Pinal Counties and slightly more, 11 to 16 inches, in eastern Pima County. Detailed hydrologic and geological data of the study area are presented in Appendices C through G.

[1] The 2000 census indicates that more than 3 million people live in the Phoenix metropolitan area and an additional 1 million persons reside in the Tucson metropolitan area. More than 75 percent of the current population of Arizona lives within the study area.

Figure 1-1. Central Arizona Salinity Study (CASS) Study Area



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)

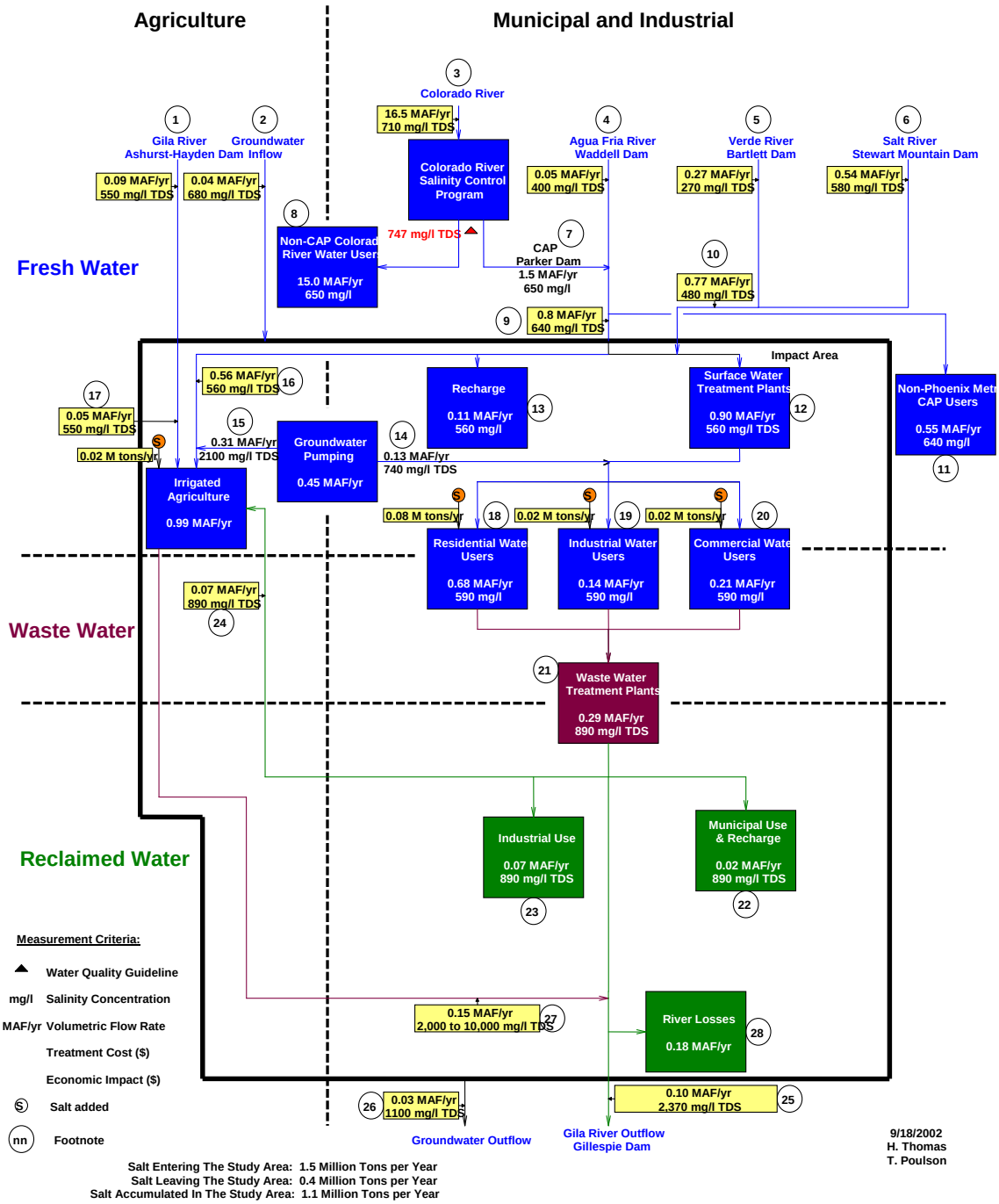


Table 2-1 summarizes the current annual salt flux for the Phoenix metropolitan area. The first row below the headings, "Groundwater," represents the flux of groundwater moving into the Phoenix area, generally from the north, and the salt load it transports. The sixth row, "Society," lists the quantity 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.

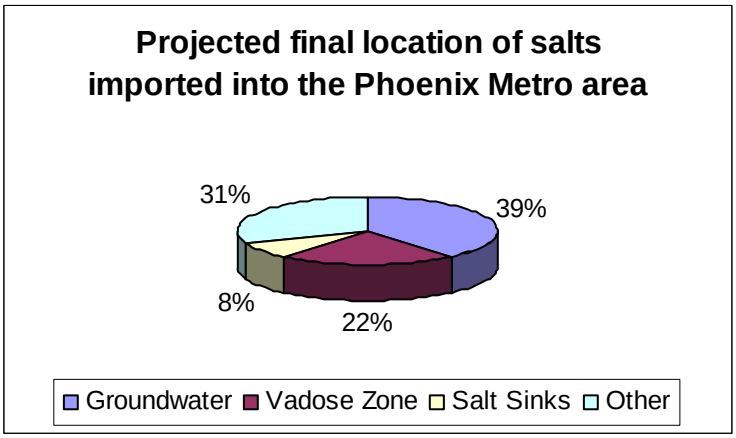


Figure 2-2. Where the Salts Accumulate

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.

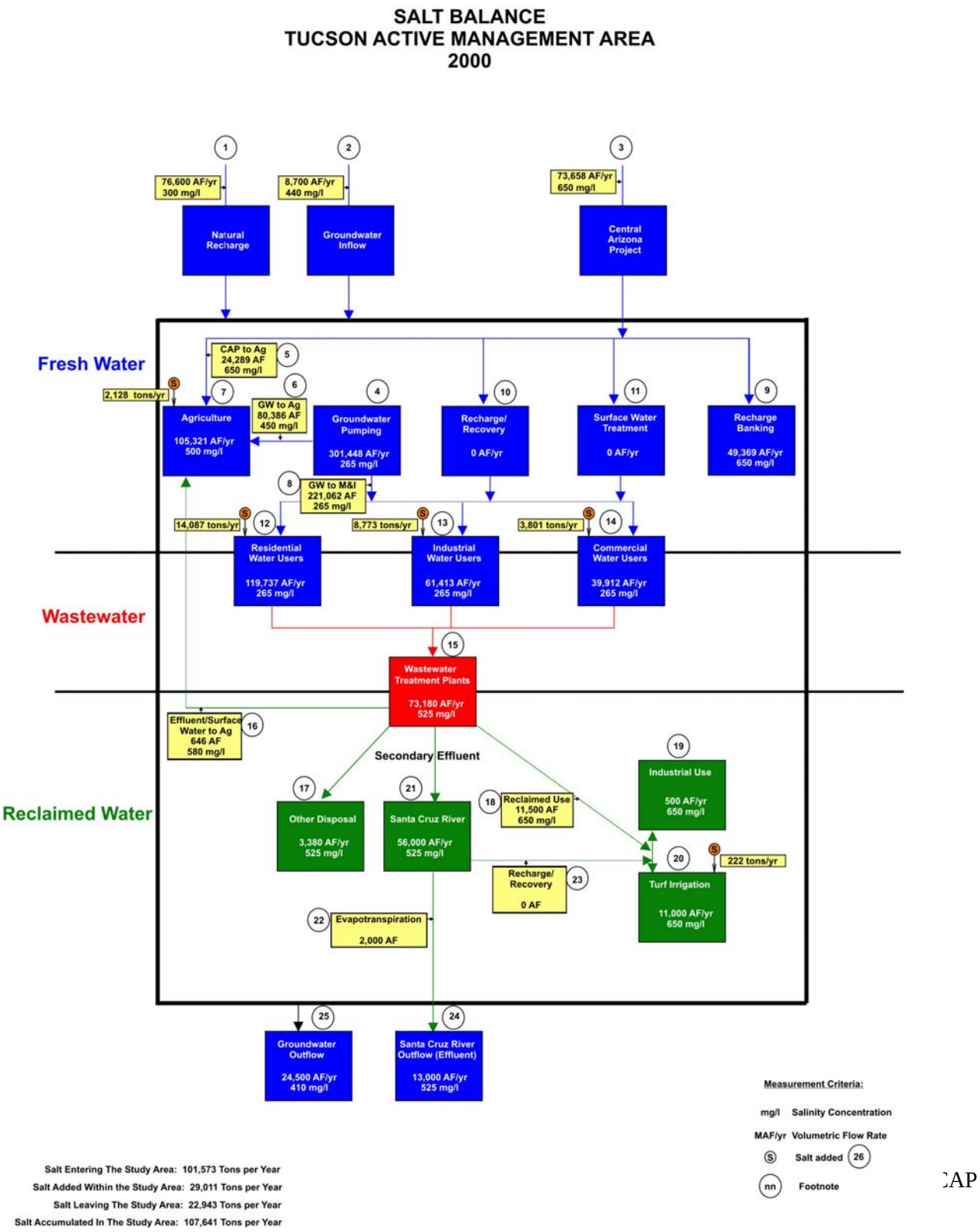
The CAP was completed to the Tucson area in the early 1990s to deliver a renewable supply of water from the Colorado River. For the purpose of this study, a TDS concentration of 650 mg/L was used to characterize CAP water typically received in the Tucson area (Tucson Water, 2003). In 2000, 24,289 af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



CAP

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.

CHAPTER 3 – EFFECTS OF SALINITY IN CENTRAL ARIZONA

INTRODUCTION

The impacts of importing high-salinity water affect all areas of society, from residents who complain of poor-tasting water and shortened lifespans of water-using household appliances to giant industries that must expend capital to purify the water used in manufacturing processes. In addition, agriculture loses millions of dollars annually as a direct result of high TDS irrigation water. In addition to the annual costs, there are long-term impacts, including impairments to groundwater, natural habitat, and effluent—a vital source of future water.

As noted in Chapter 1, salinity or TDS is a measure of the total ionic concentration of dissolved minerals in water. Table 3-1 presents a typical breakdown of the TDS components found in the Salt River and the Colorado River, which are both major sources of renewable water and the major contributors of salts to central Arizona. Typically, the Salt River is higher in sodium and chlorides and the Colorado River is higher in sulfates. Sulfates have a bitter taste at about 500 mg/L and can be tasted by some people at levels as low as 200 mg/L (Bookman-Edmonston, 1999). Studies indicate water with sulfates at about 1,000 mg/L have a laxative effect.

Table 3-1. Typical TDS Components of Central Arizona Source Waters

Constituents	Salt River (below Stewart Mountain Dam, in mg/L)*	Colorado River (below Parker Dam, in mg/L)**
TDS	593	570
Calcium	49	69
Magnesium	14	24
Sodium	154	76
Alkalinity (as $CaCO_3$)	157	130
Sulfate	56	215
Chloride	237	66
Fluoride	0.32	0.29
Nitrate (as N)	0.13	0.22

Sources: * Salt River Project, Water Operations Department, 2000.
** U.S. Geological Survey, Water Resources Data, Arizona Water Year 2000

URBAN IMPACTS

Residential Users

Residential water use accounts for approximately three-quarters of all non-industrial urban water consumed, or about 23 percent of water consumed in central Arizona. Typical homeowners are not well informed of the impacts of increased salinity in their water, although many are broadly aware of salinity in terms of taste and obvious visible effects, such as spotting on dishes and residue in bathtubs and sinks. The impacts of salinity to the residential user can be broadly classified into three areas:

1. Reduced efficiency of detergents;
2. Reduced life of water-using appliances and plumbing; and
3. Avoidance costs, including purchasing bottled water, water softening devices, and under-the-sink RO systems.

Water high in calcium and magnesium is colloquially referred to as "hard water." While hardness in water is not a health risk, it is a nuisance and has both short and long-term impacts. Calcium and magnesium will combine with some soils to form insoluble salts that are difficult to remove. For example, clothes washed in hard water often look dingy and feel harsh and scratchy. Clothes continuously washed in hard water can have a shortened lifespan of up to 40 percent (Maunders, 2003). Similarly, bathing with soap in hard water leaves a film of sticky soap curd on the skin that can prevent removal of soil and bacteria. Soap curd in the hair may make it dull, lifeless and difficult to manage.

Hard water contributes to inefficient and costly operation of water-using home appliances. Heated hard water forms a scale of calcium and magnesium minerals (limescale deposits) that can lead to shortened life of water heaters. Evaporative coolers will be coated with limescale deposits as the water is evaporated and the minerals remain behind, which requires more frequent replacement and higher maintenance costs. Solar heating units also are prone to limescale buildup and thus early replacement. Pipes can become clogged with scale that reduces water flow and ultimately requires pipe replacement.

The most common method of combating hard water is through household water softeners. A softener replaces the calcium and magnesium with sodium. While this process reduces hardness, it does not reduce the TDS. Water softening devices release the calcium and magnesium into the sewer and the sodium added eventually contributes to higher TDS levels at wastewater treatment plants. Another method of combating hard water is under-the-sink RO units. These units remove all the salts and provide very good quality water to the customer. In addition, they also do not contribute to a higher TDS at the wastewater treatment plants. However, these units must be maintained properly to efficiently remove salts and to prevent bacterial buildup. The most common method of avoiding high salinity water is bottled water. Bottled water, with the exception of expensive spring water brands, for the most part consists of regular tap water processed through RO or distillation. Bottled water is used almost exclusively for drinking and does not help with the other problems associated with hard water.

Commercial

The commercial sector is quite broad, encompassing nearly all uses not included in the residential and industrial/manufacturing classifications. The commercial classification includes a broad spectrum of businesses, from auto insurance offices to car washes to hospitals and many other service and retail

establishments. The commercial sector consumes approximately 7 percent of the water in central Arizona (Arnold, 2002). The impacts of high TDS water in the commercial sector are very similar to the impacts felt by the residential users. Water high in TDS shortens the life of the faucets and plumbing of schools, restaurants, hospitals, hotels, and other commercial buildings. Water heaters, garbage disposals, and other water-using appliances employed in the commercial sector are affected by hard water. Commercial water softeners are also used by businesses such as restaurants, hospitals, car washes, laundries, and other businesses which do better without hard water. Commercial water softening not only contributes additional salts to the wastewater treatment plants but also contributes to higher costs for goods and services, which are initially incurred by the businesses but passed on to the consumer.

Large commercial buildings commonly utilize cooling towers to provide air conditioning. Cooling towers operate by evaporating water using the same principle as evaporative coolers for individual homes, but employ a more sophisticated process in which the cooled water is passed through a heat exchanger to cool the air. As water evaporates it leaves behind salts, which inevitably accumulate in the remaining water. After a few cycles, depending on the source water salinity and other factors, the water has to be discharged or the salts will precipitate out or scale on the copper tubing of the heat exchanger or the tower itself, reducing the efficiency of the system. Several problems arise because of high TDS source water in a cooling tower. For example, if the salt-enhanced water is discharged to the sewer it raises the TDS of the effluent at the wastewater treatment plant. A second problem relates to the cycling of water through cooling towers. High TDS water can be used through fewer cycles of concentration before that water is discharged and fresh water or makeup water must be brought into the tower. The use of make-up water has an associated cost.

Golf is a major contributor to the tourism industry in Arizona, contributing more than $1 billion annually to the regional economy. The ADWR Third Management Plan 2000–2010 encouraged golf courses to reduce groundwater use and convert to renewable water sources, preferably effluent (Arizona Department of Water Resources, 1999). As an incentive to do so, ADWR provides regulation relief to golf facilities. In a response, developers made major capital investments in infrastructure to convert existing golf courses and develop future golf courses towards using effluent. One example of this is the Reclaimed Wastewater Distribution System in north Scottsdale. Wastewater reclaimed at Scottsdale's Water Campus is transported through a system of pipelines and delivered to approximately 20 golf courses in the area. However, effluent is 300 to 500 mg/L higher in TDS than groundwater, and the use of high-TDS effluent has resulted in additional costs to the golf courses. There are many problems associated with high TDS effluent. It tends to limit the ability of certain species of turf grasses to grow and flourish. Salt buildup in the root zone is endemic and must be flushed with additional water. High-TDS water stains those facilities that receive any overspray. High sodium also causes clay soils to disperse, resulting in a relatively impermeable layer and poor subsequent infiltration and high nitrates levels cause problems with the greens. With aggressive maintenance regimens, golf course managers have been able to maintain the greens and fairways but at a substantial increase in cost for chemicals and labor.

Industrial/Manufacturing

Industry in central Arizona consumes approximately 5 percent of the total water use. Arizona industries typically include high-tech manufacturing of chips, computer parts, cell phones, LCD crystals, and other retail consumer goods such as food and beverage production, metalwork, woodwork, and furniture assembly. Other Arizona businesses such as dairy farms, power plants, sand and gravel plants, feed lots, and mineral mining also fit into the industry sector definition. Industry has several basic functional aspects in which water is used: these include process water, boiler feed water, and cooling water, as well

as sanitary, secondary cleanup, and irrigation water. To meet their manufacturing needs, some industries use advanced water treatment to produce one or more kinds of "improved" water such as softened water, RO water, and/or ultra-pure water.

Water treated by RO will characteristically have a TDS between 50 and 100 mg/L. A typical use where RO water is needed is the manufacture of cosmetics and in the food and beverage industry. RO is used for boiler feed water to prevent scaling and also as a first step in producing ultra-pure water for high-tech industry. Ultra-pure water, which is very close to having 0.0 mg/L TDS, is employed in the manufacture of electronic chips, where any impurity can damage the end product. Water of this purity is extremely aggressive and is expensive to produce. Aggressive water is water that is soft and acidic and can corrode plumbing, piping, and appliances.

Cooling towers used in the industrial sector are usually larger and more robust than the commercial sector cooling towers, but have the same problems described earlier. Industrial cooling tower water may be softened or it may be used directly as received. In Arizona, the number of cycles for large cooling towers at power plants is set by ADWR for water conservation purposes (seven cycles for pre-1984 plants and 15 cycles for post-1984 plants). Biological growth, pH, and scaling are controlled by chemicals. Chemical suppliers publish a recommended maximum of six cycles, but in practice, because of the TDS in Arizona's source waters, the actual number of cycles is considerably lower, between 2.5 and 4.5.

The water supply for the Phoenix metropolitan area includes several different source waters, which is a benefit in terms of reliability. However, it is also a potential concern because the chemistry and TDS of the different waters can cause operational challanges for operators of advanced water treatment systems. The extreme difference of salinity between the Verde River and Salt River salinities provides an example of this potential concern. SRP typically delivers Salt River water during the summer months when extra hydroelectric power is needed and begins to deliver Verde River water each year in September or October. Verde River water is delivered throughout the winter to create space in the reservoirs for the spring runoff. While this is operationally sound in terms of water resource management, it can cause problems for the recipients of the water since there can be a 500-mg/L difference in salinity between the two rivers. When the water supply changes and the chemistry in the source water is different, operators of RO systems must adjust the treatment chemicals and/or proportions required. So far, industries in the Phoenix metropolitan area have adapted to the salinity, but at a cost. The economic impacts of the salinity for the industrial sector are summarized in Chapter 4.

Utilities

The newest source of surface water to be delivered to central Arizona, the Colorado River, contains high levels of sulfate particulates on the other hand, the Salt River is high in sodium and chlorides. Corrosion in water and wastewater facilities is a concern and is primarily the result of sulfides and chlorides. Corrosion can be controlled at the water and wastewater facilities by using corrosion resistant construction materials such as stainless steel.

Of more concern to some wastewater utilities is the rising salinity in effluent, because effluent is a major component of the future water supply. The concern is that salinity might increase to a concentration where the effluent can no longer be used for current or an intended future purposes. For example, at the 91st Avenue Wastewater Treatment Plant (WWTP) operated by SROG, in the future it is estimated that 62,000 af/yr will be recharged in the Agua Fria Linear Recharge Project. For the effluent to remain a valuable and reliable resource for recharge, the salinity must remain at a tolerable level. The salinity concentration in

the effluent is especially high in the summer when higher TDS Salt River water is delivered, compounding the addition of 300 to 500 mg/L TDS by society via human activities (Figure 3-1). Salts are added to water cycle by humans in many ways; disposing food, water softeners, industrial salts, etc. This can bring the salinity level of the effluent at the 91st Avenue WWTP above 1000 mg/L TDS which is a higher TDS then many areas of the aquifer. Soil aquifer treatment does not reduce TDS when recharging water. If customers perceive a noticeable change in taste to their water when the Agua Fria Linear Recharge Project goes online, it could lead to a public relations problem and jeopardize the recharge project.

Although salinity is not regulated under existing Arizona law, Title 18 of the Arizona Administrative Code, Section R18-11-405(c), Narrative Aquifer Water Quality Standards, states, "A discharge shall not cause a pollutant to be present in an aquifer which impairs existing or reasonably foreseeable uses of water in an aquifer." Water providers facing long-range planning issues wrangle with questions such as: Could recharging high TDS effluent be challenged under this statute? How high would the TDS have to be to be considered a pollutant?

Another concern to WWTP managers is that salinity levels could rise to the point that the biomonitoring organisms—typically fathead minnows (*Pimephales promelas*) and water fleas (*Ceriodaphnia dubia*)—would experience long-term toxicity effects from the high-salinity effluent being discharged into their habitat. It is not yet known whether high-salinity effluent could inhibit their reproduction or disrupt their habitat enough to impact these and other species' lifecycles. However, it would be expensive for cities to make operational or facility changes at the WWTP to reduce the salinity level to meet environmental protection requirements.

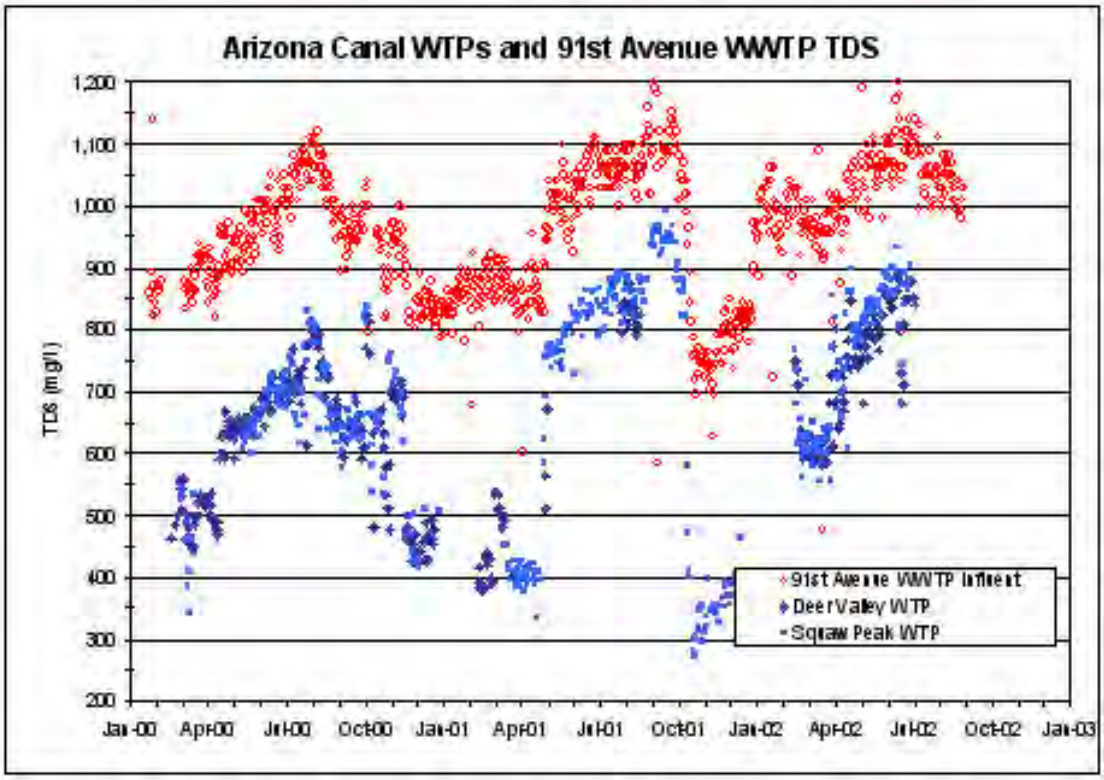


Figure 3-1. Source-Water TDS at Water Treatment Plants and Effluent TDS at 91st Avenue Wastewater Treatment Plant

Managing salinity at the WWTP will likely become necessary in the near future, but effectively managing salinity will mean making tough decisions regarding who will pay for the technology required. Specific taxes could be applied on known industrial contributors of salts. Residential users contribute twice the quantity of salts added by the industrial and commercial sectors so the cost should or could be borne by them. In either case new taxes or rate increases are unpopular with both the populace and politicians.

Municipalities in central Arizona must consider all possible water sources, including effluent and brackish groundwater, to meet the demands of a growing population. In the Phoenix metropolitan area two locations, one in the southwest (Goodyear area) and the other in the southeast (Chandler area), may be prime candidates for a RO plant to recover brackish groundwater. Different strategies could be employed, including construction of one or two advanced regional water treatment facilities or numerous smaller advanced water treatment facilities. While several options to process the impaired water may be considered, membrane treatment produces a concentrate that must be disposed and the cost of disposing of that concentrate can be more than double the treatment costs. There are as yet no cost effective solutions on what to do with the concentrate when there is no ocean within easy access. Smaller RO facilities (Chandler and Gila Bend) have built evaporation ponds to dispose of the concentrate. The largest RO facility in the Phoenix metropolitan area, operated by the City of Scottsdale, disposes of its concentrate in the sewer system. Unfortunately, this raises salinity levels at the waste water treatment plants.

AGRICULTURAL IMPACTS

Agriculture in the Phoenix metropolitan area is on the decline. In 1904, SRP had 238,400 acres of irrigated agricultural lands in their service area. By 2000, SRP had slightly fewer than 45,000 acres under irrigation. Agricultural lands in the western portion of the Phoenix metropolitan area have also decreased as urban areas continue to expand. However, even with the decline of irrigated land, agriculture in 1995 still consumed 54 percent of the water used in the Phoenix AMA and, overall, agriculture used 65 percent of the water consumed in central Arizona (ADWR, 1999). With the exception of the Indian lands of the GRIC and the Salt River Pima-Maricopa Indian Community (SRPMIC), agriculture in the Phoenix area may completely end as urban development continues to build out the metropolitan area. In the Tucson metropolitan area agriculture began to decline in the mid-1970's, largely due to Tucson Water's purchase and retirement of over 20,000 acres of agricultural lands in Avra Valley. By the mid-1980's municipal water use exceeded that of agriculture in the Tucson Active Management Area demonstrating the increasing shift away from agriculture as urban areas continued to expand. The Pinal County economy, by contrast, is primarily based on agriculture and is expected to remain so until it is no longer economically feasible to pump groundwater. The Harquahala area, west of Phoenix, is expected to follow the same path as Pinal County, continuing to pump groundwater until it is no longer economically feasible to grow crops. The Gila Bend area utilizes the Gila River and groundwater as a source of water for agricultural irrigation. However, by the time the Gila River reaches Gila Bend, it is comprised only of effluent from the 91st Avenue WWTP and return flows from irrigation districts. As long as this water continues to flow down the Gila River, agriculture will be viable in the Gila Bend area. Agriculture will most likely remain a significant, although diminished, portion of the economy in central Arizona through the 21st century.

Agricultural practices concentrate salts in the groundwater. Irrigation water is consumed by plants but the plants do not absorb the salts, which are left behind in the root zone. The salts also change the osmotic pressure gradient and make it more difficult for plants to take in water. The energy used by the plant to

overcome this osmotic pressure is not used for growth, and thus crop yields are lowered. Farmers therefore need additional water to flush the salts away from the root zone. Another problem of sodium is that it has a tendency to disperse clay soils and inhibit the ability of the soil to drain. An interesting side note about the introduction of Colorado River water comes from the original planning work on the CAP. The 1972 Central Arizona Project Environmental Impact Statement concludes that the two source waters may be beneficial to each other, noting "There is significantly more calcium and magnesium in Colorado River waters than local waters, which will tend to keep soils permeable by exchanging with sodium on the clay particles."

Figure 3-2 provides an illustration of this process. In this example, the crop takes 5 af/yr and consumes 4 af/yr of the water, leaving the salts behind in the root zone. The one additional acre-foot of water flushes the salts through the root zone. If the farmer started with 650 mg/L of water (typical CAP water salinity), the flushing water would yield salinity at five times the initial level, or 3,250 mg/L. Many variables, including depth to groundwater, soil type, soil porosity, application rate, and field capacity, factor into the rates at which this high-salinity water reaches the groundwater table.

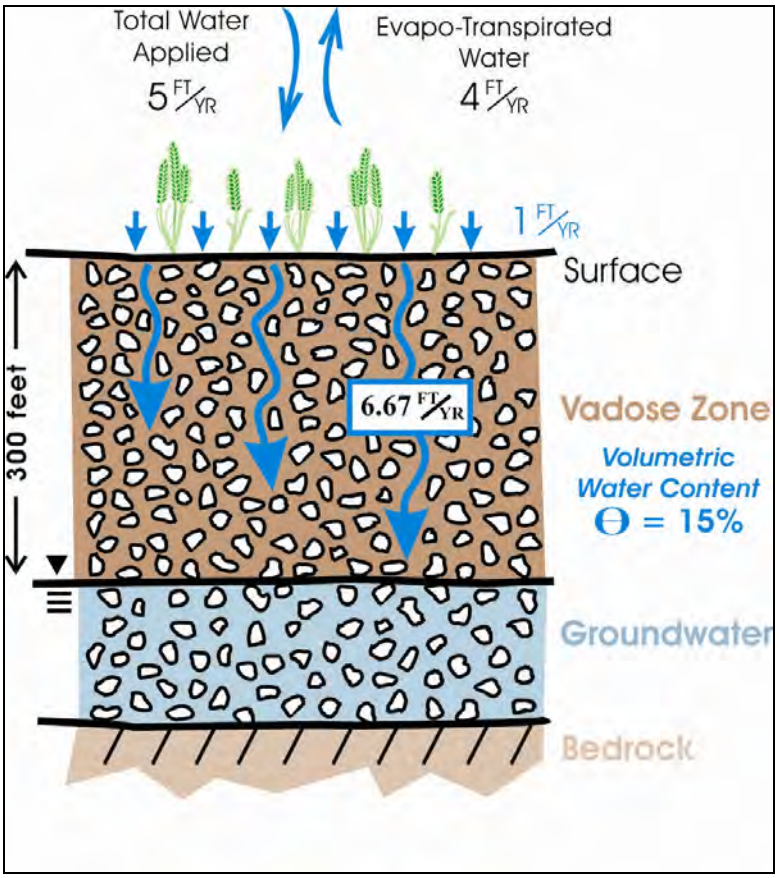


Figure 3-2. Agriculture and Salt Concentration

Using Figure 3-2 again, this example assumes a volumetric water content of 15 percent and a depth to groundwater of 300 feet. While downward flow of deep percolation water below the root zone is unsteady and occurs in pulses following each irrigation event, the pulses flatten out with depth to become

a steady flow. The actual downward water velocities, or pore velocities deeper in the vadose zone, can be estimated as the average deep percolation Darcy flux divided by the volumetric water content of the vadose zone. Therefore, with a deep percolation rate of 1 ft/year and a volumetric water content of 15 percent in the vadose zone, the pore velocity of the deep percolation water would be 1/ 0.15 = 6.75 ft/yr. Using this example, the deep percolation water would reach the groundwater table in approximately 45 years. However, once the water reaches the groundwater table, and assuming a porosity in the vadose zone of 20 percent, the water table will start rising at the rate of 1/0.20 = 5 ft/yr. When saline water reaches groundwater it will basically remain on the top of the water table, as there is not much mixing in the groundwater. In this example, the 3,250 mg/L saline water would rise over the years and, if it eventually reached the surface, would evaporate and leave the surface coated with salts, spoiling the land for agricultural use. Some of the agricultural areas in Pinal County and the Harquahala Basin currently receiving CAP water have seen the groundwater table recover. In the southwestern portion of the Phoenix metropolitan area, large sectors of land are designated as waterlogged and farmers must pump groundwater into the Gila River to keep the water table below the root zone. The groundwater table in agricultural areas in central Arizona varies from just a few feet under the surface to hundreds of feet below the surface. The above example illustrates how the process works, but each area has its own timetable in terms of eventual impacts from salinity. Yet the final result will be the same—the groundwater in these areas will be impaired when agriculture ceases to be a viable land use.

In addition to concentrating of salts through evapotranspiration, a variety of minerals and nitrates are introduced into the groundwater table through fertilizers. Although fertilizers add only about 1.5 percent of the salts contributed to the Phoenix metropolitan area annually, nitrates are a potentially significant concern. Water with nitrate concentrations above 10 mg/L is no longer considered potable, and some agricultural lands in the area have groundwater with nitrate levels above this benchmark.

Two major economic impacts high-TDS water has on agriculture are reduced crop yields and the costs associated with flushing salts out of the root zone. The U.S. Salinity Laboratory in Riverside, California has developed crop yield curves over the last 25 years establishing yield-per-acre declines as salinity levels increase in the irrigation water. Of course, different crops have different tolerances to salinity. The crop yield rates developed by U.S. Salinity Laboratory show the crop yield at different levels of salinity in the irrigation water, but because growing conditions can vary dramatically, these findings can only approximate the actual change in yield. Cotton, barley, and alfalfa are quite tolerant to salinity and are major crops in central Arizona. Some of the impacts that salinity has on agriculture in central Arizona may be considered hidden impacts, such as the loss of income because more valuable crops can not be grown due to high-TDS irrigation water.

Leaching salts from the root zone and the “wasting” of water used in this process may also be considered an impact to agriculture in the region. Approximately 10 to 20 percent of agricultural water usage must be allocated to leaching salt out of the root zone. As water becomes more expensive and more difficult to deliver to municipal users, the use of water to flush salts may be perceived as wasteful. Both of these subjects are discussed in more detail in Chapter 4, *Economic Assessment Model*, and in Appendix J.

Although in agricultural areas the problem of salts added through fertilizers is readily acknowledged, urban areas have a similar problem. Some people refer to cultivated vegetation in the cities as “urban agriculture”—the grass, flowers, trees and other plants that are grown in an attempt to make the cities a little greener. Figure 3-4 presents a false color infrared photograph of the Phoenix metropolitan area in 2000. Though there are still large areas of traditional agriculture in the west, which show up as a dark red, the pink shade through the heart of the cities reflects urban agriculture. Approximately 50 percent of the water consumed by the residents of the cities is used outdoors, and most of that is for irrigation.

While some golf courses may overwater turf expressly to leach salts out of the root zone, most urban irrigation does not intentionally use additional water to leach salts. In fact, most homeowners are not aware that salts may accumulate in the root zone and eventually impact landscaping, so they may add water to "brown spots" unaware of whether that brown spot is due to lack of water or salt in the root zone. Just as in agricultural irrigation, as urban landscaping is irrigated salts are flushed towards the groundwater table. These salts at present are still contained within the vadose zone, and it may take as much as 50 to 100 years for them to reach the groundwater table, depending on the depth to groundwater and other factors. However, the same basic principles apply to urban agriculture as previously described for traditional farming: salts become concentrated in the deep percolation water and eventually that water may reach the groundwater table.

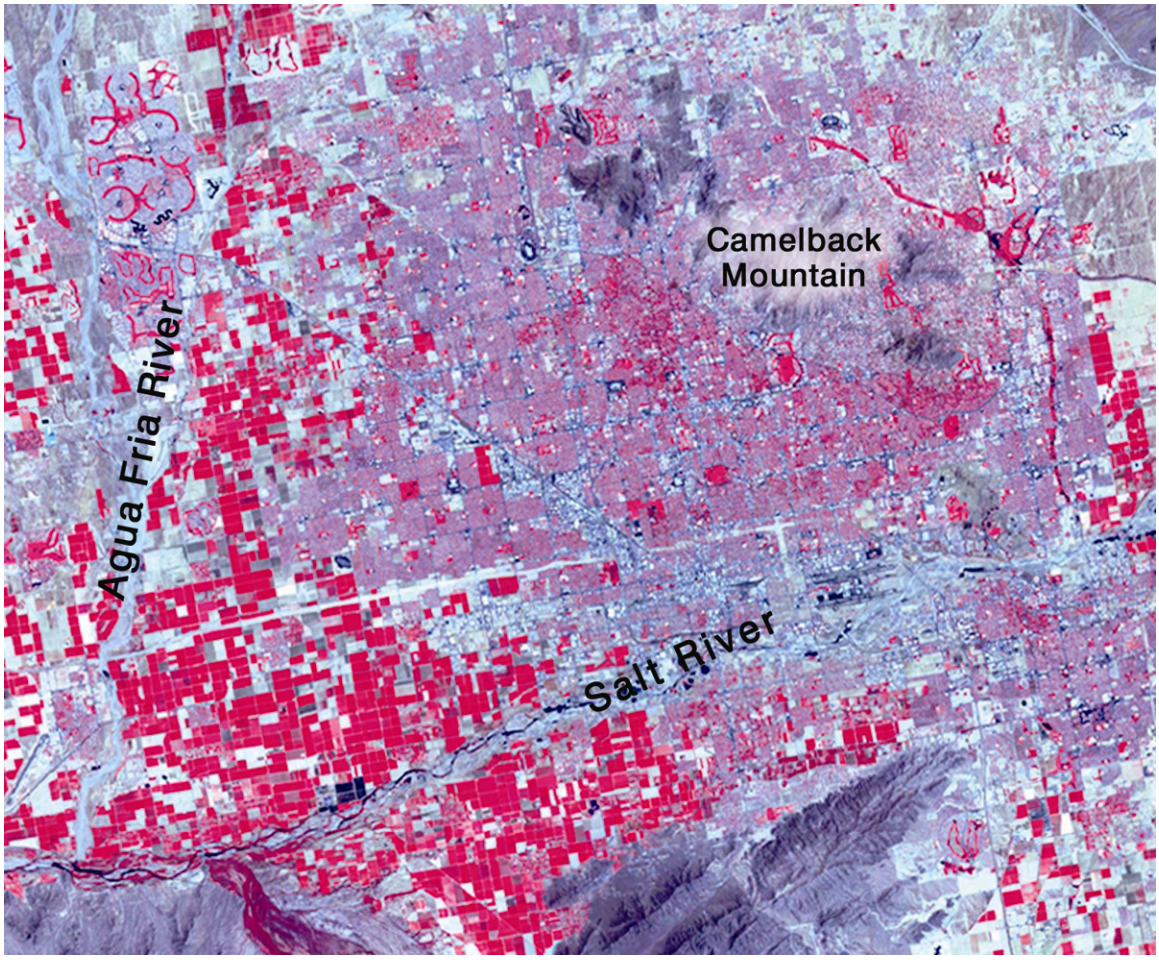


Figure 3-3. Infrared Image of Phoenix Metropolitan Area, 2000 (Red Indicates Irrigated Areas)

ENVIRONMENTAL IMPACTS

Groundwater Recharge

Indirect groundwater recharge results from both traditional and urban agricultural practices, as described above. Artificial recharge has become common in central Arizona, conducted both by municipalities and the State. Effluent and CAP water are the two major sources of water being recharged. Two types of recharge sites, Groundwater Savings Facilities (GSFs) and Underground Storage Facilities (USFs) (Figure 3-4), are used for recharging Colorado River water.

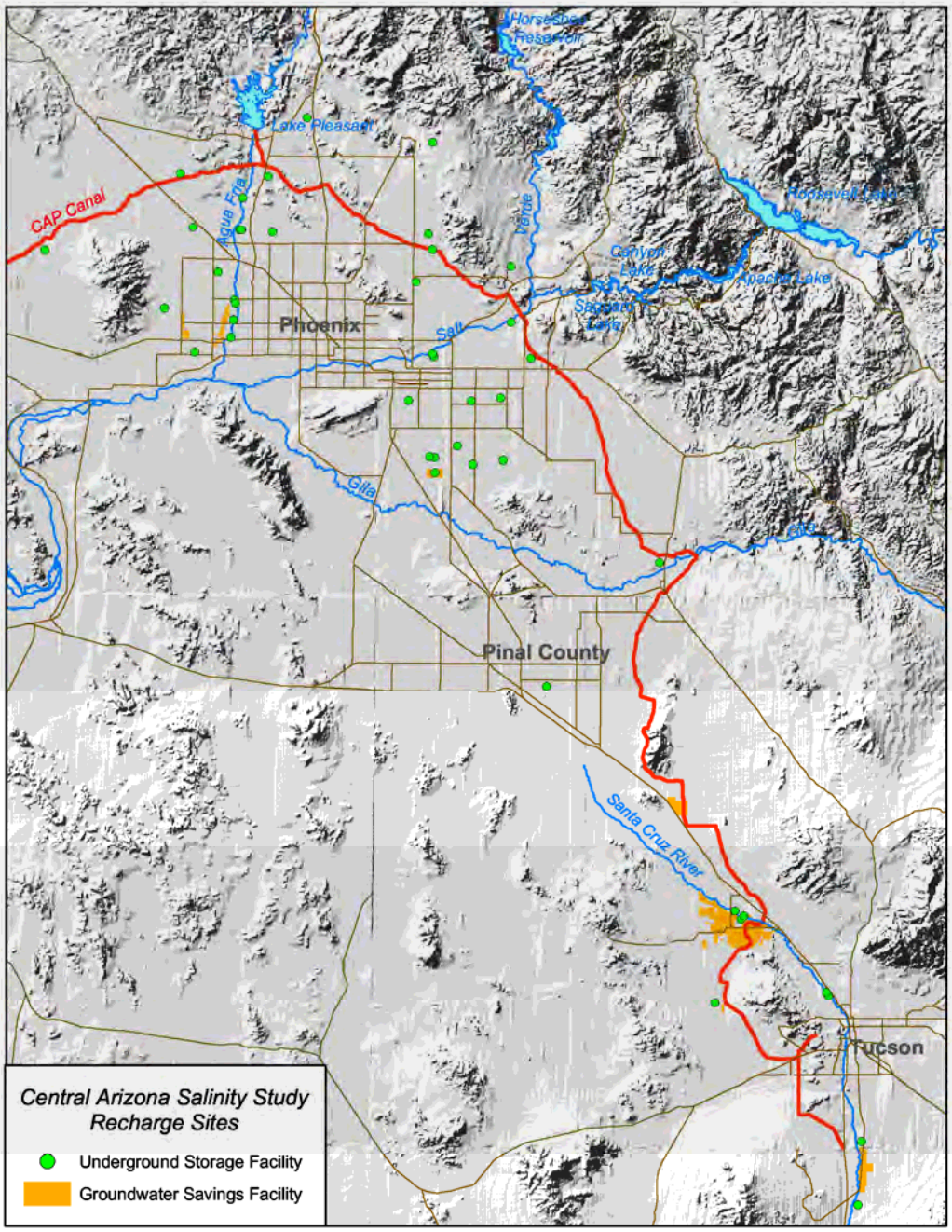


Figure 3-4. Groundwater Recharge Locations in Central Arizona

GSFs are owned and operated by irrigation districts that forgo pumping groundwater and use CAP water or effluent owned by another entity. The irrigation district uses the non-groundwater source water for irrigating crops and the groundwater saved through this process is credited to the entity that supplied the alternative water.

The other type of facility, the USF, maybe a constructed or managed facility in which water (usually CAP water or effluent) is recharged into the groundwater. Bigger recharge facilities are usually comprised of large basins or dry river beds where water infiltrates into the ground to recharge the water table. Some of the smaller USF sites are comprised of pressure injections wells or dry wells.

Recharging CAP water and effluent contributes to the increased salinity in local groundwater. The salts in the Gila River, Salt River, and more recently the Colorado River that would have eventually traveled to the oceans if not intercepted are now being introduced into the groundwater through recharge facilities.

Changing Habitat

The environmental impact of accumulating nearly 1.1 million tons of salts annually in the Phoenix metropolitan area is not entirely known at the present time, as it is a relatively new phenomenon related primarily to the use of surface waters high in TDS. Many of these salts have accumulated in the southwestern portion of the Phoenix metropolitan area near the Gila River, making the local groundwater very high in TDS. The Gila River itself is also high in TDS (averaging approximately 2,350 mg/l TDS), a direct result of agricultural return flows and effluent.

Tamarisk, or saltcedar (*Tamarix* spp.), was introduced into the western United States at the beginning of the 20th century. This invasive species has spread throughout the Southwest and, along many rivers, has dominated the native vegetation. Saltcedar can thrive during drought periods and also flourish on high-TDS water, which gives it an advantage over native species. A mature saltcedar can consume vastly more quantities of water, up to 300 gallons a day, than most native plants. Because of these traits, saltcedar is considered a nuisance plant in most locations and millions of dollars have been spent trying to eradicate it. The Gila River downstream of the 91st Avenue WWTP is dominated by saltcedar. The saltcedar invasion is just one impact to the environment that is exacerbated by high-TDS water. The full range of other potential environmental impacts has yet to be determined.

CHAPTER 4 – CENTRAL ARIZONA SALINITY ECONOMIC ASSESSMENT MODEL

INTRODUCTION

Managing the salts imported with CAP and Salt River waters into central Arizona and mitigating the salt imbalance in the region has economic benefits to society. However, if steps to manage salinity are not implemented, at some point the economies and groundwater resources of affected communities will be adversely impacted beyond current levels.

The high salinity levels of imported CAP and Salt River waters cause economic impacts to residential, commercial, industrial, and agricultural sectors. The general population must pay for more frequent replacement of water-using household appliances and elective home water softeners and other treatments. The high-tech industry bears increased costs to remove salts from the water used in manufacturing. Farmers lose income as a result of reduced crop yields and increased operational costs, and are forced each year to procure additional water to leach salts out of the root zone from the previous year's irrigation. And in the long run, continuing to import waters high in salinity will continue to degrade the groundwater, which will exacerbate these problems. The CASS Technical Committee worked to quantify the economic impacts brought about by salinity in the water that is imported into central Arizona.

In the late 1980s, USBR developed a computer model to assess the economic impacts of Colorado River salinity on the entire Lower Colorado River Basin. The model produced an initial estimate of damages on a regional basis. The Metropolitan Water District (MWD) of Southern California, in cooperation with USBR, updated that model for a salinity management study of southern California conducted in the late 1990s. This update of the model was done to better understand the economic impacts of salinity in MWD's water delivery area. MWD improved the model by focusing only on their delivery area and included knowledge specific to their local water systems and salinity problems. The Technical Committee, building on what MWD had accomplished, revised the model further by only focusing on central Arizona and incorporating factors inherent in or common to central Arizona. One of those factors, was accounting for the importation of salts from the Salt, Verde, and Gila Rivers, in addition to the salts imported with Colorado River water into central Arizona.

The data on water use and water quality in central Arizona was much more detailed and accurate than previous projections made with the model. The model calculates salinity impacts to five sectors of society: (1) residential, (2) commercial, (3) industrial, (4) agricultural, and (5) water utilities. For the residential sector, the impact of salinity is calculated in terms of reduced useful life of household appliances such as water heaters, evaporative coolers, faucets, garbage disposals, clothes washers, and dishwashers. Also calculated for residential consumers are "avoidance costs," such as buying bottled water and installing and maintaining water softening systems. Costs to the commercial sector are similar to those considered for residential users, but include impacts related to non-industrial sized cooling towers. Industrial sector impacts include costs associated with demineralizing and softening water used in manufacturing processes, costs of maintaining industrial cooling towers, and costs associated with treating boiler feed water. Agricultural costs fall into two primary categories: loss of income due to reduced crop yields and the cost of water to leach the salts out of the crop root zone. Water utilities' costs are calculated based on the lowered useful life of water treatment facilities when processing high-salinity water.

The baseline data used in the analysis represented a typical Arizona year of water use and water quality in Arizona. The reasoning for using a "typical year" was that currently Arizona is in a drought. The Technical Committee did not want to use the latest water year data because the Salt and Verde Rivers are delivering much lower amounts of water and have much greater salinity concentrations. The Technical Committee concluded that these factors would skew the results, so a "typical year" was created. The typical year uses population numbers from the 2000 census and water consumption rates derived from that year. But the water supply values are from either averages or medians of the Colorado, Gila, Salt, and Verde Rivers. Average water supply numbers were adjusted to match the demands for the year 2000. Water quality, including groundwater quality, is an average TDS value expressed in mg/L. The data was collected from ADWR, ADEQ, USGS, SRP, CAWCD, the City of Phoenix, and many other local sources. Because the salinity level of the consumed water was the most important analytical factor, water was tracked by source, not by legal owner. For example, SRP may have delivered CAP water to its customers, but for purposes of this model the water was considered CAP water, not SRP water.

The model calculates the economic impacts due to a change in the salinity of water in the five sectors of society previously discussed. For example, in a typical year the TDS in CAP water is 650 mg/L, and in SRP water is 475 mg/L, these salinity levels are used as the baseline. Those values are derived from the 30 year average TDS for CAP which is 649 mg/L, rounded to 650 mg/L and the 20 year weighted average of the Salt and Verde Rivers which is 475 mg/L. When the salinity level increases or decreases, the model calculates the economic impacts between the baseline salinity level and the new salinity level. As the salinity levels increase the resulting information can be graphed. The curve of the graph shows the annual impacts to society as salinity levels change from the baseline (Figure 4-1).

Three separate analyses using the model were performed to assess the economic impacts due to changes in salinity of imported waters. The analyses examined: (1) improvement and degradation of the Colorado River water imported via the CAP, (2) improvement and degradation of the Salt and Verde River water imported via the SRP system, and (3) a combination of (1) and (2). The groundwater salinity level remained the same in all three analyses. Salinity in effluent was calculated as the average TDS of the consumed water in the area, including both imported and groundwater, plus 300 mg/L TDS to reflect the input of salts by society. The model then used a weighted average TDS of imported waters, groundwater, and effluent in proportion to their use to produce the salinity economic impact calculations.

In the first analysis, CAP water was changed by 100 mg/L TDS increments from a starting point of 650 mg/L TDS (25-year average of Colorado River). All other waters were held constant except for effluent, which varies with the salinity of the other waters in the area as explained above. As shown in Figure 4-1, an increase or decrease of 100 mg/L TDS of CAP water results in just under a $15 million annual impact to society. All values are in 2002 dollars the year the analysis was done.

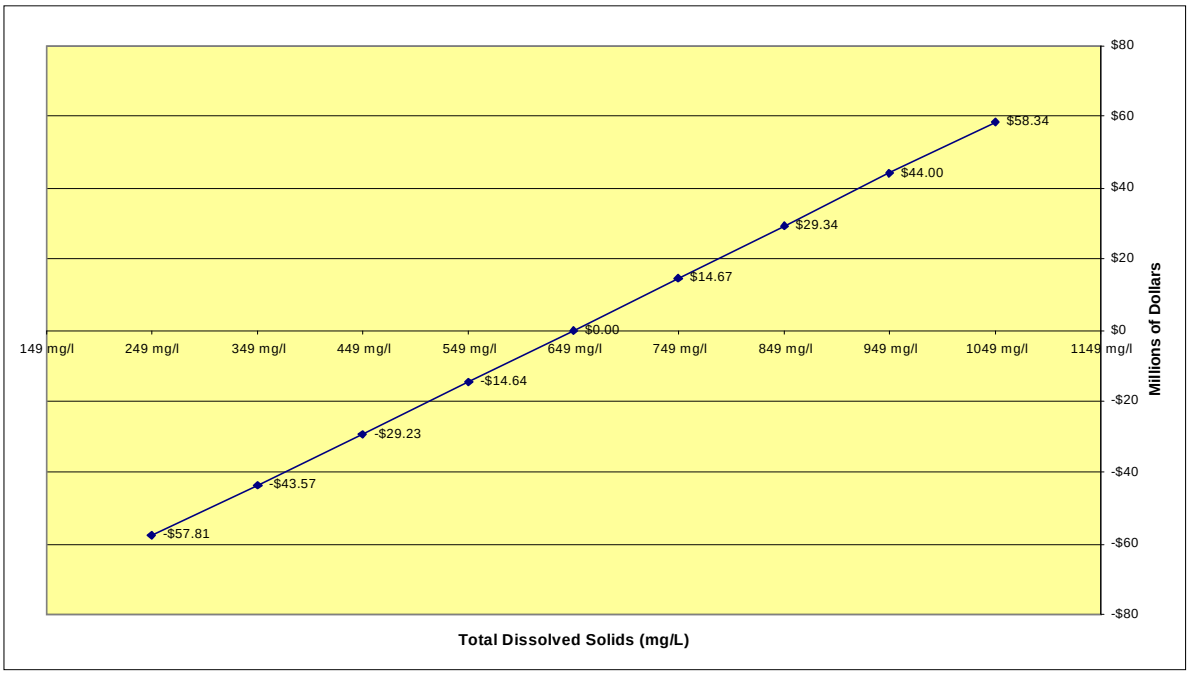


Figure 4-1. Annual Costs Due to Changes in Salinity of CAP Water (Colorado River)

Figure 4-1 demonstrates that the economic impacts of increasing salinity in CAP water are nearly linear. At two points—when the weighted average TDS was so high that it was no longer considered potable and when the weighted average TDS was so low that the water would be extremely aggressive—would the economic impacts diverge from the nearly linear results. Neither one of those conditions are feasible within the range of anticipated salinity of CAP water. (Aggressive water is water that is soft and acidic and can corrode plumbing, piping, and appliances.)

Table 4-1 shows the costs incurred by different sectors of society within the study area from the same analysis that produced Figure 4-1. The portion of the table shown reflects the annual cost increase to water users due to an increase of salinity of the Colorado River water from 650 mg/L to 750 mg/L. The majority of the impacts occur in the Phoenix metropolitan area. All values are in 2002 dollars the year the analysis.

Table 4-1. Costs of Increased Salinity in CAP Water

TDS = 750 mg/L	Residential	Commercial	Industrial	Agriculture	Utilities	Total
Phoenix Metro Area	$6,430,921	$1,948,078	$2,400,992	$1,673,841	$342,928	$12,796,761
Gila River Indian Community	$8,935	$2,179	$0	$82,548	$0	$93,662
Harquahala Basin	$2,091	$407	$0	$426,859	$0	$429,358
Tucson Metro Area	$0	$0	$0	$2,402	$0	$2,402
Pinal Study Area	$310,298	$58,830	$95,476	$887,154	$0	$1,351,758
Gila Bend Basin	$0	$0	$0	$0	$0	$0
Total	$6,752,245	$2,009,495	$2,496,469	$3,072,805	$342,928	$14,673,941

For several obvious reasons, the Phoenix metropolitan area experiences the highest impacts in this analysis: this study area has the most residents, uses the most water, and has greatest number of industrial consumers (industrial water processing costs are high). Conversely, Tucson has very minimal impacts because they are not at this time directly using CAP water, except for a relatively small amount for crop irrigation. However, Tucson is currently using a blend of CAP water and groundwater, and the composition of the blended water will eventually approximate the composition of CAP water unless additional steps are taken to control salinity. Because the large-scale introduction of CAP water has only recently begun in Tucson, the "typical year" for Tucson will likely occur around 2015. Continued use of CAP water in the Tucson metropolitan area will cause the impacts in that area to increase. Table 4-1 is only a small portion of the data output. The complete data output is included as Technical Appendix J.

Figure 4-2 shows the economic impacts due to change increments of 100 mg/L TDS in Salt River and Verde River water delivered by SRP, starting from a baseline of 475 mg/L TDS (25-year weighted average of the Salt and Verde Rivers). The graph indicates that the economic impact is slightly above $15 million for each increase or decrease of 100 mg/L TDS. Again, the economic impact of change of salinity concentration in the Salt and Verde Rivers is nearly linear. All of these impacts occur in the Phoenix metropolitan area because it is the only area where SRP water is used.

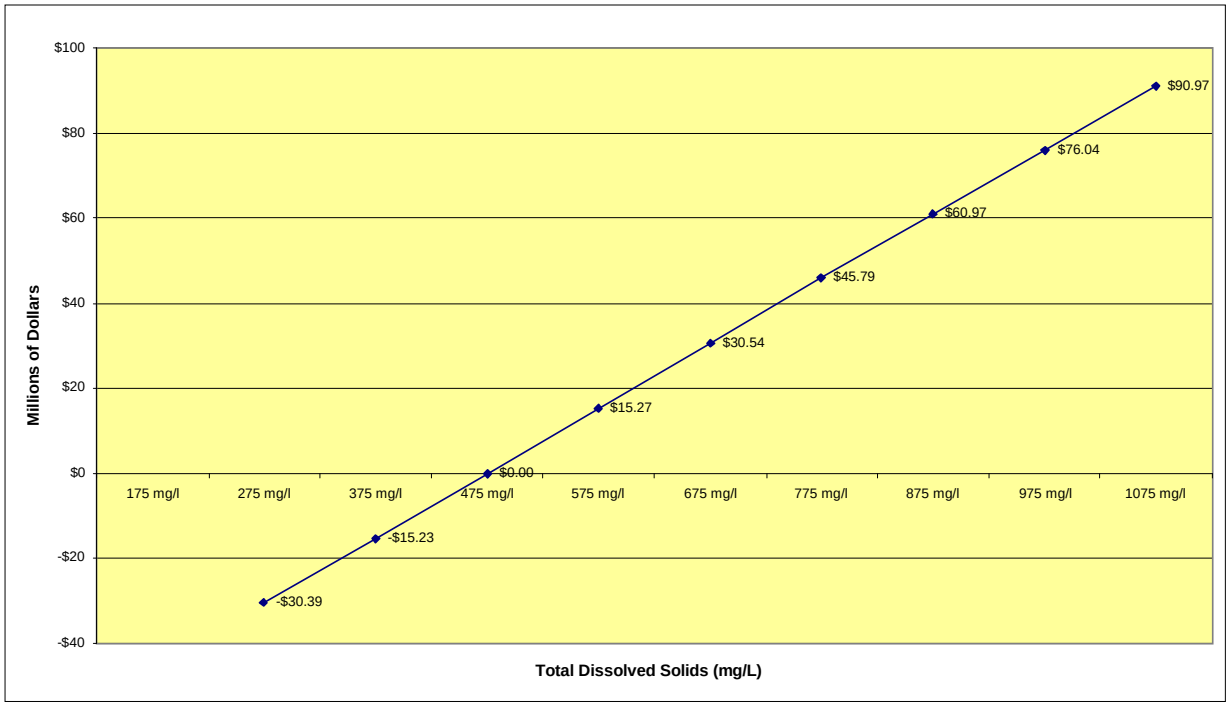


Figure 4-2. Annual Costs Due to Changes in Salinity of SRP Water (Salt and Verde Rivers)

The economic impacts of salinity changes in CAP and SRP water are calculated at approximately $15 million per incremental change in salinity of 100 mg/L. However, it is coincidental that these impacts are similar. More CAP water than SRP water is used on an annual basis, but proportionally more CAP water is used for agriculture and recharge. The similarity in overall economic impact of high salinity in these water sources may be attributed to the differing use characteristics.

Figure 4-3 depicts changes in salinity of 100 mg/L TDS in the combination of both the CAP and the SRP waters. As might be expected, the economic impacts are approximately twice the value, at nearly $30 million for every 100 mg/L of change in salinity concentration.

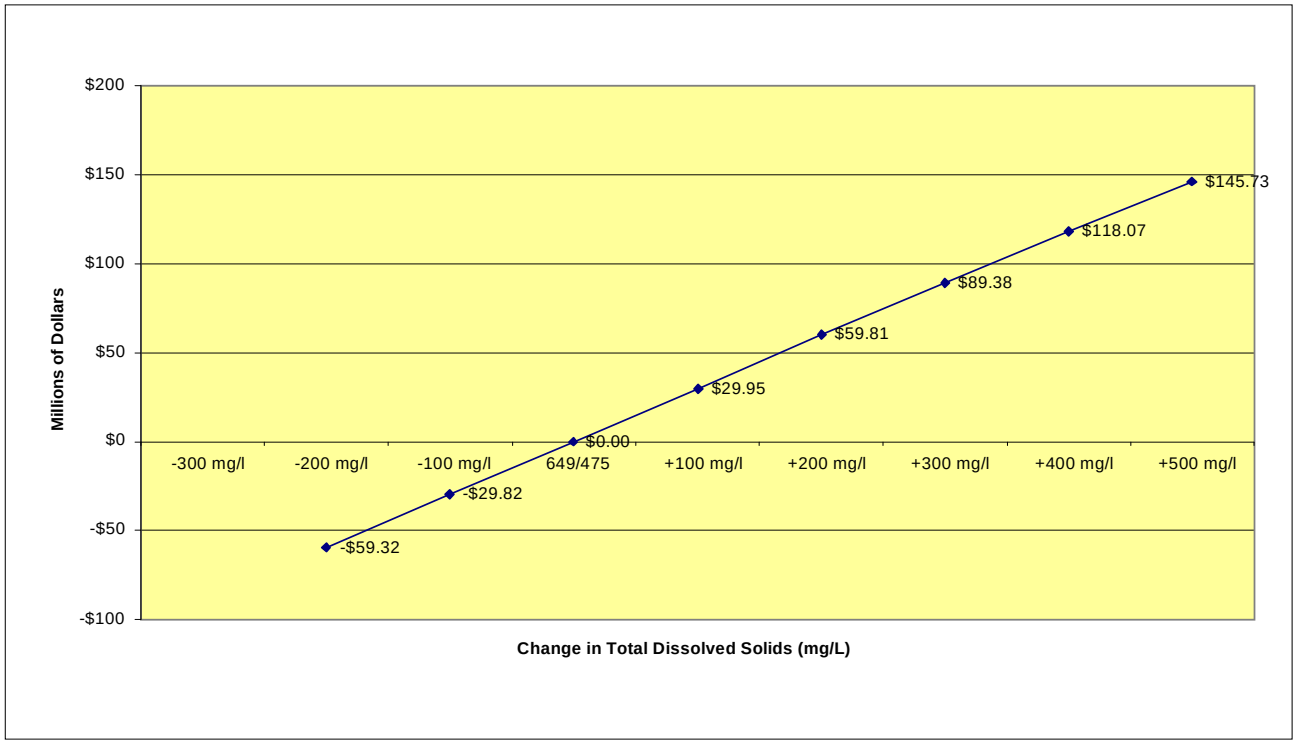


Figure 4-3. Annual Costs Due to Changes in Salinity of SRP and CAP Waters

Another way of assessing the annual impacts is to compare the current salinity concentration to EPA's secondary MCL standard of 500 mg/L TDS. The 30-year average TDS of Colorado River water is 650 mg/L at the entrance of the CAP at Lake Havasu. If CAP water delivered to users met the secondary MCL, the estimated savings to central Arizona users is calculated to be about $22 million annually. These savings would be in the form of extended life of residential water appliances, larger crop yields, less water used to leach salts from the soil, and reduced costs to businesses and industry for such things as cooling tower maintenance and treatment of water used in manufacturing processes. The annual Gross Domestic Product (GDP) for Maricopa County is approximately $93.6 billion. The economic burden of using high-TDS water is assessed at approximately 0.02 percent of the GDP. These costs are spread throughout society, with the majority of the costs allocated to individual homeowners. If these annual costs were equally divided among the citizens of Maricopa County, each person would pay about $7.10 per year.

The model does not, and cannot, include all the economic ramifications of importing high-salinity water into central Arizona. Other economic impacts not considered in the model include abandoning wells due to high TDS in the groundwater and the costs of importing additional water because of poor quality groundwater. Increased maintenance costs at private golf courses and other non-municipal recreational areas are also not included in the model. While the costs of additional water used by farmers to flush salts

from the root zone are considered, the higher payroll expenses associated with salinity management are not. The model is a not a fully comprehensive tool, but it does provide a working concept of the magnitude of the costs associated with high salinity, and some conclusions can be reached from the modeling work. One is that if the SRP and the CAP water quality were improved by 100 mg/L, the savings to central Arizona would amount to approximately $30 million per year. Residents incur about 45 percent of the cost impacts, but industrial, commercial, and agricultural users are also impacted. Another conclusion drawn from the model analysis is that there is not a particular "break point" at which the economic impacts rapidly improve or degrade. Rather, the results indicate that the impacts associated with salinity follow a linear path. There is no "magic" range of water quality to shoot for that will dramatically reduce the economic impacts to society.

And finally, it is important to notice, as shown in Table 4-1, that the vast majority of economic impacts projected by the model occur in the Phoenix metropolitan area. As previously stated, this not just a function of the high salinity CAP water, but a combination of CAP and SRP water coupled with the largest concentration of population and industrial water use in the state.

Technical Appendix J provides more detail on the economic assessment model.

CHAPTER 5 – FUTURE TRENDS ANALYSIS

INTRODUCTION

This chapter examines each of the study areas in central Arizona and discusses the potential impact of continued importation of Colorado River and Salt River water and the salts associated with that water. Many different assumptions can be made about the future, but one of the certainties in central Arizona's future is a continued rapid growth in population. Another is that municipal effluent will continue to grow in importance as a supplemental water source.

PHOENIX METROPOLITAN AREA

With regard to salinity, the Phoenix metropolitan area is the most highly impacted area in central Arizona. This trend will continue for a number of reasons. First, a large volume of surface water from both the Salt River and the Colorado River will continue to be imported into the Phoenix area. In the future, the annual influx of salts entering the Phoenix area is expected to increase beyond current rates. The increase will be due to two factors: an increase in the importation of Colorado River water and the increasing contribution of salt from society.

Second, the concentration of salts at Phoenix-area reclamation and wastewater treatment plants will also increase, driven by four main factors: the growing population, an increase in the number of cooling towers, groundwater quality degradation due to salt importation, and expanded water conservation measures. The result will be a less "valuable" effluent coming out of the wastewater treatment plants.

Maricopa County is one of the fastest growing counties in the United States. During the 1990s, approximately 900,000 people moved into Maricopa County. The 2000 census recorded Maricopa County's population at 3,072,149. The Maricopa Association of Governments (MAG), drawing upon research conducted by Arizona State University and the University of Arizona for the Department of Commerce State Economic Strategies Study, developed an updated set of population projections (Maricopa Association of Governments, 2003). Projections up to the year 2040 are shown in Table 5-1. MAG examined land use data provided by the various communities in the Phoenix metropolitan area to estimate how many people may eventually reside in the Phoenix area. Using that data, MAG estimated population at total buildout in the Phoenix area at 12,000,000, but did not specify when total build out would occur.

Table 5-1. MAG Projections of Population Growth in Phoenix Metro Area

2000	2010	2020	2030	2040	Buildout
3,072,149	4,145,000	5,210,000	6,241,000	7,326,000	12,000,000

Most of the salts entering the Phoenix metropolitan area are transported by either the Colorado River or Salt River. An estimate of the year 2000 annual salt flux for the Phoenix area, based on a population of 3 million using 238 gallons per capita per day (gpcd), is shown in Table 5-2.

Table 5-2. Year 2000 Estimated Annual Salt Flux for the Phoenix Metro Area[a]

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[b]	300[c]	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**

Notes:

[a] Estimate assumes population of 3 million and water use of 238 gpcd

[b] Water entering sewer after use

c Salts added by society

The Colorado River has increased in salinity over time with the increased population and re-use along the river. In the early 1900s the salinity level at Yuma was around 400 mg/L TDS, but is presently around 800 mg/L TDS. Salinity levels also increase as the Colorado flows from its headwaters to the sea. The Green River in Wyoming, which feeds the Colorado, measures about 50 mg/L TDS. Moving downstream, the Colorado at Lake Havasu City carries approximately 650 mg/L TDS and, as mentioned, about 800 mg/L TDS at Yuma.

The Colorado River Basin Salinity Control Forum (Forum) has as one of its goals to prevent any further increase in the overall salinity of the Colorado River. The Forum has in many respects succeeded—despite increased river usage—through implementation of an aggressive farm irrigation improvement program and other programs. If the Forum continues with its aggressive programs to control salinity entering the Colorado River, salinity levels should remain relatively constant over the long term. However, for the near term, the salinity concentration in the river will fluctuate following the drought cycles, rising during dry years and declining during wet years. Nonetheless, as the population in the Phoenix area continues to increase, greater quantities of available Colorado River water will be imported and with it additional salts.

Like the Colorado River, the Salt River also exhibits cyclic behavior in salinity concentration with respect to dry and wet years. The greatest contributor of salts are the natural salt springs located along the White River and upper reaches of the Salt River. Society is a very small factor in introducing salts into the Salt River, and the general increase in the population of central Arizona is not expected to add significantly to the TDS levels of this waterway. Furthermore, in contrast to the Colorado, the Salt River already delivers the maximum of available water to the Phoenix metropolitan area. As a result, there will not be an increase in salinity loading associated with continued deliveries of Salt River water to the Phoenix area.

One sector of society, agriculture, has been declining in Maricopa County for the last 50 years as farmers sell their farm properties to developers for residential and other construction. SRP began with 238,400 acres of irrigable land in 1904. By 2000, 194,180 acres of SRP land had been urbanized. Western portions of the Phoenix metropolitan area have shown a similar decline in irrigated acreage. As the agricultural acreage decreases, the contribution of salts into the groundwater from fertilizers will similarly decrease. This trend may be offset to a certain extent, however, by an expansion of urban agriculture, including parks, baseball fields, soccer fields, greenbelts, and lawns.

An estimate of the annual salt flux into the Phoenix metropolitan area in 2040, when MAG projects the population will be 7.3 million, is shown on *Table 5-3*. This is more than double the current population, and is certain to place great demands on water providers. Due to the greater demands, the use of CAP water will shift from agriculture to municipal uses. It is likely that CAP water will be leased from Native American tribes and the increased importation of CAP water will be the primary contributor of additional salts, but society's contribution of salts will also increase simply as a result of the growth in population.

In this analysis, it is assumed the current water usage of 238 gallons per capita per day (gpcd) is reduced to 200 gpcd mandated by law because of the greater demand on limited water supplies. It is also likely that salts will be more concentrated due to water conservation measures as society adds the same amount of salts but returns less water to the sewer system.

The decline in irrigated agriculture will lead to a corresponding reduction in fertilizer use, thereby reducing that source of salts but on the other hand, salts transported out of the Phoenix area will decrease with reduced agriculture return flows and increased recharge of effluent and urban agriculture will expand with a corresponding increase in salts from urban fertilizer.

With these assumptions, the estimate of salts remaining in the Phoenix metropolitan area may increase to 1.6 million tons annually. While this analysis can not done predict an precise value, it is based on reasonable assumptions, and the sum of those assumptions indicate the annual salt influx will increase in the future.

Table 5-3. Year 2040 Estimated Annual Salt Flux for the Phoenix Metro Area[a]

Entering Phoenix Metro	Volume (ac-ft)	TDS (mg/L)	Salt (tons)
Groundwater	37,000	680	34,218
SRP	810,000	480	528,768
CAP	1,000,000[b]	650	884,000
Gila River	90,000	550	67,320
Agua Fria River	50,000	400	27,200
Society	593,000	360	290,333
Agricultural fertilizer			8,700[c]
Turf fertilizer			9,400
Total			**1,849,938**

Exiting Phoenix Metro	Volume (ac-ft)	TDS (mg/L)	Salt (tons)
Groundwater	28,000	1,100	41,888
Gila River	50,000[d]	2,370	161,160
Total			**203,048**

Residual Salt Load (tons)	**1,646,890**

Notes:

[a] Estimate assumes population of 7.3 million and water use of 200 gpcd

[b] New demands met by Indian lease, CAGRD, and by decline of agriculture

c Agriculture reduced by 1/2 (assumed value)

d Reduced agricultural return and increased recharge from 91st Ave WWTP

An estimate of salt flux into the Phoenix metropolitan area at projected maximum buildout of 12 million people is provided in Table 5-4. There will likely be significant changes in the way our society functions when or if this population level is reached. For example, at the projected buildout population, water conservation efforts would most likely need to be maximized, and therefore in Table 5-4 the projected water usage was reduced to an assumed 150 gpcd. CAP importation is assumed to be at the maximum available through Indian leases, municipal demands and Central Arizona Groundwater Replenishment District (CAGRD) commitments, with the remainder of the CAP allocations going to the Tucson metropolitan area and Indian commitments. New sources of water will also need to be found and imported into the Phoenix area, to include projects such as importing water from McMullen Valley in western Arizona. To sustain projected buildout in the Phoenix metropolitan area it is assumed that there would be no agricultural irrigation, that Gila River water would be devoted exclusively to municipal rather than agricultural uses, and that all waste water area-wide would be reused (i.e., no water would be “wasted” by allowing it to flow out of the area via the Gila River channel). Again it is assumed that society will add additional salts because of a larger population, but that salts would be added at the same relative rate. Under these assumptions, the salts remaining in the Phoenix metropolitan area would surpass 2 million tons annually.

Table 5-4. Estimated Annual Salt Flux for the Phoenix Metro Area at Buildout[a]

Entering Phoenix Metro	Volume (ac-ft)	TDS (mg/L)	Salt (tons)
Groundwater	37,000	680	34,218
SRP	810,000	480	528,768
CAP	1,200,000	650	1,060,800
Gila River	90,000[b]	550	67,320
Agua Fria River	50,000	400	27,200
Society	731,000	475	472,226
New Water	50,000[c]	400	27,200
Turf fertilizer			11,280
Total			**2,229,012**

Exiting Phoenix Metro	Volume (ac-ft)	TDS (mg/L)	Salt (tons)
Groundwater	28,000	1,100	41,888
Gila River	0[d]	2,370	0
Total			**41,888**

Residual Salt Load (tons)	**2,187,124**

Notes:

[a] Estimate assumes population of 12 million and water use of 150 gpcd

[b] Gila River now used for human consumption, not agriculture

c New water sources (McMullen Valley-type projects), TDS assumed

d Due to new demands all water is re-used, and no water exits via Gila River

The introduction of more total salts into the Phoenix metropolitan area would be followed by an increase in salt concentrations at area wastewater and reclamation facilities. This would occur for a number of reasons.

The increased use of membrane technology, specifically RO and nanofiltration membranes, will also contribute to higher salinity levels. Before 1993, there were 134 RO or nanofiltration plants in operation across the United States; currently 471 plants are in operation, and more are in the planning or construction phase. Although, planners from the cities of Phoenix, Mesa and Tempe have stated they do not anticipate the need for membrane treatment plants at this time there is a possibility that brackish groundwater RO plants may be built to utilize an unused water source. An analysis of the future trends of this technology is included as Technical Appendix S. RO concentrates salts in brine that is sometimes discharged to the sewer system. Greater use of RO will further increase the salinity concentration at wastewater treatment plants.

Another factor likely to increase salinity concentrations at wastewater treatment and reclamation plants is a predicted slow, long-term rise in groundwater salinity levels. Agricultural and urban irrigation practices and the importation of salts from the surface waters will, over a period of time, increase the salinity of groundwater. This more saline groundwater will be pumped back up, used and sent to the wastewater treatment plants.

As the population increases, additional water conservation measures will be implemented. When indoor water conservation measures (such as low-flow toilets) are implemented, less water per person is returned to the sewer. Assuming that society still contributes salts at the same relative rate per person, more salts and proportionally less water will enter the system. Another factor will be the increased need for cooling towers to maintain workplaces at an acceptable level of comfort for the larger workforce. Temperatures in the Phoenix metropolitan area will increase as concrete and blacktop replaces agricultural areas. Currently, there is a 10 degree temperature differential on a summer night between downtown city streets and downtown park areas. With future increased water conservation measures, there may be fewer parks, lawns, golf courses and greenbelts. Without the cooling effect of the grassy open areas, a higher percentage of cooling towers will need to be built to keep workplaces comfortable. Cooling towers create a brine which is disposed into the sewer. Increasing the percentage of cooling towers will increase the overall concentration of salts at area wastewater treatment plants.

Table 5-2, representing the current annual salt flux for the Phoenix metropolitan area, shows the concentration of salts added by society to be 300 mg/L. This is in addition to the base level of the source water. In Table 5-4, representing annual salt flux for the Phoenix area at projected buildout, the value of salts added by society has increased to 475 mg/L. This increase was calculated by assuming that the rate of salts introduced into the sewer system remains at the same relative rate per person, even with a lower water usage. But it must be considered that a portion of the source water (groundwater) will also have a higher salt concentration, and that cooling towers and membrane plants will discharge brine but less water to the sewers. With these assumptions, 475 mg/L is probably conservative. The projected 175 mg/L rise in concentration is an educated estimate and not an exact value.

In summary, the volume of salts imported and retained in the Phoenix metropolitan area will in the future increase significantly, potentially by as much as double the present rate. It should also be noted that the current annual retention of approximately 1.1 million tons of salts within the area is a very recent phenomenon—one that has only been occurring since the mid-1980s. Within the next 40 years, this salt influx could increase by another 500,000 tons annually. The concentration of salts in effluent will also continue to rise, although this rise is not likely to be as dramatic (a projected increase of another 150 mg/L TDS concentration is possible within the next 40 years). The ultimate consequences of both these actions will be continued degradation of Phoenix-area groundwater and an increase in economic damages.

TUCSON METROPOLITAN AREA

The Tucson metropolitan area currently has good quality groundwater. As Tucson increasingly utilizes its CAP allocation, however, the area will begin to see the effects of importing high-TDS Colorado River water. The Tucson metropolitan area has 215,333 af of CAP water allocated to various water providers. Of that total, the City of Tucson has the largest single allocation at 138,920 af. The City initiated direct delivery of CAP water in November 1992 with plans to ramp up to full utilization of the allocation over several years. But problems with corrosion leading to rust-colored water and breaking mains due to the different chemical composition of the water (as well as overdue main replacements) quickly became apparent. This led the City to halt direct delivery in October 1994, when the canal was temporarily shut down for scheduled maintenance. A citizens' initiative resulted in the 1995 passage of Proposition 201, the Water Consumer Protection Act, prohibiting direct delivery of CAP water for a 5-year period and establishing specific uses for CAP water within Tucson Water's service area. In addition, the Act required all CAP water for direct delivery to be equal to or better in quality (i.e., salinity, hardness, and dissolved organic material) than the 1995 quality of groundwater from Tucson Water's Avra Valley well field. As a result of the problems experienced with direct CAP delivery and the ensuing Act, the City of Tucson launched a massive main replacement and lining project and began exploring recharge possibilities to utilize CAP and enable compliance with state regulations requiring renewable water resources.

In 1996, Tucson Water began a recharge and recovery pilot project in Avra Valley called the Central Avra Valley Storage and Recovery Project (CAVSARP). In 1999, Tucson Water began delivering a blend of recovered CAP water and groundwater to four neighborhoods in a series of pilot projects to demonstrate that the blended water would be acceptable to area residents and would not cause the same corrosion problems as before. The demonstration projects were successful, and Tucson Water began system-wide delivery of the blended groundwater/recovered CAP water in May of 2001 through the Clearwater Renewable Resources Facility. CAVSARP is the primary structural element of the larger Clearwater facility. Full-scale recharge operations were initiated in 2003 with expected annual recharge and recovery of about 60,000 af. The recharge component of the Clearwater facility will soon be increased to 80,000 af/yr, which will provide capacity for long-term water banking.

It is anticipated that the salinity level of the recovered water will gradually rise over time as a larger percentage of the recovered water is CAP water. Tucson Water's current water quality policy limits maximum salinity in the delivered water to 450 mg/L TDS. Groundwater modeling indicates that this salinity level will be reached by the year 2010. In time, the City of Tucson will have to address how it will meet its long-term water quality objectives. Depending on what the City's future water quality goals and policies will be, it may be necessary to desalinate a portion of the delivered water, blend more native groundwater with CAP water, and/or change the policy.

The CAP also delivers Colorado River water to three other recharge facilities near the Tucson metropolitan area: the Pima Mine Road recharge facility, the Avra Valley recharge facility, and the Lower Santa Cruz recharge facility. Each of these plants will influence the salinity level of the native groundwater. Eventually, this water will be used by municipal users. The economic study prepared for this report indicates that the tangible costs caused by higher salinity can be absorbed by society. What may be more of a problem in the Tucson metropolitan area is the public's perception of CAP or a CAP/groundwater blend as poorer quality water.

Just north of Tucson, the communities served by Marana, Oro Valley, and the Metropolitan Domestic Water Improvement District (MDWID) are analyzing options to use their allocations of CAP water directly. One plan under review involves using slow sand filtration for water treatment, a small reservoir for storage, and a pipeline to deliver CAP water to their customers. Because of the very good quality water that is now delivered to these customers, if it is at all economically possible, the plan would also include an RO membrane facility to remove salts. A plan to dispose of the concentrate will also be necessary if this treatment plan moves forward.

The City of Tucson projects that it will utilize its full allocation of CAP water by 2015. With that CAP water will come large amounts of salts. The projected amount of salts entering into the study area through CAP allocations, groundwater, and society will be approximately 260,000 tons. Of that amount, approximately 55,000 tons are projected to leave the study area, resulting in a buildup of just over 200,000 tons of salts annually in the Tucson metropolitan study area. The projected salt balance for the Tucson area is shown in Figure 5-1.

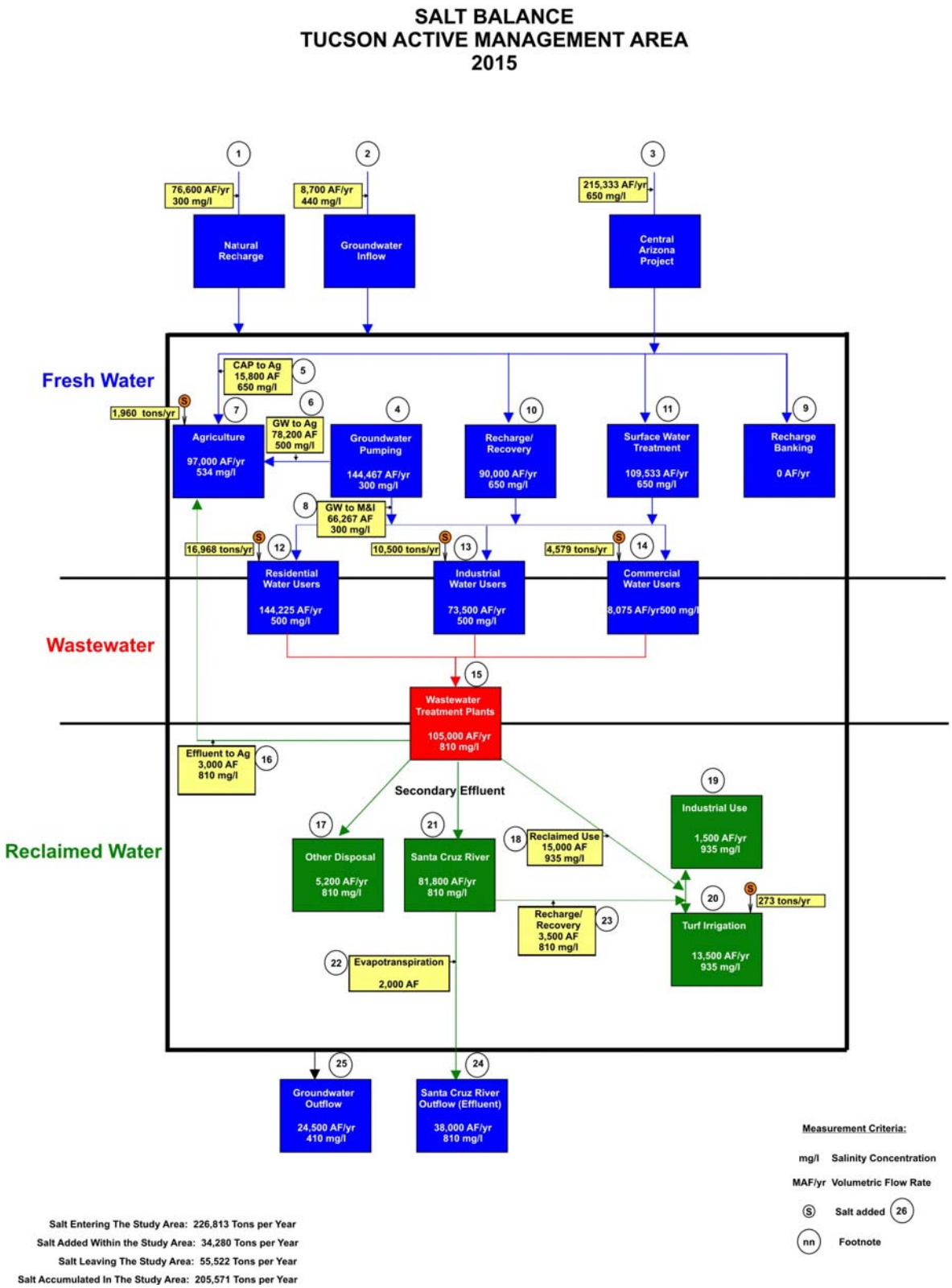


Figure 5-1. Year 2015 Salt Balance in the Tucson Active Management Area

GILA RIVER INDIAN COMMUNITY

The economy of the Gila River Indian Community (GRIC), though supplemented by tourism and gaming, will continue to have a significant agricultural component.

The aquifer beneath the GRIC is continuous and characterized by relatively shallow depths to water, ranging from approximately 25 feet to 150 feet. The total size of the aquifer is small compared to the Phoenix or Tucson metropolitan areas because bedrock is only a few hundred feet below the surface. Elevated concentrations of TDS and nitrates occur in the groundwater underlying agricultural areas. Distribution of TDS in the groundwater is, as with all the study areas, complex in location and depth. Generally speaking, lower TDS concentrations are located in the eastern half of the GRIC and higher TDS concentrations are in the central, northern, and northwest areas. TDS levels commonly range from 500 to 2,000 mg/L, but are as high as 3,500 mg/L in some areas. A substantial volume of groundwater now moves out of the GRIC to the south due to cones of depression in Pinal County. Groundwater also flows in the traditional direction to the northwest, downstream along the Gila River. The salts associated with this groundwater movement contribute to the high concentration of salts in the southwest Phoenix metropolitan area.

If the Indian water rights settlement and the CAP re-allocation is approved by Congress, GRIC will have 328,000 af of CAP water in their total 653,500 af water portfolio (U.S. Bureau of Reclamation, 2000). GRIC has negotiated a contract with Chandler and Mesa to trade 32,500 af of CAP water in exchange for 40,600 af of effluent on an annual basis. GRIC will use the effluent for agriculture. Effluent already being delivered to GRIC is high in TDS, averaging approximately 1,200 mg/L, and most likely the new effluent will be high in TDS also. As noted earlier in this chapter, agricultural irrigation has a tendency to concentrate salts in the root zone as water is consumed by plants. The salts are then flushed from the root zone with additional water. The flushing water with the concentrated salts eventually makes its way to the groundwater table. The groundwater table on GRIC lands may rebound or rise with the importation of Gila River water, CAP water, and effluent.

With the new CAP water allocated to them through the Indian water rights settlement, GRIC plans to convert approximately 53,000 acres of desert to agricultural use. Reclamation estimates that 800,000 tons of salts will be flushed from the soils when these new acres are put into agricultural production. GRIC can expect continued reduction in the groundwater quality with continued use of CAP, additional use of Gila River water, the concentrating effect of agricultural irrigation, and the importing of high-TDS effluent. Reducing or eliminating groundwater pumping may also lead to concerns with potential waterlogging in these areas. Waterlogging and drainage will present challenges that must be managed in the future.

As the population continues to increase in central Arizona, the need to purchase CAP water to meet customer demand and the appeal of additional revenue may put great pressure on GRIC and other Indian communities to lease their water. GRIC may choose to lease a portion of their CAP allocations to municipalities, deciding that this is a more profitable use of a valuable resource than diversion to agricultural irrigation. A leasing agreement may be a win-win situation, because the municipalities will need additional water and GRIC can gain revenues for capital improvements from the leased water.

PINAL COUNTY

The economy of Pinal County is primarily agricultural; in 1995, 75 percent of the water use in the county was for agriculture. The local agricultural economy has historically relied on groundwater supplemented by Gila River water. Years ago the groundwater table began to drop rapidly due to large-scale irrigation, but with the introduction of CAP water the water table rebounded in those areas receiving CAP allocations.

The salts follow the water. Importation of salts into Pinal County come from the Gila River, Santa Cruz River, CAP water, and fertilizers. Approximately 600,000 tons of salts are currently imported into Pinal County (Table 2-3), with approximately half these salts entering the basin from the CAP.

The future use of CAP water for Pinal County non-Indian agriculture is difficult to project. Most of the irrigation districts with an allotment of CAP have switched to using excess CAP water because it is much cheaper than their allotted water as there are no capital charges and the rate is reduced as an incentive to use Arizona's entire Colorado River allotment.

A plan recently put forward by the CAWCD, the operators of the CAP, will set aside a pool of excess water reserved for non-Indian agriculture. This set-aside will commence in 2004 with 400,000 af/yr, be reduced to 300,000 af/yr in 2017, then to 225,000 af/yr in 2024, and end in 2030. If this plan is implemented, the majority of non-Indian agricultural use of CAP water will conclude at that point. As CAP water use in Pinal County diminishes, farmers are left with the choice of using more groundwater or retiring the land. The State's groundwater management goal for the Pinal AMA is to extend the life of the agricultural economy for as long as is feasible, while retaining adequate water supplies for non-agricultural uses.

Groundwater will be used as long as it remains economical. Rising costs to pump groundwater in some irrigation districts will render certain crops uneconomical and lead to those crops no longer being grown. It is generally accepted that at about 1,000 feet of head it is not economically feasible to pump groundwater to grow lower-valued crops. The water below 1,000 feet will be used for future municipal purposes.

Agricultural practices generally lead to a decline in the groundwater quality by concentrating salts and as a result of the effects of fertilizers (see Chapter 3, *Effects of Salinity in Central Arizona*). In several locations within Pinal County, groundwater use for potable purposes is already limited by excessive levels of nitrates. Groundwater quality, however, is not a limiting factor for irrigated agriculture in all areas of Pinal County. In locations where salinity of the groundwater is excessive, leaching and the cultivation of more salt-tolerant crops have helped mitigate the problem.

When agriculture is no longer economically feasible and agricultural lands are developed for urban uses, the quality of water left for those urban uses tends to range from poor to extremely poor. Vast quantities of the water will need membrane treatment to remove the salts, nitrates, and other contaminates before it can be delivered for potable use. The challenges of brine disposal, expensive water (from both RO and very deep pumps), and limited supply will not be easy to overcome.

HARQUAHALA BASIN

The Harquahala Basin is experiencing the classic case of a declining groundwater table that recovered once alternate water sources were found. Harquahala agriculture began by using groundwater in the early 1950s. Groundwater pumping from 1951 to 1985 resulted in a substantial decline in the groundwater table. With the introduction of CAP water in the mid 1980s, groundwater pumping decreased dramatically and the groundwater table recovered. But as the CAP water for agriculture is phased out, Harquahala farmers will likely once again resort to groundwater mining.

CAP water imports about 66,000 tons of salt a year into the Harquahala Basin, which far surpasses the salt load from agricultural fertilizers of about 2,000 tons annually. As the future use of CAP water for agriculture declines, the influx of salts from that source will decline as well. The Vidler Recharge Facility, however, has a permit to recharge up to 100,000 af/yr. If this facility operates at maximum capacity, it would annually bring as much as 76,000 tons of salt into the basin. Most of these salts will be returned with the water that is recovered and delivered to the Phoenix metropolitan area.

GILA BEND BASIN

The Gila Bend area is the ultimate salt sink in Central Arizona. High concentrations of salts from agricultural return and wastewater effluent are delivered into the basin via the Gila River. Additional salts are then added by agricultural fertilizers. The Gila Bend area has extremely poor groundwater. As early as 1946 the USGS had concluded that the groundwater was generally unsatisfactory for agriculture. Concentrations of salts within the majority of the basin are between 1,000 mg/L and 5,000 mg/L TDS.

As a result of agricultural practices and the present surface water quality, the groundwater in the Gila Bend area can only be expected to get worse. The Gila River consists of effluent from the 91st Avenue WWTP and return flows from Buckeye Irrigation District and Roosevelt Irrigation District, and almost all the water leaving the Phoenix metropolitan area via the Gila River is diverted for irrigation. The river averages 2,350 mg/L TDS, and the vast majority of these salts end up in the Gila Bend basin. The only time measurable quantities of salt do not remain in the basin is during a major flood event when water is released at Painted Rock Dam.

The citizens of Gila Bend have been drinking bottled water for years. The water delivered to the citizens has historically been of such poor quality that it was used only for bathing. In June 2003, Gila Bend opened a 1.2-million-gallon-per-day advanced RO water treatment facility. The TDS of water delivered to customers was reduced from between 1,200 and 1,800 mg/L to 75 mg/L. The concentrate is disposed in two evaporation ponds. This type of alternative treatment (or other emerging technology) is the likely future for all areas with significantly impaired waters.

In the relatively distant future, perhaps 80 to 100 years from now, agriculture will end in the Gila Bend area when the Gila River ceases to flow. Leaders in the Phoenix metropolitan area may decide that the water (effluent and irrigation drainage) going down the Gila River is too valuable a resource to waste. This water will be treated and reused at some point to supply the growing Phoenix metropolis. When no Gila River water reaches Gila Bend agricultural areas, agricultural production will depend on groundwater. The groundwater table will decline until it is no longer economically feasible to continue growing crops.

CONCLUSIONS

The major metropolitan areas of Phoenix and Tucson can expect to import and accumulate more salts on an annual basis in the future. Currently, the salinity problem is not preventing population growth or economic development. When the importation of salts will become a major burden is not clear at this point but the rate salts are accumulated is increasing.

The agricultural areas of Pinal County, Gila Bend, and the Harquahala Basin will reduce their rate of importation of salts as the excess pool of CAP water diminishes. As agriculture declines in these areas, the groundwater left behind will be impaired due to agriculture practices. As urban areas expand into the former agricultural areas, water providers may have to desalinate groundwater before delivering it to customers.

CHAPTER 6 – STRATEGIC CONCLUSIONS

CASS PHASE I PRELIMINARY FINDINGS

The Current Salt Imbalance

In a typical year, 1.5 million acre-feet of CAP water at 650 mg/L TDS, carrying more than 1.32 million tons of salts, is transported into central Arizona. This is the salt load via CAP water alone. The SRP system carries another 0.53 million tons of salts into central Arizona. Though the CAP and Salt River are the main sources of salts to the region, the Gila River, Agua River, and society itself import additional salts. The vast majority of the salts never leave central Arizona. The net result is nearly 1.1 million tons of salts remaining in the Phoenix metropolitan area each year. Tucson is currently retaining 100,000 tons of salts annually, Pinal County is retaining 600,000 tons annually, Harquahala is retaining 60,000 tons annually, and Gila Bend is retaining 450,000 tons annually.

These salts accumulate in groundwater, in the vadose zone, in salt sinks, and essentially wherever evaporation takes place. Initial estimates show that in the Phoenix Metro area about 39 percent of the salts are ending up in the groundwater through agriculture and recharge projects. About 22 percent of the salts are locked up in the vadose zone as a result of urban landscaping practices, where they remain until sufficient percolation water is available to flush the salts to the water table. Depending on the particular setting, this infiltration to groundwater may occur in a few years or require a couple of decades. Approximately 8 percent of the salts end up in salt sinks, which include lined ponds such as the Palo Verde Nuclear Generating Station evaporative ponds, effluent lagoons, and urban lakes. The remaining 31 percent of the salt is deposited in cooling towers, evaporative coolers, water fixtures, water heaters, and virtually anywhere else that evaporation occurs.

This salt imbalance began in the early 20th century with the damming of the Salt and Verde Rivers. Salts that would normally have been carried away to the sea were channeled to irrigate the farm fields that were helping expand the local agricultural industry. During the 70 years between the completion of Roosevelt Dam and the completion of the CAP, the volume of salts retained in the Phoenix metropolitan area was estimated at about 0.5 million tons. These salts were brought in from the Salt, Verde, Gila, and Agua Fria Rivers, along with input from residential, commercial, industrial, and agricultural (particularly fertilizer) use. With the completion of the CAP canal to Phoenix in the mid-1980s, the salt loading substantially increased. Estimates of future salt loading suggest by 2040 that retention of salts in the Phoenix metropolitan area may exceed 1.5 million tons annually.

Public Impacts

Hard water in the Phoenix metropolitan area is a pervasive problem. This water typically contains elevated levels of calcium and/or magnesium, resulting in poor taste, water spots on dishes, buildup of minerals on plumbing fixtures, and other annoying properties. Homeowners and businesses install water softeners to exchange the calcium and magnesium ions for sodium ions. This process removes the hardness from the water but it contributes to the increase of salinity at the wastewater treatment plants.

Groundwater delivered to users in the Tucson metropolitan area is generally very low in TDS. As CAP water becomes a larger portion of the water delivered to the residents, TDS levels will increase. Salinity problems may become noticeable. The public in the Tucson area is very sensitive to water quality issues

and previously rejected the direct use of CAP water. As TDS levels rise with increasing utilization of CAP water, water managers in the Tucson metropolitan area will need to consider options for managing the issue of declining water quality to maintain public acceptance of CAP water.

Economic Impacts

The economic impacts related to the importation and use of high-salinity water have not restricted population growth and urban development, nor prevented agriculture from thriving in central Arizona. Currently, the economic impacts are subtle, and the costs of managing high-TDS water are spread among municipalities, businesses, and agriculture. This spreading of the economic costs throughout society has lessened the impact.

An economic analysis on the impact of salinity to central Arizona was conducted for CASS. One of the things learned from that economic modeling was that the Phoenix metropolitan area currently experiences the majority of the economic impacts. Tucson currently has minimal economic impacts from salinity, but as Tucson expands its use of CAP water the economic impacts due to salinity in that area will increase.

Colorado River water can be compared to established water quality standards and the economic costs can be estimated for not meeting those standards. The secondary MCL for TDS, as established by the Environmental Protection Agency, is 500 mg/L. The 30-year average TDS of Colorado River water is approximately 650 mg/L at the entrance of the CAP at Lake Havasu. If CAP water delivered to users met the secondary MCL, the savings to central Arizona users is calculated to be about $22 million annually. These savings would be in the form of extended life of residential water appliances, larger crop yields, less water used to leach salts from the soil, and reduced costs to businesses and industry for such things as cooling tower maintenance and treatment of water used in manufacturing processes.

The TDS of Salt and Verde River waters is about 475 mg/L and the TDS of the CAP water is about 650 mg/L, if salinity levels were lowered by 100 mg/L in both of these water sources, the savings could be about $30 million annually.

It is important to remember that the economic model used to calculate these impacts is a simplified tool. However, the model provides useful information for identifying where those impacts are taking place, assessing the magnitude of the economic impacts to society, and as a means of comparing these costs against the cost of implementing solutions.

Phase I Conclusions

The salinity problem in central Arizona is a pervasive problem that subtly affects everyone living in this area. The importing of 1.32 million tons of salts annually through the CAP system and 0.53 million tons of salts annually through the SRP system cannot be ignored. In the Phoenix metropolitan area alone over 1 million tons of salts are retained annually, this will eventually cause long-term economic and environmental impacts. However, for the short term, salinity impacts are not restricting growth and development in central Arizona.

The Tucson metropolitan area has just begun to import quantities of CAP water and its accompanying salt load. Managing salt will be an emerging challenge for Tucson. In addition, continued irrigation in the agricultural areas of Pinal County, the Harquahala Basin, and the Gila Bend Basin will result in impaired

groundwater. This groundwater will require advanced water treatment prior to use for potable purposes as well as methods to dispose or minimize the concentrate.

The Technical Committee believes it is important that Phase II of the Central Arizona Salinity Study proceed. Phase II will involve a more detailed look at the salinity problem and a comprehensive assessment of possible solutions. At this point there is no clear solution, but it is recognized that the salt load must be managed to keep central Arizona economically and environmentally sound.

CASS PHASE II

Phase II of the CASS will consist of analyzing different strategies to manage salinity and investigating the salinity problem further. This will be accomplished through continued research, strategizing among the various study partners, and additional economic modeling. Several facets of the salinity problem will require additional attention, such as concentrate disposal, brackish groundwater treatment, salinity control in wastewater treatment plants, and the long-term implications of importing over 1 million tons of salts into the Phoenix metropolitan area. The Tucson metropolitan area will need special focus to cope with their developing salinity issues. Phase II of CASS will require approximately two years for completion.

The following is not a "task list"—rather, it presents a series of concepts that will be used as an outline as Phase II of CASS develops.

1. One of the main topics of Phase II will be an economic cost-benefit analysis for different approaches to managing salinity. Different regional management strategies will be devised and analyzed. Some of the varying approaches may include managing salinity on the watershed, removing salts on the CAP and Salt River, removing salts at water treatment plants, removing salts at wastewater treatment plants, and removing salts from recovered groundwater.
2. Management of brine concentrate and recovery of as much water from the concentrate as possible are important issues that need to be solved to allow central Arizona the ability to manage the salts that are brought into the region. Costs for desalinization of water are decreasing, as evidenced by the number of desalinization plants along the west coast of the U.S. Desalinization will continue to grow in importance in central Arizona through the foreseeable future, but disposal of the brine concentrate will be an associated challenge. For this reason, Phase II of CASS will examine disposal options.
3. Brackish groundwater is a resource that will need to be utilized to meet the potable water demands of a growing population. Treating brackish groundwater may be cheaper than importing water from distant sources. An appraisal level study of the construction of a brackish groundwater treatment facility, or facilities, to use this important water resource will be conducted during Phase II.
4. The Phase II study will further examine continued salt loading, determine where the bulk of salts are accumulating, and estimate the rate of impact to groundwater as well as other economic and environmental consequences of this salt imbalance.
5. While regional strategies may be implemented in the future, these ventures will take time, cooperation, and funding to make major changes in the way central Arizona manages salts. One of the Phase II study objectives will be to identify smaller, less expensive near-term strategies that may be immediately implemented by individual communities.
6. Salinity is not a well-publicized issue. Obviously, there are more pressing issues in central Arizona that demand immediate attention and funding. The development of a public awareness campaign on

salinity issues will also be a part of the Phase II study. The public awareness campaign may initially be directed toward providing essential information to community officials, politicians, and city management personnel, for eventual distribution to their communities.

7. The Phase II study will incorporate any other investigation or research that the Technical Committee feels is necessary to fully understand and report on the salinity issue and solutions in central Arizona.

CHAPTER 7 – REFERENCES

Printed References

Arizona Department of Water Resources. 1999. ADWR Third Management Plan 2000–2010. Phoenix, AZ.

Arizona Department of Water Resources. 2003. Tucson Active Management Area <http://www.water.az.gov/adwr/content/WaterInfo/InsideAMAs/amatucson.html.>

Bookman-Edmonston Engineers, Inc. 1999. Salinity Management Study, "Salinity and Total Dissolved Solids" (Technical Appendix). Prepared for the Metropolitan Water District of Southern California and U.S. Bureau of Reclamation.

Chemical Quality of Low Flow in the White, Black, and Salt Rivers. Map. United States. Geological Survey. 1977.

Graf, C.G. 1980. Arizona Department of Water Resources: Maps Showing Ground-Water Conditions in the Harquahala Plains Area, Maricopa and Yuma Counties, Arizona -1980

Hedley, J.D., 1990. Arizona Department of Water Resources: Maps Showing Groundwater Conditions in the Harquahala Irrigation Non-Expansion Area and Tiger Wash Basin, Maricopa and La Paz Counties, Arizona - 1989

Lee, T.L., 1905, Underground Waters of Salt River Valley, Arizona; U.S. Geological Survey Water –Supply and Irrigation Paper No. 136.

Maricopa Association of Governments. 2003. Interim Projections Presentation 6/25/03 <http://www.mag.maricopa.gov/detail.cms?item=2481>

Maunders, P. 2003. Hard Water Information < http://www.hardwater.org >

Osterkamp, W.R., 1973. Ground-Water Recharge in the Tucson Area, Arizona. United States Geological Survey, Map I-844-E

Pima Association of Governments, October, 1994. CAP Water Salinity Impacts on Water Resources of the Tucson Basin

Rascona, S.J., July 1996. Arizona Department of Water Resources: Maps Showing Groundwater Conditions in the Gila Bend Basin, Maricopa County, Arizona - 1993

Tucson Water. 2001. Clearwater, 2001, Tucson's New Blended water Resource <http://www.ci.tucson.az.us/water/water resources/clearwater/clearwater production/Clearwater production.htm>

Turek, F. 2003. Salinity in the Salt River Valley, Arizona: An Historical Perspective. Prepared for the U.S. Bureau of Reclamation, Central Arizona Salinity Study.

United States. Bureau of Reclamation. 1948. Report on Central Arizona Project Planning Report No. 3-8b.4-2. January.

United States. Bureau of Reclamation. 1972. Final Environmental Impact Statement: Proposed Central Arizona Project. Washington, DC.

United States. Bureau of Reclamation. 2000. Draft Environmental Impact Statement – Allocation of Water Supply and Long Term Contract Execution – Central Arizona Project. <http://www.usbr.gov/lc/phoenix/user/eis/instruct.html>

Personal Correspondence

Arnold, T., Senior Management Analyst, Tucson Water Department, Tucson, AZ. Email regarding commercial water use in central Arizona—February 2002.

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CENTRAL ARIZONA SALINITY STUDY—PHASE I

Technical Appendix A

SALINITY AND TOTAL DISSOLVED SOLIDS

Introduction

Salinity or Total Dissolved Solids (TDS) is a measure of the total ionic concentration of dissolved minerals in water. Owing to broad variation in the TDS of both imported and local water supplies, water resource managers for many years have been forced to balance the consumer's demand for high quality water with the quality of available water supplies. This issue paper provides brief background information related to the chemical constituents comprising TDS and their analytical determination, and includes discussions on the limitations of these chemical constituents relative to their ultimate uses. The purpose of this issue paper is to provide a background reference guide on the threshold concentrations of salinity that impact various uses.

Chemical Components of TDS and Their Measurement

TDS is composed of the following principal cations (or positively charged ions): Sodium (Na^{+}), Calcium (Ca^{2+}), Potassium (K^{+}), Magnesium (Mg^{+2}), and anions (or negatively charged ions): Chloride (Cl^{-}), Sulfate (SO_4^{2-}), Carbonate (CO_3^{2-}), Bicarbonate (HCO_3^{-}), and, to a lesser extent by Nitrate (NO_3^{-}), Boron (B^{3+}), Iron (Fe^{3+}), Manganese (Mn^{2+}) and Fluoride (F^{-}). TDS can be readily estimated in the field or laboratory by measuring the electrical conductivity (EC) of an aqueous solution. Electrical conductance is a measure of the electrical current produced (typically in micromhos per centimeter (μmhos/cm) or microsiemens per centimeter (μS/cm) by the dissolved ions. For water containing less than 5,000 milligrams per liter (mg/l) TDS, the ratio of EC:TDS generally ranges from about 1.04:1 to 1.85:1 and averages about 1.56:1. In the laboratory, TDS is typically determined by evaporating a known quantity of filtered water at 18° C then weighing the residue. The TDS of a water sample may also be estimated by summing the concentrations of the principal cations and anions. However, to accurately obtain, by summation, a result comparable to that determined by the evaporation method, only one-half of the HCO_3 value is to be used since, under the evaporation method, carbon dioxide (CO_2) and water of hydration (H_2O) which make up approximately one-half of the HCO_3 would be driven off and not included in the residue.

The individual cations and anions comprising TDS, with the exception of CO_2 and HCO_3, are measured by specific analytical methods in the laboratory. Carbonate and HCO_3 are typically determined by means of a calculation based on the results of alkalinity analyses and the associated pH at the titration endpoints. Nitrate, Fe, Mn, F and B concentrations are also determined through specific chemical analyses.

Other Related Analyses

Another item of concern to water resources managers is the hardness of the water supply. Hardness results from the presence of divalent metallic cations, of which Ca and Mg are the most abundant. Excessive hardness causes scale formation in boilers and reacts with soap to form a scum which prohibits lathering. Hardness can be measured experimentally or calculated through the formula: $H = 2.5\ Ca + 4.1\ Mg$ (Todd, 1980) where Ca and Mg concentrations are in mg/l. Hardness may also be calculated by multiplying the sum of the milliequivalents per liter of Ca and Mg by 50 [As reference, the milliequivalent of an ionic species calculated based on the atomic weight of the ionic species divided by its valence (e.g., Ca = 40.08/2 = 20.04) which is then divided by the concentration (in mg/l) of the ionic species in water].

Limitations of TDS and Related Chemical Constituents to Water Use

The beneficial uses of imported water and local water supplies generally consist of domestic or municipal, industrial, and agricultural. The concentration of TDS and/or the related chemical constituents comprising TDS in water supplies can limit the beneficial use of these waters. The following sections provide information on the limitations of water supplies based on TDS and related chemical constituent concentrations.

Drinking Water Quality Standards

The Safe Drinking Water Act (SCWA) was signed into law in 1974. The SDWA has been amended several times since, most recently in 1996 (Safe Drinking Water Act Amendments of 1996, Public Law 104-182). The SDWA mandates that the United States Environmental Protection Agency (USEPA) develop maximum contaminant levels (MCLs) or treatment techniques for drinking water constituents that may be of a health or aesthetic concern. MCLs for a wide range of constituents have been established, some of which are summarized in Table 1 for drinking water relative to TDS and related chemical constituents. Primary standards are for substances with a health risk. Secondary standards are recommended levels for substances, which can affect the aesthetic quality of water such as color, taste, or odor: but have no health risk.

Table 1 - Summary of Primary and Secondary State and Federal Drinking Water Standards for Total Dissolved Solids and Related Chemical Constituents

Chemical Constituent	Arizona Department of Environmental Quality MCL (mg/l)	USEPA MCL (mg/l)
Primary MCLs		
Fluoride	4.0	4.0
Nitrate	10	10[1]
Secondary MCLs		
Iron	--	0.3
Manganese	--	0.05
Chloride	--	250
Sulfate	--	250
TDS	--	500

1. Measured as N. In addition, the MCL for total nitrate/nitrite = 10 mg/l.

Domestic/Industrial Limitations

Presented in Table 2 is a summary of the various limitations of TDS and related chemical constituents for domestic and industrial use. It should be noted that some types of industry (e.g., computer microchip manufacturers) require water that exceeds drinking water standards and therefore must treat the water supply prior to use.

Table 2 - Principal Chemical Constituents Related to TDS, their Natural Concentrations in Water and Suitability for Use [1]

Chemical Constituent	Concentration in Natural Water	Suitability for Industrial and Domestic
Calcium (Ca^{2+})	Generally less than 100 mg/l; brine may contain as much 75,000 mg/l.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate and silica to form heat retarding, pipe clogging scale in boilers and in other heat-exchange equipment. Calcium and magnesium combine with ions of fatty acid in soaps to form soap scum; A high concentration of magnesium has a laxative effect, especially on new users of the supply.
Magnesium (Mg^{2+})	Generally less than 50 mg/l; ocean water contains more than 1,000 mg/l, and brine may contain as much as 57,000 mg/l.	
Sodium (Na^{-})	Generally less than 200 mg/l; about 10,000 mg/l in seawater; about 25,000 mg/l in brine.	More than 50 mg/l sodium and potassium in the presence of suspended solids causes foaming which accelerates scale formation and corrosion in boilers. Sodium and potassium carbonate in recirculating cooling water can cause deterioration of wood cooling towers. More than 65 mg/l of sodium can cause problems in ice manufacture.
Potassium (K^{+})	Generally less than about 10 mg/l; as much as 100 mg/l in hot springs; as much as 25,000 mg/l in brine.	
Carbonate (CO_3^{2-})	Commonly less 10 mg/l in groundwater. Water high in sodium may contain as much as 50 mg/l of carbonate	Upon heating, bicarbonate is changed into steam, carbon dioxide, and carbonate. The carbonate combines with

Bicarbonate (HCO_3^-)	Commonly less than 500 mg/l; may exceed 100 mg/l in water highly charged with carbon dioxide.	alkaline earth – principally calcium and magnesium – to form crust like scale of calcium. Carbonate that retards flow of heat through pipe walls and restricts flow of fluids in pipes. Water containing large amounts of carbonate alkalinity is undesirable in many industries.
Sulfate (SO_4^-)	Commonly less than 300 mg/l except in water supplies influenced by acid mine drainage. As much as 200,000 mg/l in some brine	Sulfate combines with calcium to form an adherent, heat-retarding scale. More 250 mg/l is objectionable in water in some industries. Water containing about 500 mg/l of sulfate tastes bitter; water containing about 1,000 mg/l may have a laxative effect.
Chloride (Cl^-)	Commonly less than 10 mg/l in humid regions but up to 1,000 mg/l in more arid regions. About 19,300 mg/l in seawater; and as much as 200,000 mg/l in brine.	Chloride in excess of 100 mg/l imparts a salty taste. Concentrations greatly in excess of 100 mg/l may cause physiological damage. Food processing industries usually require less than 250 mg/l. some industries – textile processing, paper manufacturing, and synthetic rubber manufacturing – desire less than 100 mg/l.
Fluoride (F^-)	Concentrations generally do not exceed 10 mg/l. Concentrations may be as much as 1,600 mg/l in brine.	Fluoride concentration between 0.6 and 1.5 mg/l in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. Fluoride in excess of 1.5 mg/l in some areas causes "mottled enamel" in children's teeth. Fluoride in excess of 6.0 mg/l causes pronounced mottling and disfiguration of teeth.

Nitrate (NO_3^-)	Commonly less than 10 mg/l.	Water containing large amounts of nitrate (more than 100 mg/l) is bitter tasting and may cause physiological distress. Water containing more than 45 mg/l has been reported to cause methemoglobinemia in infants. Small amounts of nitrate help reduce cracking of high-pressure boiler steel.
Iron (Fe^{3+})	Generally less than 0.50 mg/l in fully aerated water. Groundwater having pH less than 8.0 may contain 10 mg/l; rarely as much as 50 mg/l may occur. Acid water from thermal springs, mine wastes, and industrial wastes may contain more than 6,000 mg/l.	More than 0.1 mg/l Fe^{2+} precipitates after exposure to air; causes turbidity, stains plumbing fixtures, laundry, and cooking utensils, and imparts objectionable tastes and colors to foods and drinks. More than 0.2 mg/l is objectionable for most industrial uses. Precipitates if the iron is in the Fe^{2+} (Ferrous) valence state. Not all iron and manganese precipitate out.
Manganese (Mn^{2+})	Generally 0.20 mg/l or less. Groundwater and acid mine water may contain more than 10 mg/l.	More than 0.2 mg/l Mn^{2+} precipitates upon oxidation; causes undesirable tastes, deposits on foods during cooking, stains plumbing fixtures and laundry, and foster growth of Iron/Mn bacteria in reservoirs, filters, and distribution systems. Most industrial users object to water containing more than 0.2 mg/l.

Dissolved Solids	Commonly contain less than 5,000 mg/l; some brine contains as much as 300,000 mg/l.	Less than 500 mg/l is desirable for drinking. Less than 300 mg/l is desirable for dyeing of textiles and the manufacture of plastics, pulp paper, rayon. Dissolved solids cause foaming in steam boilers; the maximum permissible content decreases with increases in operating pressure.
[1] Modified after Todd (1980)		

As indicated previously, the concentrations of Ca and Mg ions are used to calculate hardness. The effects of hardness (i.e., hard water producing scale or soap scum) are directly related to the concentrations of Ca and Mg ions in the water supply (described above in Table 2). Owing to these observed reactions, hard water is considered undesirable for most domestic and industrial uses. In order to determine if water softening is required prior to beneficial use, several researchers have developed hardness classification to assess these potential deleterious impacts. Table 3 presents two of these hardness classification schemes.

Table 3 - Hardness Classification

Hardness Range mg/l (as $CaCO_3$)	Hardness Range mg/l (as $CaCO_3$)[2]	Description
0 – 60	0 – 75	Soft
61 – 120	75 – 150	Moderately Hard
121 – 180	150 – 300	Hard
Over 180	Over 300	Very Hard

In the water softening industry, hardness is expressed in grains per gallon (one grain per gallon equals 17.1 mg/l). No State of Federal drinking water MCL has been established for hardness due to lack of unequivocal data relating to public health.

Crop Irrigation Limitations

The suitability of the water supply for crop irrigation is contingent upon the ability of the dissolved constituents to be consumptively used by the crops for maintaining proper growth. Adequate drainage of applied water is also an important facet of proper crop irrigation. Two principal limitations to crop growth are salt tolerance and sodium content. Table 4 list various

crop families by relative salt tolerance and provides a range of salinity in (μ S/cm) and mg/l) in which the various crops in each crop family are capable of growing.

Table 4 - Relative Tolerances of Crops to Salt Concentrations [1,2]

Crop Division	Low Salt Tolerance	Medium Salt Tolerance	High Salt Tolerance
Fruit Crops	Avocado Lemon Strawberry Peach Apricot Almond Plum Prune Grapefruit Orange Apple Pear	Cantaloupe Date Olive Fig Pomegranate	Date Palm
Vegetable Crops	3,000 μ S/cm (1,900 mg/l) Green bean Celery Radish 4,000 μ S/cm (2,550 mg/l)	4,000 μ S/cm (2,550 mg/l) Cucumber Squash Peas Onion Carrot Potato Sweet corn Cauliflower Bell pepper Cabbage Broccoli Tomato 10,000 μ S/cm (6,400 mg/l)	10,000 μ S/cm (6,400 mg/l) Spinach Asparagus Kale Garden beet 12,000 μ S/cm (7,700 mg/l)
Forage Crops	2,000 μ S/cm (1,300 mg/l) Burnet Ladino clover Red clover Alsike clover Meadow foxtail White Dutch clover 4,000 μ S/cm (2,550	4,000 μ S/cm (2,550 mg/l) Sickle milkvetch Sour clover Cicer milkvetch Tall meadow oat grass Smooth brome Big trefoil Reed canary	12,000 μ S/cm (7,700 mg/l) Birdsfoot trefoil Barley (hay) Western wheat grass Canada wild rye Rescue grass Rhodes grass Bermuda grass Nattal alkali grass

	mg/l)	Meadow fescue Blue grame Orchard grass Oats (hay) Tall fescue Alfalfa Huban clover Sudan grass Dallis grass Strawberry clover Mountain brome Perennial rye grass Yellow sweet clover White sweet clover 12,000 μ S/cm (7,700 mg/l)	Salt grass Alkali sacaton 18,000 μ S/cm (11,500 mg/l)
Field Crops	4,000 μ S/cm (2,550 mg/l) Field bean 6,000 μ S/cm (3,850 mg/l)	6,000 μ S/cm (3,850 mg/l) Castor Bean Sunflower Flax Corn (field) Sorghum (grain) Rice Oat (grain) Wheat (grain) Rye (grain) 10,000 μ S/cm (6,400 mg/l)	10,000 μ S/cm (6,400 mg/l) Cotton Rape Sugar beet Barley (grain) 16,000 μ S/cm (10,250 mg/l)

1. Crops are listed in order of increasing salt tolerance.
2. Electrical conductance values represent salinity levels of the saturation extract at which a 50 percent decrease in yield may be expected as compared to yields on nonsaline soils under comparable growing conditions. The saturation extract is the solution extracted from a soil at its saturation percentage.

Table 5 provides a listing of irrigation water salt tolerances for a select group of crops, some of which are also shown in Table 4. It is noted that for some of the crops shown in Tables 4 and 5 (e.g. tomatoes), the range of eletroconductivities (EC) in Table 4, when converted to TDS, do not correspond with the indicated TDS values shown in Table 5. This may be due , in part, to the fact that the EC ranges shown in Table 4 reflect the crop salt tolerances of extract saturation of the soil corresponding to a 50 percent reduction in crop yields: whereas, the TDS values in Table 5 correspond to an irrigation water salinity level that causes no reduction or a 10 percent

reduction in crop yields. The salt tolerance ranges in Table 5 will depend on the salinity content in the soil and the salinity of water applied to reach saturation.

Table 5 - Irrigation Water Salt Tolerances for Selected Crops [1,2]

Crop	Irrigation Water TDS (mg/l)
Apples	725
Avocado	555
Citrus	768
Grapes	640
Macadamia	840
Persimmons	768
Strawberries	427
Roots, bulbs, tubers	640 – 2,560
Carnations	640 – 1,280
Gladiolas	429 – 840
Poinsettias	1,058 – 1,728
Roses	1,472
Beans	427
Corn	726
Cucumbers	1,087
Mushrooms	Highly Insensitive
Potatoes	725
Squash	853
Tomatoes	1,067
Fescue	1,864
Bermuda Grass	2,944

1. Under normal conditions, soil moisture salinity (ECe) is approximately 1.5 * irrigation water salinity (ECw), i.e., (ECe = 1.5 * ECw)
2. Under drought conditions, soil salinity can be as much as 3 * Ecw. Salinity tolerance levels assume no yield reductions.

Boron

Boron, in minute concentrations, is essential to the normal growth of all plants. However, when present in larger concentration boron becomes toxic. Table 6 provides a list of crops based on their relative tolerance to boron. Boron in excess of 2.0 mg/l in irrigation water is deleterious to certain plants and some plants may be affected adversely by concentrations as low as 1.0 mg/l.

Table 6 - Relative Tolerance of Plants to Boron (Listed in Order of Increasing Tolerance)

Sensitive	Semi-tolerant	Tolerant

Lemon	Lima bean	Carrot
Grapefruit	Sweet potato	Lettuce
Avocado	Bell pepper	Cabbage
Orange	Pumpkin	Turnip
Thornless blackberry	Zinnia	Onion
Apricot	Oat	Broadbean
Peach	Milo	Gladioulus
Cherry	Corn	Alfalfa
Persimmon	Wheat	Garden beet
Kadota fig	Barley	Date palm
Grape	Olive	Palm
Apple	Ragged robin rose	Asparagus
Pear	Field pea	Athel
Plum	Radish	
American elm	Sweetpea	
Navy bean	Tomato	
Jerusalem artichoke	Cotton	
English walnut	Potato	
Black walnut	Sunflower	
Pecan		

Exchangeable Sodium Content (Percent Sodium) and Sodium Adsorption Ratio

The concentration of sodium in irrigation water supplies is important because sodium reacts with soil causing a reduction in soil permeability. Exchangeable Sodium Content (%)in irrigation water supplies is usually expressed as percent sodium using the equation:

$$ESP = ((Na)/(Ca + Mg + K + NH_4 + Na)) * 100 (\%)$$

Where all ionic concentrations are expressed in milliequivalent per liter.

The Sodium Adsorption Ratio (SAR) is also used to estimate the probable impact of sodium adsorption by soils for irrigation of crops. The SAR is calculated using the formula:

$$SAR = \frac{Na}{[(Ca + Mg)/2]^{1/2}}$$

Where the concentrations of the chemical constituents are expressed in milliequivalents per liter. SAR is used in conjunction with the salinity of the irrigation water. The higher the salinity the lower the SAR should be.

Classification of Irrigation Water Quality

A typical water quality classification scheme for irrigation water supplies is presented in Table 7. The data shown in the table are useful in the these numerical ranges may be compared with the relative tolerances to salinity, e.g., EC, in Tables 4 and 5 and boron in Table 6.

Table 7 - Quality Classification of Water for Irrigation

Water Class	Percent Sodium	Electrical Conductivity /TDS [(μ S/cm)/(mg/l)]	Boron (mg/l)		
			Sensitive Crops	Semi-Tolerant Crops	Tolerant Crops
Excellent	<20	<250/(160)	<0.33	<0.67	<1.00
Good	20 – 40	250 – 750/(160 – 480)	0.33 – 0.67	0.67 – 1.33	1.00 – 2.00
Permissible	40 – 60	750 – 2,000/(480 – 1,300)	0.67 – 1.00	1.33 – 2.00	2.00 – 3.00
Doubtful	60 -- 80	2,000 – 3,000/(1,300 – 1,900)	1.00 – 1.25	2.00 – 2.50	3.00 – 3.75
Unsuitable	>80	>3,000/(1,900)	>1.25	>2.50	>3.75

Other Issues

The relationship between TDS and related chemical constituents to the taste of water supplies has emerged as an issue. However, the regulation of TDS (or other related chemical constituents) to meet a particular range of taste thresholds (which is not in itself a public health issue, but rather for aesthetic purposes) would most likely raise concerns among water resources managers regarding the potential additional levels of water treatment required and the associated potential costs for such enhanced water treatment.

References

1. Salinity Management Study, Final Report, Technical Appendix: Salinity and Total Dissolved Solids", Metropolitan Water District of Southern California and U.S. Department of the Interior, Bureau of Reclamation, prepared by Bookman-Edmonston Engineers Inc., June 1999.

CENTRAL ARIZONA SALINITY STUDY --- PHASE I

Technical Appendix B

COLORADO, SALT, VERDE and GILA RIVERS

COLORADO RIVER

The Colorado River Basin (Basin) covers an area of 242,000 square miles in the United States and 2,000 square miles in Mexico. The River extends 1,400 miles from the Rocky Mountains to the Gulf of California. The Colorado River supplies water to 4 million people within the United States portion of the Basin, and through export, a full or supplemental water supply to an additional 19 million including 3 million within Central Arizona Project's delivery area.

The in-basin economy is based on irrigated agriculture, livestock grazing, mining, forestry, manufacturing, oil and gas production, recreation and tourism. About 3.5 million acres are irrigated within the Basin and hundreds of thousands of acres by water exported from the Basin. The Colorado River also serves about 1.7 million people and 500,000 irrigated acres in Mexico.

Like most western rivers, the Colorado's salinity increases as it moves downstream in its watershed. Mineral salts in the Basin are indigenous and pervasive. Significant portions of the geologic formations were deposited in ancient saline marine environments. Salts deposited within the sedimentary rocks are easily eroded, dissolved, and transported into the river system. The salinity concentration is highly variable due to large variations in the magnitude of runoff. The United States Geological Survey (USGS) has estimated that the natural salt load of Colorado River at Lees Ferry, Arizona is 5.3 million tons per year. The Bureau of Reclamation (Reclamation) has determined that the salt load currently entering Lake Mead is about 9 million tons annually.

The U.S. Environment Protection Agency (EPA), in 1971, concluded that about half (47 percent) of the salinity concentration arriving at Hoover Dam is from natural sources. Natural sources include contributions from saline springs, groundwater discharge into the river system (excluding irrigation return flows), erosion, and dissolution of sediments, and the concentrating effects of evaporation and transpiration. As identified by EPA, about 53 percent results from human activity. Irrigated agriculture accounts for 37 percent, reservoir evaporation amounts to 12 percent, out-of-basin export 3 percent, and one percent is attributed to in-basin municipal and industrial uses.

Salinity Control on the Colorado River

Sustained attention to water quality problems in the River dates back to 1960 when the Conference in the "Matter of the Pollution of the Interstate Waters of the Colorado River and Its Tributaries" was formed under the provisions of the Federal Water Pollution

Control Act, as amended, PL 84-660. Representatives of each of the Colorado Basin States participated in the Conference sessions. Six sessions of the Conference were held from 1960 through 1967.

The long-range salinity problem was identified early in the deliberations, but the paucity of data cast doubt upon the ability to deal effectively with it until more data were collected and evaluated. The seven states advocated and supported efforts to improve the database. During the series of meetings of the Conferees held in 1966 and 1967, a document (that) was formulated known as "Guidelines for Formulating Water Quality Standards for the Interstate Waters of the Colorado System." These guidelines were adopted in January 1967. The guidelines said in part:

> "*In order to develop practicable and reasonable quality standards for interstate waters in the Colorado River System, full consideration must be given to the numerous factors and variables connected with the control, development, utilization, conservation, and protection of the System's water resources. It is evident that future development and utilization of the System's water resources for expansion of irrigated agriculture, increases in population, and industrial growth will be accompanied by progressive increases in consumptive losses of water and attendant increases in concentration of dissolved solids."*
>
> *"The states served by the Colorado River System recognize that answers to important questions regarding total dissolved solids, chlorides, sulfates and sodium are lacking or are based on factors that are not yet well-defined. In respect of this recognition the states agree that pending the development of acceptable answers to enable the setting of criteria for total dissolved solids, chlorides, sulfates and sodium for the Colorado River system, such criteria should be stated in qualitative terms. At the same time it is agreed that all identifiable sources of water pollution will be managed and controlled to the maximum degree practicable with available technology in order to provide water quality suitable for present and potential future uses of the System's interstate waters."*

In 1968, the Secretary of Interior, in testimony before Congress, stated that the Department of the Interior (Interior) would pursue an active program to lay a foundation setting numerical standards that will equitable, workable, and enforceable.

The Colorado River Board of California in 1970 released its report, which presented an appraisal of salinity sources; probable future increases in salinity, impacts of such increases on California users.

The EPA, in December 1971, released the results of its eight-year study of Colorado River salinity. The report recommended the adoption and enforcement of salinity criteria to hold the maximum mean monthly concentration of total dissolved solids at Imperial Dam at 1,000 mg/l—approximately the maximum mean monthly concentration then of record.

The 1971 EPA report was the major subject of the Seventh Session of the Conference in the "Matter of Pollution of the Interstate Waters of the Colorado River". At the February 17, 1972 Reconvened Seventh Session, the State Conferees unanimously adopted a resolution regarding Colorado River salinity standards. The significant part of that resolution states:

> *"I. It is recommended that:*
>
> *"A salinity policy be adopted for the Colorado River system that would have as its objective the maintenance of salinity concentrations at or below levels presently found in the lower main stem. In implementing the salinity policy objective for the Colorado River system, the salinity problem must be treated as a basin-wide problem that needs to be solved to maintain Lower Basin water salinity at or below present levels while the Upper Basin continues to develop its compact-apportioned waters.*
>
> *"II. The salinity control program as described by the department of the Interior in their report entitled 'Colorado River Water Quality Improvement Program', dated February 1972, offers the best prospect for implementing the salinity control objective adopted herein…."*

Enactment of Federal Water Pollution Control Act Amendment (PL 92-500) in 1972 introduced a new factor into the salinity problem. The legislation was interpreted by EPA as requiring that numerical criteria be set for salinity on the Colorado River. In the fall of 1973, EPA submitted to the Colorado River Basin States proposed regulations for water quality standards for salinity and procedures for salinity control in the Colorado River Basin, including the establishment of an interstate organization to develop a salinity control plan.

In response to EPA's proposed regulations, representatives of water quality and water resource interests from the seven Basin states met on November 8 and 9, 1973 to consider EPA's submittals and to establish a mechanism for interstate cooperation. During the meeting the representatives formed the "Colorado River Basin Salinity Control Forum," and adopted the "Seven Colorado River Basin States Accord" which expressed the consensus of the States with respect to the proposed EPA regulations.

The Forum is comprised of two to three representatives from each state, appointed by the Governor, with representation from both water resources and water quality interests. The Forum operates by consensus with each state having only one vote in developing the consensus.

On November 26, 1973 in a letter from Lynn M. Thatcher, chairman of the newly created Forum to Paul DeFalco, Jr., Director, Region IX, the Environmental Protection Agency, Mr. Thatcher advised of the creation of the Forum and submitted the statement "Seven Colorado River Basin States Accord." The key elements of the statement were:

"The States have established a mechanism for interstate cooperation (Colorado River Basin Salinity Control Forum) and for preparation of semi-annual reports on the development of numeric criteria and the adoption of such criteria by October 18, 1975.

"(b) The final statement on proposed water quality standards and plan of implementation for salinity control should be consistent for all seven States of the Colorado River Basin; and

"(c) Opportunity should be provided for further direct discussion between representatives of the Environmental Protection Agency and the Forum before the proposed regulations are published in the Federal Register."

Water Quality Standards for Salinity

In response to the EPA draft regulations, the Forum released its proposed salinity standards in June 1975. Following public meetings and receipt of comments, the Forum adopted the numeric criteria and plan of implementation and recommended its adoption to each of the Basin states. The numeric criteria and plan of implementation were set forth in the document "Proposed Water Quality Standards for Salinity Including Numeric Criteria and Plan of Implementation for Salinity Control." Eventually, each state adopted the Forum recommended standards as its state standards for the Colorado River. Subsequently, EPA approved the standards.

Federal regulations, Section 303 of the Clean Water Act, require that the standards be reviewed at least once during each three-year period. The 1999 Review, the eighth triennial review, has been completed and adopted by the Forum. Each review has been documented in a report. This Review is consistent with the EPA approved 1975 standards and deals only with that portion of the Colorado River Basin above Imperial Dam.

The numeric criteria were established at three lower main stem locations at the points where the Lower Basin states divert Colorado River water. The numeric criteria correspond to the flow-weighted average annual concentrations in the lower main stem of the Colorado River during the calendar year 1972. The numeric criteria are:

Below Hoover Dam	723 mg/l
Below Parker Dam	747 mg/l
Imperial Dam	879 mg/l

Below Imperial Dam, the river's salinity is to be controlled by agreement with Mexico on salinity as set forth in Minute 242 of the International Boundary and Water Commission. The agreement calls for measures to be taken to assure that the waters delivered to Mexico upstream of Morelos Dam will have a salinity of no more than 115 mg/l +/- 30

mg/l greater than the average annual salinity of Colorado River arriving at Imperial Dam. The implementation plan for compliance with Minute 242 is a federal responsibility and separates from the Forum's basin-wide implementation program.

Implementation Plan for Salinity Control

The implementation plan is designed to maintain the salinity of the River at or below the numeric criteria of the three lower main stem stations while the Basin states continue to develop their compact apportioned waters. This is accomplished mainly by reducing the salt contributions from existing natural and existing human caused sources and minimizing future increases in salt loading by human activity.

The Federal agencies have a significant role in implementing the salinity control program. Reclamation is implementing a number of specifics units to reduce salt loading to the River system. The units authorized for construction by Congress are Grand Valley, Lower Gunnison, Dolores, Paradox Valley, and Las Vegas Wash in Colorado and Nevada.

The 1974 Salinity Control Act legislation was a unit-specific approach to control with unit authorization and funding requiring congressional approval. This constraint limited the effectiveness of the implementation plan, causing delays in completion and the ability to select the most cost – effective units from an array of potential measures.

The Colorado River Basin Salinity Control Act was amended in 1984 by P.L. 98-569 to authorize two additional units for construction by Reclamation. The amendments directed the Secretary of the Interior and the Secretary of Agriculture to give preference to the salinity control units with the least cost per unit of salinity reduction. The Act was also amended to establish a voluntary on-farm salinity control program to be implemented by the Department of Agriculture and provided for voluntary replacement of incidental fish and wildlife values foregone on account of the on-farm measures. Many cost-effective salt-load reducing activities were accomplished in the decade following that authorization. P.L. 98-569 also directed the Bureau of Land Management (BLM) to implement salinity controls.

The Department of Agriculture's basin-wide on-farm voluntary cost-share program was authorized in the 1984 Amendments to the Salinity Control Act. Currently, control measures are being implemented to reduce salt loading from agricultural activities in Grand Valley, Lower Gunnison and McElmo Creek in Colorado; Uinta Basin in Utah, and Big Sandy River in Wyoming

The Bureau of Land Management's program provides for watershed improvement and rangeland management for watershed improvement in Colorado, Utah, and Wyoming.

The U.S. Geological Survey, U.S. Fish and Wildlife Service, and the Environmental Protection Agency all have an active role in salinity control activities.

Reclamation and the Forum, in 1994, concluded that the existing Act, as amended, with its unit-specific approach and authorization ceiling, was limiting salinity control opportunities. In 1995, the Act was amended by P.L. 104-20 – Amendments to the Colorado River Basin Salinity Control Act to authorize an entirely new way of implementing salinity control. Reclamation's new basin-wide Salinity Control Program opens the program to competition through a public process and has greatly reduced the cost of salinity control. An additional $75 Million of expenditures by Reclamation were authorized by P.L. 104-20. In 2000, P.L. 106-459, an amendment to the Colorado River Basin Salinity Control Act both increased the authorization ceiling for the Basin wide Salinity Control Program from $75 million to $175 million and authorized additional measures to carry out the control of salinity upstream of Imperial Dam in a cost-effective manner.

The 1995 amendments resolved the problem by authorizing Reclamation to implement a Basin-wide approach with an additional $75 million for expenditures. This change permits Reclamation to select the most effective means of control.

The Federal Agriculture Improvement and Reform (FAIRA) of 1996 – P.L 104-127 – further amended the U.S. Department of Agriculture's (USDA) role in salinity control by creating a new conservation program known as the Environmental Quality Incentives Program (EQIP) which combined four conservation programs, including USDA's Colorado River Basin salinity control program. FAIRA provided authority for funding the nationwide EQIP through the year 2002. USDA has created rules and regulations concerning how EQIP funds are to be allocated. The past authority for the states to cost-share from the Basin funds was retained in the new EQIP program with linkage to Reclamation's authority to distribute Basin funds for cost sharing. The Forum's experience has been that the enacted rules and regulations for EQIP do not consider the significant benefits in downstream states, thus creating a situation which disadvantages salinity control efforts when compared to other local initiatives. The past authority for the states to cost-share from the Basin funds was retained in the new EQIP with linkage to Reclamation's authority to distribute Basin funds for cost sharing.

The Farm Security and Rural Investment Act (FSRIA) of 2002 (P.L. 107-171) reauthorized EQIP from 2002 through 2007 at significantly increased funding levels. If the percentage of EQIP funds dedicated to the Colorado River Salinity Control Programs continues at the previous rate, more than $10 million would available in 2002 and would rise to a high of $33 million in 2007, the final year of FSRIA. Final rules have not been published and the full input of FSRIA on salinity control have not been analyzed.

The Basin states' role in the program involves the control of total dissolved solids through the National Pollutant Discharge Elimination System Permit (NPDES) program and non-point source water quality management plans as well as implementation of the Forum's recommended and adopted polices. The policies include:

1. "Policy for Implementation of Colorado River Salinity Standards Through the NPDES Permit Programs";

2. "Policy for Use of Brackish and/or Saline Waters for Industrial Purpose";

3. "Policy for implementation of the Colorado River Salinity Standards Through the NPDES Permit Program for Intercepted Ground Water'; and

4. "Policy for Implementation of the Colorado River Salinity Standards Through the NPDES Permit Program for Fish Hatcheries."

Mexican Salinity Issues

The salinity of waters delivered to Mexico increased markedly in the winter of 1961-62, increasing from less than 1,000 mg/l in prior years to 2,600 mg/l. Mexico protested the increase. In 1962, the Presidents of the United States and Mexico agreed to find a mutually satisfactory solution to this problem.

The increase in salinity was attributed to two major factors. The Wellton-Mohawk Project began receiving irrigation water from the Colorado River in 1952. By 1960, a drainage system was implemented returning about 300 cubic feet per second (cfs) (217,000 AF/yr) of highly saline drainage water to the Colorado River above the Mexican diversion point, Morelos Dam. This, combined with the completion of Glen Canyon Dam and the filling of Lake Powell, greatly reduced flows at the international boundary.

Temporary measures were implemented through a number of Minutes to the 1944 Mexican Water Treaty. In 1965, the U.S. with the agreement of the seven Basin state governors executed Minute 218 of the International Boundary and Water Commission. Under this agreement the U.S. constructed and extension to bypass Wellton-Mohawk drainage beyond Morelos Dam and delivered about 50,000 AF/yr of additional Colorado River water to Mexico to substitute for bypassed drainage water.

In 1972, President Nixon and Mexico' President Echeverra met to discuss matters of mutual concern. High on the list was the salinity of the water being delivered to Mexico. They agreed to find a "permanent, definitive and just" solution to the salinity problem. As part of the agreement, Minute 248 replaced Minute 218. The new Minute increased the amount of Colorado River water that would be substituted for Wellton-Mohawk drainage water from 50,000 AF/yr to 118,000 AF/yr. The remaining drainage was also bypassed around Morelos Dam at Mexico's request but was deducted from the required 1.5 million acre-feet of annual deliveries to Mexico.

A presidential representative, former Attorney General Herbert Brownell, worked closely with a federal task force and the Committee of Fourteen, which is the seven-state advisory body to the U.S. Department of State on the Mexican Water Treaty. An agreement was reached and approved by the two Presidents in August 1973. The agreement was formalized as Minute 242. Minute 242 terminated Minute 241.

The key provision of Minute 242 was a commitment by the United States to adopt measures to ensure that the water delivered to Mexico upstream of Morelos Dam would have an average annual salinity of not more than 115 mg/l plus or minus 30 mg/l over the average annual salinity. The guarantee on the salinity of deliveries was to become effective upon authorization by Congress of funds required to construct the necessary works.

While Minute 242 was considered a permanent solution, it was understood by Mexico and recognized by the U.S. that control of salinity upstream of Imperial Dam was critical to the resolution of the salinity problems with Mexico. Herbert Brownell stated "…that unless the U.S. does control this threatened and almost certain increase in salinity above Imperial Dam, the water we deliver to Mexico may become unacceptable, and we shall in the future, have a new salinity problem with that country." Similar expressions of concern over future salinity in the River were expressed by Mexico's Foreign Secretary Rabasa.

Colorado River Basin Salinity Control Act

The Colorado River Basin Salinity Control Act, P.L. 93-320, contains two titles, Title I – Programs Downstream from Imperial Dam and Title II – Measures Upstream from Imperial Dam.

Title I authorizes measures which include:

1. Construction of a desalting complex near Yuma Arizona to reduce the salinity of Wellton-Mohawk drainage water;
2. Construction of a lined bypass facility to the Gulf of California to carry brine reject water from the desalting plant;
3. Improvement of irrigation efficiency in Wellton-Mohawk Irrigation and Drainage District to reduce the amount of drainage water to be desalted;
4. Implementation of protective groundwater pumping in a five-mile wide strip along the Arizona – Sonora border; and
5. Replacement of the first 49 unlined miles of the Coachella Canal with a lined reach to reduce water lost through seepage. The recovered seepage loss can be used by federal government to reduce storage releases until the first year that the Secretary of the Interior delivers an amount less than requested by the California agencies under contract pursuant to the Boulder Canyon Project Act. At that time, California will benefit from the salvaged Coachella Canal water in the less water will be lost to seepage than would have otherwise been the case if the canal were not lined.

The Yuma desalting complex facility has been completed with an ultimate capacity of about 73 million gallons per day of product water of 300 mg/l. The desalted water will be blended with raw drainage water to provide 73,000 AF/yr, which will be returned to the Colorado River upstream of Morelos Dam. Only about one-third of the reverse osmosis membranes are install and the plant is not operating. The River system has, at

this time, adequate water to meet the Basin's demands and bypass the Wellton-Mohawk drainage water to the Santa Clara Slough. Costly operation of desalting can be avoided under these conditions. It is understood that Reclamation is currently negotiating with non-Federal interests to operate the plant at one-third capacity in return for rights to the desalted water for an interim period until the water is needed for meeting Minute 242.

The lined bypass drain from Morelos Dam to Santa Clara Slough in Mexico has been completed. It currently is carrying irrigation return flow from Wellton-Mohawk. At such time that the desalting plant becomes operational, reject brines will be bypassed to Santa Clara Slough.

The goal of the agricultural improvements in the Wellton-Mohawk Irrigation and Drainage District is to reduce the amount of drainage water to be desalted. In order to achieve the goal, 10,000 acres of irrigable lands were fallowed. On-farm irrigation efficiencies have been improved for a time, on-farm canals have been lined, lands have been leveled and more efficient irrigation systems have been installed. The ultimate goal of the overall program is to reduce irrigation drainage pumping to about 110,000 AF/yr.

The cost of the work required by Title I is to be borne by the federal government.

Title II provided for:

1. The Secretary of the Interior (Secretary) to implement the salinity control policy adopted in 1972 for the Colorado River by the seven Basin states in the "Conclusions and Recommendations" published in the Proceedings of the Reconvened Seventh Session of the Conference in the "Matter of Pollution of the Interstate Waters of the Colorado River and Its Tributaries", 1972;
2. The Secretary to expedite the planning and implementation of the program described in Reclamation's report "Colorado River Water Quality Improvement Program", February 1972.
3. The Secretary to expedite completion of planning reports on 12 irrigation, point, and diffuse salt sources identified in Reclamation's 1972 report;
4. Creation of the Colorado River Basin Salinity Control Advisory Council consisting of gubernatorial-appointed state representatives. (The members of the Advisory Council are generally the same individuals who are members of the Forum.)
5. Seventy-five percent of the total cost of construction, operation, maintenance, and replacement to be a federal cost and non-reimbursable. Twenty-five percent of the total costs are allocated between the Upper Colorado River Basin Fund and Lower Colorado River Basin Development Fund. Of the 25 percent reimbursement, a maximum of 15 percent is from the Upper Basin Fund with the remainder, currently 85 percent repaid from the Lower Basin Fund. Repayment of construction, operation and maintenance is over 50 years without interest. (The allocation of 75 percent of the costs to the federal government is because a major portion of the lands within the Basin from

which the dissolved salt originates is in federal ownership and/or from federal projects.)

SALT RIVER

The Salt River drains an area of approximately 5,980 miles (5%of the state's land area) and is the largest tributary of the Gila River. The headwaters of the Salt River are the White and Black Rivers which originate at elevations near 11,400 feet above mean sea level in the White Mountains. From the confluence of the White and Black Rivers, the Salt River roughly follows a 140-mile course southwesterly to its confluence with the Gila River at an elevation of about 900 feet above mean sea level.

The Salt River is perennial from its headwaters to Granite Reef Diversion Dam near Mesa, Arizona. The Black and White Rivers originate on the Fort Apache Indian Reservation in the White Mountains and together drain a total of nearly 1,900 square miles.

Numerous streams that start as springs and seeps along the Mogollon Rim and in the White Mountains feed the tributaries of the Salt River. The perennial flows in these areas are primarily a result of geologic barriers discharging groundwater to streams. Volcanic rocks are exposed along the east-central portion of the state in the Central highlands. Water is forced through this volcanic material through joints and fractures and discharges as springs where these fractures intersect the ground surface.

Water Quality

Surface runoff from the Upper Salt River watershed and its headwaters are of relatively good quality and free of dissolved solids. However, significant changes occur in the water quality by the time the Salt River enters Roosevelt Lake. A twenty-mile stretch of springs begins approximately twenty-five miles above the head of Roosevelt Lake, and are responsible for the degradation of water quality. These springs discharge waters which have high concentrations of dissolved solids, particularly sodium and chloride.

Springs occurring in and around the confluence of the White and Black Rivers, the Salt River, and the lower Carrizo Creek are known to discharge waters which have high concentrations of dissolved solids ranging from 1,600 mg/l to 17,600 mg/l. Water containing greater than 10,000 mg/l of dissolved solids is considered very saline, hence the origin of the Salt River's name. Sodium and chloride are the primary components of the dissolved solids. At the Salt Banks on the Salt River the sodium content ranges from 10,000 mg/l to 13,500 mg/l and the chloride content ranges from 15,900 mg/l to 20,800 mg/l resulting in the flow being very similar to that of a solution of common table salt. The springs emerge through Precambrian quartzite, however, the source of the saline water is not readily apparent.

Although the sodium and chloride exceed all other constituents, the Salt Banks and other saline springs along the Salt River have high bicarbonate levels which usually exceed the sulfate levels. Concentrations of bicarbonates and sulfates range from 90 to 600 mg/l and 3 to 590 mg/l respectively. Calcium and magnesium also occur in large amounts. Hardness as calcium and magnesium range from 64 to 1,800 mg/l with most sample3s in the 400 mg/l range which classifies the water as very hard. Boron concentrations are also relatively high where it occurs. High concentrations of boron may be indicative of evaporite deposits and geothermal activity. Large concentrations of boron in irrigation water is harmful to some plants.

By the time the Salt River reaches Roosevelt Lake, mixing of better quality water from surface runoff and tributaries serves to improve the river's quality. Also, good quality water from the Tonto Creek enters the lake. In the lower Tonto Creek basin dissolved solids range 255 to275 mg/l, hardness as calcium carbonate range from 157 to 185 mg/l with the main constituents being calcium and bicarbonate.

Pinal Creek, Miami Wash and Bloody Tanks Wash are reported to have total dissolved solids concentrations over 3,000 mg/l. These high levels of TDS are attributed to the mining operations in the area.

VERDE RIVER

The Verde River drains an area of approximately 6,188 square miles (6% of the state's land area) and traverses a distance of about 140 miles from Sullivan Lake Dam near Paulden, to its confluence with the Salt River. The river drains eastward from Sullivan Lake Dam to Perkinsville, then southeastward to its confluence with Fossil Creek where it continues southward until it joins with the Salt River.

The Verde River is intermittent from Sullivan Lake Dam to the Granite Creek confluence, a distance of about 3 miles; perennial flow is maintained from this confluence to where it joins the Salt River. The major perennial tributaries drain the area north and east of the Verde River and flow in southwesterly direction toward the Verde River. Groundwater discharge maintains perennial flow in these tributaries and in the Verde River.

Surface water in the Verde Valley is used for irrigation purposes. The water quality generally is well suited for this use. During low flows, the dissolved solids concentrations generally increase in the downstream direction because of the increased levels in groundwater from the Verde Formation. This is especially evident in the southern part of the Verde Valley. High sodium levels occur in the Verde River downstream from Camp Verde. During medium and high flows, the dissolved solids concentration is diluted by snowmelt or surface runoff that have a lower dissolved solids concentration.

GILA RIVER

The Gila River is divided into the upper, middle and lower watersheds. The upper Gila River watershed is located in southwestern New Mexico and in southeastern Arizona above Coolidge Dam at San Carlos Reservoir. The watershed drains approximately 12,890 square miles. The river originates in the Mogollon Mountains in western New Mexico. Flows in the upper Gila River are intermittent but does maintain a 35 mile perennial stretch beginning about 20 miles into Arizona.

Agriculture is the major use of surface water in the upper watershed. Irrigation water is obtained from the Gila River at several diversions and from wells pumping groundwater. Diversions from the river above Coolidge Dam are regulated by the Gila Decree since 1936.

The middle Gila River watershed encompasses the area from below Coolidge Dam to Gillespie Dam southwest of Phoenix. The San Pedro River drainage encompasses the vast majority of this watershed. The middle Gila River watershed is approximately 5,425 square miles and of that the San Pedro drains approximately 4,485 square miles. Flow in the Gila River between Coolidge dam and Ashurst-Hayden Dam can be attributed to releases from the San Carlos Reservoir and natural flow in the river.

Irrigated agriculture, grazing and mining are the main water uses in the middle watershed. Water released from the San Carlos Reservoir is stored and regulated by the Gila Decree of 1936.

The water quality of the middle watershed is poor. The Arizona Department of Environmental Quality has reported exceedance of water quality standards for turbidity, metals, bacteria, total dissolved solids, and nutrients along the Gila River from San Carlos Reservoir to the Phoenix area. As an example the total dissolved solids in the Gila River at Kelvin had an annual average concentration of 929 mg/l (Earthinfo, Inc., 1991)

The lower Gila River watershed extends from Gillespie Dam to the confluence of the Colorado River a distance of approximately 150 miles. The lower Gila River is ephemeral and flows only in response to precipitation and releases from Coolidge Dam.

STATE PROGRAMS

A major element of the state programs is the ability of the Basin states to cost-share in the Reclamation and the USDA programs. This allows, for additional funds to be made available from the Basin states' fund through up-front cost sharing to move the salinity control effort ahead. At current federal funding levels, the Basin states contribute about $8 million each year. Basin states' funds are available to cost-share in a larger program if federal dollars were to be increased.

The states' portion of the plan of implementation also includes effluent limitations on industrial point source discharges with the objective of no-salt return whenever practicable, as well as a program which parallels USBR and USDA efforts and which is funded from the Basin states' funds.

In 1977, the Forum adopted it "Policy for Implementation of Colorado River Salinity Standards Through the National Pollution Discharge Elimination System (NPDES) Permit Program." This policy provides guidance for the regulation of municipal and industrial point source discharges of saline water. In 1980, the Forum adopted a policy to encourage the use of brackish and/or saline waters for industrial purposes where it is environmentally sound, and economically feasible. A third policy dealing with intercepted ground water was adopted by the Forum in 1982. In 1988, the Forum adopted a fourth policy which addresses the salinity of water discharges from fish hatcheries.

Important components of the plan of implementation for salinity control are the Basin states' activities associated with the control of total dissolved solids through the NPDES Permit program, and the water quality management plans. The Forum considers, from time to time, needed changes to its NPDES policies. The original policy allowed for a waiver to be granted by the permitting agency if the proposed discharge of water contained less than a ton of salt per day.

The NPDES Program is currently administered by the EPA in Arizona, however, the Arizona Department of Environmental Quality has submitted a program primacy package to EPA Region IX and anticipates receiving the program delegation on July 1, 2002. Until full program delegation, the permitting workload is shared between the two agencies, each drafting permits which are then issued by EPA. EPA is responsible for issuance of all permits on tribal lands, including the Navajo Nation, who like the State, assist EPA in drafting permits. The State and EPA follow Forum policy in the administration of the NPDES Program.

There are currently 56 NPDES permits in the Colorado River Basin portion of the state. Nineteen of the facilities are on tribal lands: 17 are municipal wastewater discharges or water treatment plants; 3 are major facilities. The two industrial discharges, Peabody Coal Company and Energy Fuels, are both on the Navajo Nation lands and are "major" facilities with numerous outfalls. There are 37 non-tribal facilities in the basin: 8 industrial (1 major); one national fish hatchery and 28 municipal systems, of which 5 are majors. Many of the facilities discharge to ephemeral drainages many miles from the river.

The Northern Arizona Council of Governments (NACOG) is the designated planning agency for the Colorado River and its tributaries in the northeast and north-central portions of the state. Along the lower main stem of the river, Mohave, La Paz, and Yuma counties, have each been delegated the planning responsibilities for their areas. NACOG and the three counties along the main stem of the river are experiencing tremendous residential growth and have also been targeted for development. With the delegation,

each county must prepare and maintain a water quality management plan that addresses both point and non-point sources of pollution. The plans encourage local control and the voluntary use of Best Management Practices to reduce non-point source pollution. As the plans are updated, the State is encouraging inclusion of salinity control issues and the importance of working cooperatively with the Salinity Control Forum in implementing its policies.

To support both the Forum goals for a basin wide approach to salinity control and to ensure compliance with the numeric criteria set for the river through the NPDES Program, in the 2002 Review of its surface water quality standards, Arizona has adopted the Forum's plan of implementation contained in the "1999 Review of Water Quality Standards." Another key change in Arizona's water quality standards is the proposed repeal of the turbidity standard in favor of Suspended Sediment Concentration (SSC) standard coupled with a narrative bottom deposit standard. The State's research has shown that the existing turbidity standard is not a good predictor of impacts to aquatic life in southwest arid environments and has proposed to replace that standard with a numeric standard for SSC and the narrative standard which includes implementation procedures.

Over half of the waters on the State's 1998 303(d) list are listed for turbidity and coliform bacteria. Nearly all of the watersheds on non-tribal lands within the Colorado River Basin have been assessed as Category 1 watersheds under the Clean Water Action Plan, Unified Watershed Assessment (UWA). The goal of the State's Non-point Source Management Program, developed pursuant to Section 319 of the Clean Water Act, is to develop and implement a program which will reduce human-induced pollutants from non-point sources from entering surface and groundwater. Arizona's program has been in place for over a decade and steady progress is being made in identifying, controlling and abating Non-point Source (NPS) pollution from various activities. In support of the program, the State has entered into cooperative agreements with other state and federal land and resource management agencies to carry out portion of the NPS plan on their lands. The State will update its NPS Management Plan in FY 03.

Section 319 also provides federal grants for demonstration projects which are reviewed by ADEQ for consistency with the NPS Plan. The State has recently revamped the Water Quality Improvement Grant Program to facilitate the funding of section 319 eligible projects to improve water quality including projects such as well-plugging, salinity control impoundments, and rangeland management.

Arizona continues to support a basin wide approach to salinity control through its participation in the Colorado River Salinity Control Forum and the Advisory Council. In addition to the Water Quality Improvement Grant Program, the State has recently amended the State Revolving Fund rules to allow use of funds for NPS projects consistent with the State's NPS Plan, including salinity control projects.

ADEQ has taken a lead role in the Colorado River Source Water Assessment Project which involves the seven Basin states developing and implementing an interstate source

water plan to protect and sustain safe drinking water quality for the border states along the River. The primary goal of the project is to provide a common approach to delineate the watershed along the Colorado River and define the process for determining those land use activities that may impact the river. A secondary goal is to provide a forum for these states to meet, discuss issues and exchange information related to source water assessment and protection.

REFERENCES:

1. "Salinity Management Study, Final Report, Technical Appendix 1: History of the Colorado River Salinity Control Program", Metropolitan Water District of Southern California and United States Department of the Interior, Bureau of Reclamation, prepared by Bookman-Edmonston Engineers Inc., June 1999.

2. 2002 Review, Water Quality Standards for Salinity Colorado River System (Proposed), Colorado River Basin Salinity Control Forum, June 2002.

3. Arizona Department of Water Resources Salt River Watershed: www.water.az.gov/AZWaterInfo/OutsideAMAs/CentralHighlands/Watershed/saltriver. Outside Active Management; Central Highlands, Surface Watersheds: Salt River Watershed, Water Quality, September, 2002.

4. Arizona Department of Water Resources Web-Site Verde River Watershed -- www.water.az.gov/AZWaterInfo/OutsideAMAs/CentralHighlands/Watershed/verderiver. Outside Active Management; Central Highlands, Surface Watersheds: Verde River Watershed, Water Quality, September, 2002.

5. Arizona Department of Environment Quality: Draft Status of Water Quality in Arizona 2002; www.adeq.state.az.us/environ/water/assess/hsa.html#draft.

CENTRAL ARIZONA SALINITY STUDY --- PHASE I

Technical Appendix C

HYDROLOGIC REPORT ON THE PHOENIX AMA

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1.0 INTRODUCTION

The Central Arizona Salinity Study (CASS) is a coalition of water and wastewater agencies evaluating salinity issues in Central Arizona. The mission of CASS is to provide its members with workable alternatives for a quality, cost effective, sustainable, and reliable water supply through partnerships and cooperative efforts in regional salinity planning and management. CASS was formed in November 2001. CASS is a study group and not a legal entity.

Salinity from local and imported sources is increasing the salinity of groundwater in localized areas and the salinity of reclaimed water in Central Arizona. The magnitude of the salinity issue is unclear and water providers in Central Arizona decided to work together to assess the problem and, if necessary, develop regional strategies for managing it. Central Arizona water providers must work together to protect, preserve, and develop these shared resources and to respond to issues of: increasing water quality and water supply regulation; increasing reclaimed water utilization; increasing levels of salinity into water reclamation facilities; developing brine disposal strategies; deteriorating groundwater quality in localized areas; and managing costs.

If no workable solution is implemented, salinity increases may result in greater water and wastewater treatment costs, decreased agricultural production, and some water sources may become unsuitable for their intended uses.

- Increasing salinity levels may reduce the ability of water providers to use groundwater and reclaimed water to meet customer water demands. Some communities may not have enough supply to meet demand. Growth and development in these communities may become limited.

- Water reclamation plants may have water quality permit compliance problems. High salinity levels in reclaimed water supplies may make this resource unsuitable for some of its intended uses. Retrofitting water reclamation plants to manage salinity and dispose of brine may significantly increase wastewater treatment costs.

- Water customer complaints may increase due to increasing salinity of the drinking water supply. Retrofitting potable water treatment plants to manage salinity and dispose of brine may significantly increase water treatment costs.

The following white paper describes hydrologic conditions in the Phoenix Active Management Area (AMA). This report is based on literature review of publicly available information. Much of the data utilized for the salt balance was obtained from a draft CASS report titled *Salt Balance Phoenix Metro Area Typical Year (2002)*. Site-specific fieldwork was not conducted as part of this study. The purpose of the report is to provide a general framework of the physical, geologic, and hydrologic aspects of the Phoenix AMA with a primary focus on salinity.

2.0 PHYSICAL SETTING

The Phoenix AMA is located in central Arizona within the Sonoran Desert section of the Basin and Range physiographic province (Figure 1). There are seven defined sub-basins that comprise the Phoenix AMA: Hassayampa; West Salt River Valley (WSRV); East Salt River Valley (ESRV); Lake Pleasant; Carefree; Rainbow Valley; and Fountain Hills (Figure 2). The ESRV and WSRV sub-basins are collectively referred to as the Salt River Valley (SRV) and represent the primary areas of development within the Phoenix AMA. Due to a lack of available data for the Hassayampa and Rainbow Valley sub-basins, the ESRV, WSRV, Lake Pleasant, Carefree, and Fountain Hill sub-basins are referred to as the principal sub-basins in this report.

The Phoenix AMA comprises approximately 5,600 square miles. Land surface elevation ranges from 800 feet to 6,000 feet above mean sea level (amsl) and precipitation averages between approximately 7 and 8 inches per year (ADWR, 2000). The average daily mean temperature in the Phoenix Metro area is 73.3 degrees Fahrenheit (Western Regional Climate Center, 2003).

The principal surface drainage features in the Phoenix AMA include the Gila, Salt, Verde, Agua Fria, and Hassayampa Rivers and the Central Arizona Project (CAP) aqueduct. The Gila River represents the major natural drainage for surface water flowing out of the AMA. The Gila River enters the southern portion of the ESRV sub-basin between the Santan and Sacaton Mountains; flows northwest entering the WSRV sub-basin and continues west near the Sierra Estrella Mountains and Buckeye Hills. The Gila River exits the AMA at Gillespie Dam. The Salt River enters the ESRV sub-basin from the east and joins the Gila River in the southern portion of the WSRV sub-basin. The Verde River flows south through the Fountain Hills sub-basin and joins the Salt River between Stewart Mountain Dam and Granite Reef Dam. The Agua Fria River enters the AMA from the north, flows into Lake Pleasant, and joins the Gila River in the southern portion of the WSRV sub-basin. The Hassayampa River enters the Hassayampa sub-basin from the north and joins the Gila River upstream from Gillespie Dam. The CAP aqueduct flows through the northern and eastern portion of the Phoenix AMA and utilizes Lake Pleasant for storage.

3.0 GENERALIZED GEOLOGY

Basins within central Arizona are thought to have formed during the Tertiary Basin and Range Disturbance. During this disturbance, widespread extensional deformation in southern and western Arizona resulted in northwest trending mountain ranges separated by alluvium-filled troughs.

3.1 BEDROCK GEOLOGY

The principal sub-basins within the Phoenix AMA are generally bounded by the Vulture, Hieroglyphic and New River Mountains to the north; Mazatzal, Usery, Superstition, and Dripping Springs Mountains to the east; Santan, Sacaton, South, Sierra Estrella, Maricopa, and Gila Bend Mountains to the south; and Saddle and Belmont Mountains to the west (Figure 2). The mountain ranges bounding the principal sub-basins of the Phoenix AMA are predominantly comprised of Tertiary volcanic, granitoid, and metamorphic rocks and Precambrian granitoid and metamorphic rocks (Reynolds, 1988).

3.2 BASIN GEOLOGY

The sub-basins within the Phoenix AMA are primarily comprised of northwest trending structural troughs separated by low-lying mountains. The deepest basins are within the SRV sub-basins. Based on gravity modeling, the maximum depth to bedrock in the southern portion of the ESRV sub-basin and in the WSRV sub-basin is estimated at approximately 11,200 to 12,800 feet. The maximum depth to bedrock in the northern portion of the ESRV sub-basin is estimated at approximately 8,000 to 9,600 feet, and the Fountain Hills sub-basin between 4,800 and 6,400 feet (Oppenheimer and Sumner, 1980).

Three different agencies, the United States Bureau of Reclamation (USBR), the United States Geological Survey (USGS), and the Arizona Department of Water Resources (ADWR) have defined the alluvial deposits in the principal sub-basins. The USBR (1976) conducted an investigation for construction of the CAP canal and defined three units based on the dominant lithology. These units are designated as the Upper Alluvial Unit, the Middle Fine-Grained Unit, and the Lower Conglomerate Unit. The USGS also recognized three units in reports on the ESRV (Laney and Hahn, 1986) and the WSRV (Brown and Pool, 1989). These units include the Upper Unit, the Middle Unit, and the Lower Unit, which was further subdivided into an upper and lower part. The ADWR recognized and described three hydrogeologic units for the SRV; the Upper Alluvial Unit (UAU), the Middle Alluvial Unit (MAU), and the Lower Alluvial Unit (LAU) (Corkhill and others, 1993). The nomenclature and correlations for the basin-fill alluvial units described by each agency are presented in Table 3.1 below.

TABLE 3.1 CORRELATION BETWEEN THE ADWR HYDROGEOLOGICAL UNITS AND THE USGS AND USBR GEOLOGIC UNITS

ADWR (1993)	U.S. Geological Survey (1986 and 1989)	U.S. Bureau of Reclamation (1976)
Upper Alluvial Unit	Upper Unit	Upper Alluvial Unit
	Middle Unit	
Middle Alluvial Unit	Upper Part of the Lower Unit	Middle Fine-Grained Unit
Lower Alluvial Unit	Lower Part of the Lower Unit	Lower Conglomerate Unit

The UAU defined by ADWR is equivalent to the Upper and Middle Unit of the USGS, and the Upper Alluvial Unit of the USBR. The MAU defined by ADWR is equivalent to the upper part of the Lower Unit of the USGS and the Middle Fine-Grained Unit of the USBR. The LAU defined by ADWR is equivalent to the lower part of the Lower Unit of the USGS and the Lower Conglomerate Unit of the USBR.

The stratigraphic divisions defined by the ADWR are based on differences in the hydrologic and geologic characteristic of each unit while the divisions defined by the USGS and the USBR are based primarily on geologic variations of the lithology. The stratigraphic nomenclature defined by ADWR (Corkhill and others, 1993) is used for this report. A brief summary of each unit is presented below:

- ***Upper Alluvial Unit (UAU).*** The UAU was deposited in an open, integrated stream system and consists of channel, terrace, floodplain, and alluvial fan deposits. Principal material sources included the Salt and Gila River drainages. During the time the UAU was deposited, the Ancestral Salt River channel had migrated throughout the southern portions of the ESRV. Fine-grained deposits overlying coarse channel deposits were likely deposited by ephemeral streams and sheet flow associated with the migration of the Ancestral Salt River (Laney and Hahn, 1986). The UAU generally consists of silt and sand, except near principal drainages and the margins of the basins where the deposits are predominately sand and gravel.

- ***Middle Alluvial Unit (MAU).*** MAU sediments were deposited in a closed, subsiding basin. Coarse-grained alluvial fans (generally consisting of sand and gravel) were developed near the margins of the basins. In the central portions of the basins, these fans graded into fluvial, playa, and evaporite deposits that are generally fine-grained. These deposits generally consist of silt and clay with some mudstones, however interbedded sand and gravel deposits are present.

- ***Lower Alluvial Unit (LAU).*** LAU sediments were derived from erosion of the mountains surrounding the sub-basins and were deposited in a closed, subsiding basin. The unit is coarse-grained near the margins of the basins (generally consisting of conglomerate and gravel) and fine-grained near the center, generally consisting of mudstones and anhydrite.

The Luke Salt Dome is a massive evaporite deposit located in the WSRV sub-basin. It is estimated to be more than 3,500 feet thick, however the total thickness of the body is unknown (Pay Dirt, 1984). The salt dome lies within the LAU and is considered a hydrogeologic barrier in the ADWR SRV model (Corkhill and others, 1993). The aerial extent of the Luke Salt Dome is presented on Figure 2. During the late Miocene, between ten and fifteen million years ago, the salt body was formed in a local structural basin as an evaporite deposit (Shafiquallah and others, 1980 and Peirce, 1976). The age of the salt dome is based on an overlying volcanic flow that was dated at 10 million years old (Shafiquallah and others, 1980).

4.0 HYDROGEOLOGIC CONDITIONS

4.1 GROUNDWATER OCCURRENCE

The present day groundwater system in the Phoenix AMA is dominated by regional pumping centers, and recharge supplied mainly by infiltration of excess irrigation water, canal leakage, and occasional flood events. The system is dynamic in that it responds to pumping stresses and recharge by adjusting the volume of groundwater in storage (Corkhill and others, 1993). Before the beginning of large-scale irrigation, infiltration from stream flow was the primary source of recharge. However, development of the surface water system greatly minimized the occurrence of surface flows within the AMA (USBR, 1976).

The estimated pre-development volume of water stored in the Phoenix AMA (to a depth of 1,200 feet) was approximately 136 million acre-feet (Freethey and Anderson, 1986). Between 1900 and 1982, approximately 81 million acre-feet of water had been withdrawn from the Phoenix AMA (Reeter and Remick, 1986). During that period, ADWR (1992b) estimated approximately 23 million acre-feet of groundwater was removed from storage. As a result, water levels declined between 2 and 8 feet per year (Laney and others, 1978), and as much as 400 feet of groundwater level decline occurred in some areas (ADWR, 2000). Near the Santan and Usery Mountains in the ESRV sub-basin, and between the Agua Fria River and the White Tank Mountains in the WSRV sub-basin, earth fissures formed near the basin margins due to land subsidence (Schumann, 1974; and Laney and others, 1978). However, between 1983 and 1992, with utilization of the CAP and fewer acres irrigated for agricultural purposes, water levels began to stabilize and are rising in some portions of the SRV (ADWR, 2000).

Groundwater in the Phoenix AMA occurs within the UAU, MAU, and LAU. In the past, the UAU represented the major water-bearing unit in the AMA (Reeter and Remick, 1986). However, the UAU has been significantly dewatered in many areas (Corkhill and others, 1993). Due to this groundwater withdrawal, vertical hydraulic gradients have developed in many locations. In the ESRV sub-basin, vertical head differences exceeding 100 feet have been measured between the UAU and the LAU where significant dewatering of the UAU has occurred and groundwater is pumped from the finer-grained sediments of the MAU and LAU (Corkhill and others, 1993).

4.2 GROUNDWATER MOVEMENT

Based on predevelopment hydrologic conditions, groundwater in the Phoenix AMA generally flowed west in the southern portion of the ESRV sub-basin, southwest to south in the WSRV sub-basin, south in the northern portion of the ESRV sub-basin, and south in the Hassayampa, Lake Pleasant, Carefree, and Fountain Hills sub-basins (Freethey and Anderson, 1986). This groundwater flow regime roughly followed the flow directions of the surface drainages and was in dynamic equilibrium with total inflows equal to total outflows (Freethey and Anderson, 1986). Water levels in 1982 demonstrate post-development conditions in the Phoenix AMA (Reeter and Remick, 1986). Groundwater in the southern portion of the ESRV sub-basin generally flowed to

the west similar to predevelopment conditions; however pumping centers flattened the regional gradient, created several cones of depression that altered local flow directions and created a groundwater divide in the western portion of the ESRV sub-basin (Laney and Hahn, 1986). In the northern portion of the ESRV sub-basin, groundwater flowed south, however a cone of depression east of the Phoenix Mountains significantly increased the gradient from predevelopment conditions. By 1983, a groundwater divide was identified between the ESRV and WSRV sub-basins (Corell and others, 1994). In the WSRV sub-basin, 1982 water levels show groundwater flowing toward cones of depressions; a small cone was located northwest of the Phoenix Mountains and a major cone of depression was located between the Agua Fria River and the White Tank Mountains (Brown and Pool, 1989).

Prior to development, basin-to-basin groundwater inflows and outflows were essentially equal (Freethey and Anderson, 1986). However, major groundwater development altered these conditions in the Phoenix AMA. For the purpose of this study, 37,000 acre-feet per year of groundwater flows into the Phoenix AMA, compared to 28,000 acre-feet per year of groundwater flowing out of the AMA (Poulson, 2003).

4.3 GROUNDWATER QUALITY

Water quality in the SRV is generally acceptable for agricultural purposes (Reeter and Remick, 1986). However, total dissolved solids (TDS) can be an issue for municipal use and some industrial purposes. In addition, in some areas of the Phoenix AMA, nitrate, fluoride, chromium, and arsenic concentrations in groundwater exceed drinking water standards. Also of concern are several organic chemicals derived from industrial sources including tetrachloroethylene (PCE), trichloroethylene (TCE), and perchlorate.

TDS concentrations are a general measure of water quality, and specific conductivity measurements can be related to TDS concentrations. TDS concentrations in milligrams per liter (mg/l) can be estimated by multiplying the specific conductivity measured in microsiemens per centimeter (μS/cm) by 0.60 (Reeter and Remick, 1986).

TDS concentrations in groundwater vary greatly in the SRV. In general, water quality is best near mountain-front recharge sources and poorest near the Salt and Gila Rivers. Specific conductivity values generally range between 300 and 600 μS/cm (approximately 180 to 360 mg/l TDS) in the northern portion of the ESRV sub-basin (between Union Hills, Phoenix, and McDowell Mountains), and in the northern portion of the WSRV sub-basin (between the White Tank Mountains, Hieroglyphic Mountains, and Union Hills) (Reeter and Remick, 1986). Specific conductivity values generally range between 700 and 2,000 μS/cm (approximately 420 to 1,200 mg/l TDS) in the eastern portion of the ESRV sub-basin, and between 1,500 and 5,000 μS/cm (approximately 900 to 3,000 mg/l TDS) in the western portion of the ESRV sub-basin.

Water quality generally degrades near the Salt and Gila Rivers. Specific conductivity values near the Salt River are generally between 1,500 and 2,500 μS/cm (approximately 900 to 1,500 mg/l TDS). Near the Gila River, specific conductivity values range between 2,500 and 7,000 μS/cm (approximately 1,500 to 4,200 mg/l TDS) (Reeter and Remick, 1986).

The quality of groundwater inflow and outflow for the Phoenix AMA has been evaluated and is based on ADWR reported flows (Corell and others, 1994) and available groundwater quality data in the area of the identified flow. For the purpose of this study, an average TDS concentration of 680 mg/l is used for all groundwater inflow; and an average TDS concentration of 1,100 mg/l is used for groundwater flowing out of the Phoenix AMA (CASS, 2002).

4.4 ADDITIONAL SALT SOURCES AND WASTEWATER TREATMENT PLANTS

Salt accumulates in the Phoenix AMA from sources other than surface water and groundwater. These sources include agricultural and turf practices, residential contributions, and industrial and commercial processes. In the year 2000, approximately 990,000 acre-feet of surface and groundwater were utilized for agriculture in the Phoenix Metro area. As a result, approximately 17,800 tons of salt was accumulated due to agricultural practices and 4,700 tons of salt was accumulated due to turf practices (Poulson, 2003).

Treatment plants process wastewater, but do not reduce the additional salt contributed by residential, industrial, and commercial users. These users add an estimated 300 mg/l of TDS to their discharge as a result of use of the water (CASS, 2002). Approximately 290,000 acre-feet of wastewater is treated annually in the Phoenix Metro area, resulting in an estimated 118,320 tons of additional salt loading to the effluent. This effluent (average TDS concentration of 890 mg/l) is utilized for agricultural, municipal, and industrial uses. In addition, a portion of this effluent is recharged and a portion is discharged to the Gila River (CASS, 2002).

5.0 SURFACE WATER CONDITIONS

5.1 SURFACE WATER OCCURRENCE

Surface water features in the Phoenix AMA include the Gila, Salt, Verde, Agua Fria, and Hassayampa Rivers, and the CAP aqueduct. The Gila River is the principal natural surface water drainage within the Phoenix AMA, and all rivers in the AMA eventually flow into the Gila River. The Salt and Verde Rivers are extensively dammed east of the Phoenix AMA and provide surface water to AMA users. The Agua Fria is dammed north of the Phoenix AMA forming Lake Pleasant. The CAP utilizes Lake Pleasant for storage and CAP/Agua Fria River water is distributed to users in the AMA. The Hassayampa River has not been developed and is ephemeral in the AMA.

The Gila River is generally dry in the eastern portion of the Phoenix AMA due to the Coolidge Dam (located in southern Gila County) and the Ashurst-Hayden Dam (a diversion dam east of Florence, Arizona) (Pinal County, 2003). The Gila River is perennial in the western portion of the AMA due to discharge from the City of Phoenix 91st Avenue wastewater treatment plant and from irrigation return flow and groundwater pumped for drainage by the Buckeye Irrigation District (ADWR, 2003). The Ashurst-Hayden Dam provides irrigation water for the San Carlos Irrigation Project, which delivers a portion of surface water to the Phoenix AMA.

The headwaters of the Salt River are in the White Mountains near an elevation of 11,400 feet above mean sea level. The Salt River generally flows toward the southwest and includes a series of four dams capable of storing over 2 million acre-feet of water (ADWR, 2003). The Salt River Project manages surface water and generates power from the Salt and Verde Rivers. This water is diverted to users from Granite Reef Dam.

The Verde River emanates from Sullivan Lake north of Prescott, Arizona, and flows to the Salt River. The Verde River is perennial and is regulated by two dams (Horseshoe and Bartlett) that are capable of storing approximately 310,000 acre-feet of water (ADWR, 2003).

The Agua Fria River has a median flow of approximately 39,000 acre-feet per year (ADWR, 2003b). However, the river is ephemeral in the Phoenix AMA due to the New Waddell Dam located at Lake Pleasant. The primary purpose of the New Waddell Dam is to store Colorado River water for CAP use, to store flow from the Agua Fria River, and provide flood protection (Bureau of Reclamation, 2003). Lake Pleasant has a storage capacity of approximately 820,000 acre-feet of water that is used for power generation and water delivery to customers in summer months (ADWR, 2003b).

The CAP aqueduct flows from Parker Dam at Lake Havasu on the Colorado River, through the Hassayampa sub-basin and northern portion of the WSRV sub-basin, then southeast through the ESRV sub-basin to Tucson. The CAP began providing water to the Phoenix AMA in 1986 and utilizes Lake Pleasant for storage. In 2000, approximately 800,000 acre-feet of water from the CAP (including CAP storage from Lake Pleasant) were utilized in the principal sub-basins of the Phoenix AMA (CASS, 2002).

The Hassayampa River originates in the Bradshaw Mountains and generally flows south where it joins the Gila River. Just north of the Phoenix AMA, where the river enters the Hassayampa Plain, the Hassayampa River crosses a major fault. Between 1983 and 1988, an average of approximately 11,000 acre-feet per year of surface water from the Hassayampa River flows into this fault and enters the Hassayampa sub-basin as groundwater inflow (Corell and others, 1994).

5.2 SURFACE WATER UTILIZATION AND GENERAL WATER QUALITY

Based on a study by Thomas and Poulson (2002), in a typical current year, a total of approximately 1.7 million acre-feet of surface water is utilized in the Phoenix AMA. It is estimated that 90,000 acre-feet of Gila River water is utilized annually in the Phoenix AMA, however 100,000 acre-feet of Gila River water flows out of the Phoenix AMA at Gillespie Dam. An estimated 810,000 acre-feet of Salt and Verde River water is utilized annually in the Phoenix Metro area. An estimated 50,000 acre-feet of Agua Fria River water augments the 752,000 acre-feet of CAP water that is utilized annually in the Phoenix AMA. These results are summarized in Table 5.1, and assumptions are listed below the table.

The general quality of surface water utilized in the Phoenix AMA during a typical modern year was evaluated by CASS (2002). Table 5.1 summarizes average flow and general quality of surface water entering the AMA. Assumptions utilized to determine average values are listed below the table.

TABLE 5.1 SURFACE WATER UTILIZATION AND GENERAL WATER QUALITY

DESCRIPTION	TYPICAL CURRENT YEAR
Average annual Gila River utilization (acre-feet)	90,000
Average TDS concentrations in the Gila River water (mg/l)	550
Average annual Gila River outflow (acre-feet)	100,000
Average TDS concentrations in the Gila River outflow (mg/l)	2,370
Average annual Salt and Verde River utilization (acre-feet)	810,000
Average TDS concentrations in the Salt and Verde River water (mg/l)	480
Average annual Agua Fria deliveries (acre-feet)	50,000
Average TDS concentrations of the Agua Fria River water (mg/l)	400
Average annual CAP deliveries (acre-feet)	752,000
Average TDS concentrations of the CAP water (mg/l)	650

- Gila River utilization and TDS concentrations based on average of available data for water diverted at Ashurst-Hayden Dam.

- Gila River outflow and TDS concentrations based on average of available data at Gillespie Dam.

- Salt and Verde River utilization based on 10-year median flow from Stewart Mountain Dam and Bartlett Dam. TDS concentrations are the weighted average based on flow and TDS data.

- Agua Fria deliveries based on year 2000 flow at New Waddell Dam. TDS concentrations based on 12-year average.

- CAP water deliveries based on year 2000 reported deliveries to Phoenix Metro CAP users, CAP recharge projects, the Gila River Indian Community, and Agua Fria River water users.

6.0 GENERALIZED SALT BALANCE

A flow-chart for the salt balance in the Phoenix Metro Area was developed by CASS (2002). This flow-chart and assumptions (Figure 3) is a major source of data for Sections 4.0 and 5.0. The assumptions for each item on the flow chart are referenced with circled numbers that correspond to the assumptions on the following pages. Table 6.1 summarizes the salt balance flow-chart and is presented below:

TABLE 6.1 GENERALIZED SALT BALANCE FOR THE PRINCIPAL SUB-BASINS IN THE PHOENIX AMA

SOURCE	SALT ACCUMULATION (Millions of tons per year)
Gila River Utilization	0.0673
Salt and Verde River Utilization	0.5288
Agua Fria River Utilization	0.0272
CAP Utilization	0.6648
Groundwater Inflow	0.0342
Additional Salt Sources	0.1408
Total Amount of Salt Entering the Phoenix AMA	**1.4631**
Gila River Outflow	0.3223
Groundwater Outflow	0.0419
Total Amount of Salt Leaving the Phoenix AMA	**0.3642**
Net Salt Accumulation in the Phoenix AMA	**1.0989**

Based on this general salt balance, approximately 1.5 million tons of salt enters the Phoenix AMA annually, and approximately 0.4 million tons of salt leaves the Phoenix AMA. In a typical current year, it is estimated that approximately 1.1 million tons of salt is accumulated in the Phoenix AMA.

The majority of the salt entering the Phoenix AMA is associated with CAP utilization (approximately 45 percent) and utilization of Salt and Verde River water (approximately 36 percent). Approximately 10 percent of the salt entering the AMA is associated with agricultural practices and from residential, industrial, and commercial users (additional salt sources). Utilization of water from the Gila and Agua Fria Rivers and groundwater inflow accounts for approximately 9 percent of the salt entering the AMA.

The primary source of salt outflow from the Phoenix AMA is the Gila River at Gillespie Dam (88 percent), and groundwater outflow accounts for the remaining 12 percent. It should be noted that approximately 25 percent of the salt entering the AMA leaves the AMA via Gila River surface flow and groundwater outflow.

7.0 REFERENCES

Arizona Department of Water Resources (ADWR), 2003: Phoenix Active Management Area. http://www.water.az.gov/adwr/Content/WaterInfo/InsideAMAs/amaphoenix.html.

ADWR, 2003b: Agua Fria Watershed. http://www.water.az.gov/AZWaterInfo/OutsideAMAs/CentralHighlands/Watersheds/aguafriariver.html

ADWR, 2000: Phoenix Active Management Area Virtual Tour. http://www.water.az.gov/adwr/Content/Publications/files/Phoenix_AMA_Tour.ppt.

Brown, J.G. and Pool, D.R., 1989. *Hydrogeology of the Western Part of the Salt River Valley Area, Maricopa County, Arizona.* U.S. Geological Survey Water-Resource Investigations Report 88-4202.

Bureau of Reclamation Phoenix Area Office, 2003: New Waddell Dam. http://www.apo.lc.usbr.gov/user/publicrl/wdfact.html

Central Arizona Salinity Study (CASS), 2002. *Salt Balance Phoenix Metro Area Typical Year, Draft*. U.S. Department of Interior Bureau of Reclamation Central Arizona Salinity Study.

Corkhill and others, E.F., Corell, S.W., Hill, B.M., and Carr, D.A., 1993. *A Regional Groundwater Flow Model of the Salt River Valley – Phase I, Phoenix Active Management Area, Hydrogeologic Framework and Basic Data Report.* Arizona Department of Water Resources, Modeling Report No. 6.

Corell, S.W., and Corkhill and others, E.F., 1994. *A Regional Groundwater Flow Model of the Salt River Valley – Phase II, Phoenix Active Management Area, Numerical Model, Caliabration, and Recommendations*. ADWR, Modeling Report No. 8.

Freethey, Geoffrey W. and Anderson, T.W., 1986. United States Department of the Interior, U.S. Geological Survey: *Predevelopment Hydrologic Conditions in the Alluvial Basins of Arizona and Adjacent Parts of California and New Mexico.*

Laney, R.L., Ross, P.P., and Littin, G.R., 1978. Maps Showing Ground-water Conditions in the Eastern Part of the Salt River Valley Area, Maricopa and Pinal Counties, Arizona—1976. U.S. Geological Survey Water-Resource Investigations 78-61.

Laney, R.L., Raymond, R.H., and Winikka, C.C., 1978, Maps showing water-level declines, land subsidence, and earthen fissures in south-central Arizona: U.S. Geological Survey Water-Resources Investigations 78-83.

Laney, R. L., and Hahn M.E., 1986. *Hydrogeology of the Eastern Part of the Salt River Valley Area, Maricopa and Pinal Counties, Arizona.* U.S. Geological Survey Water-Resource Investigations Report 86-4147.

Oppenheimer, J.M., and Sumner, J.S., 1980. *Depth-to-Bedrock Map, Basin and Range Province, Arizona*.

Pay Dirt, 1984. *Southwest Salt Pioneered New Arizona Resource:* Arizona Pay Dirt, April 1984.

Peirce, H. W., 1976. *Tectonic Significance of Basin and Range Thick Evaporite Deposits*, in Wilt J.C., and Jenny, J.P. eds., Tectonic digest: Tucson, Arizona Geological Society Digest, v. 10, p. 325-339.

Pinal County, 2003. http://www.pinalcounty.org/PlanDev/PDCP/files/CWWaterElement.pdf.

Poulson, T., 2003. *Future Trends Analysis (Draft Phase I Document)*. U.S. Department of Interior, Bureau of Reclamation, Central Arizona Salinity Study.

Reynolds, Stephen J., 1988. Geologic Map of Arizona. Arizona Geological Survey Map 26. Produced in cooperation with the U.S. Geological Survey.

Reeter, R.W. and Remick, W.H., 1986, Maps showing groundwater conditions in the West Salt River, East Salt River, Lake Pleasant, Carefree and Fountain Hills Sub-basins of the Phoenix Active Management Area, Maricopa, Pinal, and Yavapai Counties, Arizona—1983. Arizona Department of Water Resources Hydrologic Map Series Report No. 12

Schumann, Herbert H, 1974. *Land Subsidence and Earth Fissures in Alluvial Deposits in the Phoenix Area, Arizona*. U.S. Geological Survey, Miscellaneous Investigations

Shafiqullah, M., Damon, P.E., Lynch, D.J., Reynolds, SlJl, Rehrig, W. A., and Raymond, R. H., 1980. *K-Ar Geochronology and Geologic History of Southwestern Arizona and Adjacent Areas*, in Jenney, J.P., and Stone, Claudia, eds., Studies in Western Arizona: Tucson, Arizona Geological Society Digest, V. 12, p. 201-260.

U.S. Bureau of Reclamation, 1976. *Central Arizona Project, Geology and Groundwater Resources Report, Maricopa and Pinal Counties, Arizona*.

Western Regional Climate Center, 2003. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?azphoc.

CENTRAL ARIZONA SALINITY STUDY --- PHASE I

Technical Appendix D

HYDROLOGIC REPORT ON THE GILA BEND BASIN

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1.0 INTRODUCTION

The Central Arizona Salinity Study (CASS) is a coalition of water and wastewater agencies evaluating salinity issues in Central Arizona. The mission of CASS is to provide its members with workable alternatives for a quality, cost effective, sustainable, and reliable water supply through partnerships and cooperative efforts in regional salinity planning and management. CASS was formed in November 2001. CASS is a study group and not a legal entity.

Salinity from local and imported sources is increasing the salinity of groundwater in localized areas and the salinity of reclaimed water in Central Arizona. The magnitude of the salinity issue is unclear and water providers in Central Arizona decided to work together to assess the problem and, if necessary, develop regional strategies for managing it. Central Arizona water providers must work together to protect, preserve, and develop these shared resources and to respond to issues of: increasing water quality and water supply regulation; increasing reclaimed water utilization; increasing levels of salinity into water reclamation facilities; developing brine disposal strategies; deteriorating groundwater quality in localized areas; and managing costs.

If no workable solution is implemented, salinity increases may result in greater water and wastewater treatment costs, decreased agricultural production, and some water sources may become unsuitable for their intended uses.

- Increasing salinity levels may reduce the ability of water providers to use groundwater and reclaimed water to meet customer water demands. Some communities may not have enough supply to meet demand. Growth and development in these communities may become limited.

- Water reclamation plants may have water quality permit compliance problems. High salinity levels in reclaimed water supplies may make this resource unsuitable for some of its intended uses. Retrofitting water reclamation plants to manage salinity and dispose of brine may significantly increase wastewater treatment costs.

- Water customer complaints may increase due to increasing salinity of the drinking water supply. Retrofitting potable water treatment plants to manage salinity and dispose of brine may significantly increase water treatment costs.

The following white paper describes hydrologic conditions in the Gila Bend Basin. This report is based on literature review of publicly available information, and site-specific fieldwork was not conducted as part of this study. The purpose of the report is to provide a general framework of the physical, geologic, and hydrologic aspects of the basin. The report will also discuss groundwater quality and surface water quality over time, with a primary focus on salinity.

2.0 PHYSICAL SETTING

The Gila Bend Basin is located in southwestern Arizona within the Sonoran Desert section of the Basin and Range physiographic province (Figure 1). The basin is adjacent to the Phoenix Active Management Area (AMA) to the north, Pinal AMA to the east, San Simon Wash Basin to the south, and Lower Gila Basin to the west. The Gila Bend Basin comprises approximately 1,300 square miles, and land surface elevation ranges from 524 feet to 4,084 feet above mean sea level (amsl). Precipitation in the basin averages approximately 6 inches per year, and the average daily mean temperature is 72.4 degrees Fahrenheit (°F). The principal surface drainage feature is the Gila River, which enters the basin at Gillespie Dam to the north, and exits the basin at Painted Rock Dam to the west (Figure 2).

3.0 GENERALIZED GEOLOGY

The Gila Bend Basin is thought to have formed during the Tertiary Basin and Range Disturbance. During this disturbance, widespread extensional deformation in southern and western Arizona resulted in northwest trending mountain ranges separated by alluvial filled troughs. Subsequent to the faulting and alluvial deposition, volcanic eruptions produced lava flows that likely diverted and dammed the Gila River, altering its course over time.

3.1 BEDROCK GEOLOGY

The Gila Bend Basin is bounded by the Gila Bend Mountains and Buckeye Hills on the north, the Maricopa Mountains on the east, the Sand Tank and Sauceda Mountains on the south, and the Painted Rock Mountains and White Hills on the west (Figure 2). The bounding mountain ranges are predominantly comprised of Precambrian granite and metamorphic rocks, Tertiary to Late Cretaceous granite, Tertiary volcanics and basalt, Tertiary sedimentary rocks, and Quaternary to Tertiary basalt (Reynolds, 1988). In general, the Precambrian granite and metamorphic rocks primarily occur in the northeastern portion of the basin, and the volcanics and basalt dominate the bedrock geology elsewhere in the basin.

3.2 BASIN GEOLOGY

The Gila Bend Basin is comprised of two northwest trending structural troughs that are separated by the Gila Bend and Sand Tank Mountains. Based on gravity modeling (Oppenheimer and Sumner, 1980), the depth to bedrock in the majority of the basin is 800 to 1,600 feet below land surface (bls). However, the gravity modeling also suggests a deeper portion of the basin southwest of Gila Bend with a depth to bedrock of 1,600 to 3,200 feet bls, and a low point in the basin near Gila Bend, with a depth to bedrock of 4,800 to 6,400 feet bls. Sebenik (1981) reported that the thickest alluvial deposits occur in the central portion of the basin (near Gila Bend), and are greater than 2,000 feet thick. Rascona (1996) reported that the alluvial deposits in the trough northeast of Gila Bend are generally not greater than 1,000 feet in thickness, and that the alluvial deposits in the trough southwest of Gila Bend are up to 1,480 feet thick. Although differences in depth to bedrock values are noted in each study, the deepest portion of the basin appears to be near Gila Bend, and the trough southwest of Gila Bend appears to be deeper than the trough northeast of Gila Bend.

Based on the study by Rascona (1996), the alluvial deposits in the Gila Bend Basin are separated into three distinct units, referenced as the stream alluvium, upper basin fill, and lower basin fill. A brief summary of each unit is presented below:

- ***Stream Alluvium.*** Unconsolidated fluvial deposits that are late Pliocene to Holocene in age characterize the stream alluvium. The extent of the stream alluvium deposits is restricted to the Gila River and its tributaries.

- ***Upper Basin Fill.*** The upper basin fill is characterized by unconsolidated to moderately cemented alluvial deposits. The upper basin fill deposits were likely deposited in an integrated (through-flowing) drainage basin.

- ***Lower Basin Fill.*** The lower basin fill primarily consists of weakly to highly consolidated gravel, sand, silt, and clay that were likely deposited in a closed interior drainage basin. West of Gila Bend, the lower basin fill also includes an extensive fine-grained deposit that achieves a maximum thickness of between 700 and 900 feet.

4.0 HYDROGEOLOGIC CONDITIONS

4.1 GROUNDWATER OCCURRENCE AND MOVEMENT

The upper basin fill and lower basin fill alluvial units represent the principal aquifer in the Gila Bend Basin. In general, groundwater in the upper and lower basin fill deposits is unconfined to semi-confined, although local perched conditions and confined conditions exist in areas with extensive clay layers. Based on estimates by the Arizona Department of Water Resources (ADWR) in 1988, the Gila Bend Basin contains approximately 27.6 million acre-feet of recoverable groundwater to a depth of 1,200 feet. The primary source of groundwater recharge (inflow) to the basin is stream losses (infiltration) from the Gila River and its tributaries. Additional sources of recharge include irrigation seepage and underflow from the Lower Hassayampa Basin. The primary source of outflow from the basin is groundwater pumpage (for crop irrigation) and evapotranspiration. Approximately 50 wells pump into the Gila Bend Canal (Sebenik, 1981), where the groundwater is conveyed for irrigation purposes.

Based on predevelopment hydrologic conditions in the Gila Bend Basin, groundwater flowed south from the Gillespie Dam area and generally followed the Gila River drainage before exiting the basin as underflow near the Painted Rock Dam area (Freethey and Anderson, 1986). However, major groundwater development of the basin began in 1935, altering the groundwater flow regime. Sebenik (1981) reported that groundwater did not flow toward Painted Rock Dam as occurred during predevelopment conditions, and instead noted several cones of depression due to pumping that apparently changed the groundwater flow direction. According to Rascona (1996), groundwater in the basin northeast of Gila Bend generally flowed toward the east due to extensive pumping and shallow bedrock. Near Gila Bend, the groundwater flow direction changes abruptly to the southwest, where it likely exits the basin south of the Painted Rock Mountains. The study by Rascona (1996) also indicated that no significant cones of depression or groundwater mounds were observed as in the previous report by Sebenik (1981). Although historic groundwater declines up to 100 feet have been noted in the Gila Bend Basin (Schumann and Genualdi, 1986), Sebenik observed groundwater level rises up to 65 feet during 1973 to 1979, likely due to recharge following significant flooding.

4.2 GROUNDWATER QUALITY

The United States Geological Survey (USGS) conducted the initial water quality study in the Gila Bend Basin in 1946. Based on this study, groundwater throughout the basin was generally unsatisfactory for most agricultural uses, and had a high total dissolved solids (TDS) content. In particular, the groundwater contained high concentrations of sodium and chloride. The study conducted by Sebenik (1981) reported TDS concentrations in groundwater ranging from 900 to 5,100 milligrams per liter (mg/l), with sodium and chloride as the major ions. Sebenik noted that the highest TDS concentrations were generally northeast of Gila Bend (1,200 to 4,920 mg/l), and that wells southwest of Gila Bend typically produced groundwater with TDS concentrations less than 1,200 mg/l. Northwest of Gila Bend, near the area inundated by the Painted Rock Reservoir, two likely perched zones were sampled with TDS concentrations of 3,900 and

5,100 mg/l. The map showing TDS content of groundwater in Arizona by Daniel (1981) indicated TDS concentrations ranging from 1,000 to 5,000 mg/l in the majority of the basin, and TDS concentrations greater than 10,000 mg/l near portions of the Gila River.

The study conducted by Rascona (1996) included comprehensive water quality sampling from 1991 to 1993. In general, Rascona concluded that groundwater quality has not changed significantly since the initial USGS study in 1946, nor has it changed significantly since the Sebenik study from 1976 to 1993. TDS concentrations northeast of Gila Bend averaged 2,100 mg/l, and TDS concentrations southwest of Gila Bend averaged 1,380 mg/l. In addition, fluoride concentrations averaged 2.1 mg/l northeast of Gila Bend, and averaged 4.9 mg/l southwest of Gila Bend. However, Rascona noted that most of the wells northeast of Gila Bend are perforated above 1,000 feet, whereas the majority of the wells southwest of Gila Bend are perforated below 1,000 feet, primarily due to alluvium thickness. Therefore, an apparent relationship exists between TDS and fluoride concentrations with well depth. Rascona also noted increased sulfate and alkalinity concentrations northeast of Gila Bend, and relatively high concentrations of boron and selenium in the groundwater samples throughout the basin.

Initial interpretations in 1948 predicted a continual increase in groundwater TDS concentrations over time due to the highly mineralized nature of the Gila River surface flows. The predictions were based on infiltrated Gila River water replacing the groundwater withdrawn from the aquifer during extensive irrigation pumping. However, the majority of groundwater recharge apparently occurs during high flow (flood) events, and the Gila River water is significantly less mineralized during these events. Therefore, according to Rascona, the TDS concentrations in the Gila Bend Basin are not expected to increase unless significant recharge occurs during highly mineralized Gila River flows.

5.0 SURFACE WATER CONDITIONS

5.1 SURFACE WATER OCCURRENCE

The principal surface water feature in the Gila Bend Basin is the Gila River, which enters the basin at Gillespie Dam (Figure 2). Gillespie Dam is located at a narrow passage between the Buckeye Hills and Gila Bend Mountains, and was constructed in 1921 to divert all non-flood flows into two canals to supply irrigation water. Below Gillespie Dam, the Gila River traverses a distance of approximately 36 miles around the Gila Bend Mountains to Painted Rock Dam, where the river exits the basin. Painted Rock Dam is located at a narrow passage between the Gila Bend Mountains and Painted Rock Mountains, and was constructed in 1959 to control upstream floodwaters and to protect downstream areas.

Upstream of Gillespie Dam, the Gila River is perennial due to treated effluent discharge from the City of Phoenix 91st Avenue Wastewater Treatment Facility and from irrigation return flow and groundwater pumped for drainage by the Buckeye Irrigation District. Within the Gila Bend Basin, the Gila River is ephemeral and flows only in response to precipitation events or releases from Gillespie Dam. The Gila River below Painted Rock Dam is also ephemeral, and surface water is only released from the dam during flood events. According to Rascona (1996), the net surface water (Gillespie Dam inflow minus Painted Rock Dam outflow) entering the Gila Bend Basin from 1976 to 1993 was approximately 4.6 million acre-feet, exceeding the groundwater pumpage of approximately 3.9 million acre-feet during this period.

5.2 SURFACE WATER QUALITY

Based on the study by Rascona (1996), surface water in the Gila River is highly mineralized with calcium and sodium, and high (flood) flows are considerably less mineralized than low (normal) flows. This observation correlates well with USGS streamflow and water quality data for the Gila River at Gillespie Dam (USGS Site No. 09518000). USGS data at this site represents Gila River surface flows prior to diversion into the two canals for irrigation purposes. USGS data for this site was utilized to illustrate TDS concentrations (Figure 3) and annual surface flow (Figure 4) for the period 1960 to 2001. The annual surface flow below Painted Rock Dam (USGS Site No. 09519800) for the same time period is presented as Figure 5. Due to limited water quality data (1973 through 1976, 1979), TDS concentrations below Painted Rock Dam could not be properly evaluated.

The time period from 1960 to 2001 can be divided into three distinct intervals on the basis of annual surface flows. The period from 1960 to 1977 represents relatively low flows in the Gila River, with the exception of a minor flood event in 1966. By contrast, the period from 1978 to 1995 represents significant surface flows, including two major flood events. The recent drought conditions are reflected in the 1996 to 2001 interval, and the corresponding flows are relatively low to normal. The relationship between average annual surface flows and TDS concentrations is illustrated below in Table 1.

TABLE 1. AVERAGE ANNUAL FLOW AND TDS CONCENTRATIONS IN THE GILA RIVER

DESCRIPTION	1960 TO 1977	1978 TO 1995	1996 TO 2001
Average annual flow above Gillespie Dam diversions (acre-feet)	60,480	1,017,741	118,610
Average TDS concentration above Gillespie Dam diversions (mg/l)	4,225	2,225	2,872
Average annual flow below Painted Rock Dam (acre-feet)	47,435	740,254	3,798
Average annual net surface water entering the Gila Bend Basin (acre-feet)	13,045	277,487	114,812

6.0 GENERALIZED SALT BALANCE

Based on USGS streamflow and water quality data, a generalized salt balance was calculated for the Gila Bend Basin. Results of the salt balance are presented in Table 2, and assumptions utilized in the salt balance are listed below:

TABLE 2. GENERALIZED SALT BALANCE FOR THE GILA BEND BASIN

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

- The difference in groundwater inflow to the basin and groundwater outflow from the basin is negligible.
- The additional salt load resulting from agricultural irrigation practices is considered to be negligible.
- The TDS concentration of surface water outflow below Painted Rock Dam is equal to the TDS concentration of surface water inflow at Gillespie Dam.
- The average salt contribution is based on surface water inflows at Gillespie Dam, and the average salt removal, is based on surface water outflows below Painted Rock Dam.

The primary source of salt contribution in the Gila Bend Basin is from surface flows of the Gila River at Gillespie Dam. According to the ADWR Assessment in 1993, municipal and industrial water demands in the basin are met entirely by groundwater, and no additional sources of surface water are utilized in the basin. Rascona (1996) estimated that approximately 600 acre-feet 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 this salt balance. Groundwater pumpage for crop irrigation averaged approximately 233,000 acre-feet per year between 1971 and 1990 (ADWR, 1993). Based on previous salt contribution calculations from irrigation in the Salt River Valley, the crop irrigation in the Gila Bend Basin would result in approximately 0.005 million 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 below 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. Since Painted Rock Dam is designed to retain non-flood flows, the Gila Bend Basin is essentially a closed basin during normal flow on the Gila River. Therefore, groundwater pumpage, treated wastewater flow, and irrigation return flows are not considered in the salt balance, as they originate and terminate within the basin.

7.0 REFERENCES

Arizona Department of Environmental Quality: Middle Gila Watershed. www.adeq.state.az.us/environ/water/assess/305/2002/13mg.pdf.

Arizona Department of Water Resources: Gila Bend Basin. www.water.az.gov/adwr/Content/WaterInfo/OutsideAMAs/LowerColorado/Basins/gilabend.html.

Arizona Department of Water Resources: Lower Gila River Watershed. www.water.az.gov/adwr/Content/WaterInfo/OutsideAMAs/LowerColorado/Watersheds/lowergilariver.html.

Arizona Department of Water Resources, April 1993. Draft Water Resources Assessment, Inventory and Analysis of Water Resources Issues.

Daniel, D.L., January 1981. Arizona Department of Water Resources: Maps Showing Total Dissolved Solids Content of Groundwater in Arizona.

Denis, E.E., August 1975. Arizona Water Commission: Maps Showing Ground-Water Conditions in the Waterman Wash Area, Maricopa and Pinal Counties, Arizona—1975.

Freethey, Geoffrey W. and Anderson, T.W., 1986. United States Department of the Interior, U.S. Geological Survey: Predevelopment Hydrologic Conditions in the Alluvial Basins of Arizona and Adjacent Parts of California and New Mexico.

Long, M.R., June 1983. Arizona Department of Water Resources: Maps Showing Groundwater Conditions in the Hassayampa Sub-basin of the Phoenix Active Management Area, Maricopa and Yavapai Counties, Arizona—1982.

Oppenheimer, J.M., and Sumner, J.S., 1980. Depth-to-Bedrock Map, Basin and Range Province, Arizona.

Rascona, S.J., July 1996. Arizona Department of Water Resources: Maps Showing Groundwater Conditions in the Gila Bend Basin, Maricopa County, Arizona—1993.

Reynolds, Stephen J., 1988. Geologic Map of Arizona. Arizona Geological Survey Map 26. Produced in cooperation with the U.S. Geological Survey.

Schumann, Herbert H, and Genualdi, Robert B, 1986. Map of Land Subsidence, Earth Fissures, and Water-Level Change in Southern Arizona.

Sebenik P.G., May 1981. Arizona Department of Water Resources: Maps Showing Ground-Water Conditions in the Gila Bend Basin Area, Maricopa County, Arizona—1979.

Stulik, R.S., June 1982. Arizona Department of Water Resources: Maps Showing Groundwater Conditions in the Waterman Wash Area, Maricopa and Pinal Counties, Arizona—1982.

United States Department of the Interior, U.S. Geological Survey, 2002. *Water Resources Data, Arizona, Water Year 2002*. Water-Data Report AZ-01-1.

United States Geological Survey: www.waterdata.usgs.gov/nwis/annual.

CENTRAL ARIZONA SALINITY STUDY --- PHASE I

Technical Appendix E

HYDROLOGIC REPORT ON THE TUCSON ACTIVE MANAGEMENT AREA

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6.1 GENERALIZED SALT BALANCE FOR THE TUCSON AMA

1.0 INTRODUCTION

The Central Arizona Salinity Study (CASS) is a coalition of water and wastewater agencies evaluating salinity issues in central Arizona. The mission of CASS is to provide its members with workable alternatives for a quality, cost effective, sustainable, and reliable water supply through partnerships and cooperative efforts in regional salinity planning and management. CASS was formed in November 2001. CASS is a study group and not a legal entity.

Salinity from local and imported sources is increasing the salinity of groundwater in localized areas and the salinity of reclaimed water in central Arizona. The magnitude of the salinity issue is unclear and water providers in central Arizona decided to work together to assess the problem and, if necessary, develop regional strategies for managing it. Central Arizona water providers must work together to protect, preserve, and develop these shared resources and to respond to issues of: increasing water quality and water supply regulation; increasing reclaimed water utilization; increasing levels of salinity into water reclamation facilities; developing brine disposal strategies; deteriorating groundwater quality in localized areas; and managing costs.

If no workable solution is implemented, salinity increases may result in greater water and wastewater treatment costs, decreased agricultural production, and some water sources may become unsuitable for their intended uses.

- Increasing salinity levels may reduce the ability of water providers to use groundwater and reclaimed water to meet customer water demands. Some communities may not have enough supply to meet demand. Growth and development in these communities may become limited.

- Water reclamation plants may have water quality permit compliance problems. High salinity levels in reclaimed water supplies may make this resource unsuitable for some of its intended uses. Retrofitting water reclamation plants to manage salinity and dispose of brine may significantly increase wastewater treatment costs.

- Water customer complaints may increase due to increasing salinity of the drinking water supply. Retrofitting potable water treatment plants to manage salinity and dispose of brine may significantly increase water treatment costs.

The following white paper describes hydrologic conditions in the Tucson Active Management Area (AMA)—one of several areas within the State which has been designated by the Legislature and the Arizona Department of Water Resources as requiring active management of groundwater. This report is based on literature review of publicly available information, and site-specific fieldwork was not conducted as part of this study. The purpose of the report is to provide a general framework of the physical,

geologic, and hydrologic aspects of the study area. The report will also quantitatively assess future salt loading from imported sources.

2.0 PHYSICAL SETTING

The Tucson AMA is located in southeastern Arizona within the Sonoran Desert section of the Basin and Range physiographic province. Tucson AMA covers approximately 3,900 square miles, and land surface elevation ranges from 1,860 feet to 9,453 feet above mean sea level (amsl). Broad, gently sloping alluvial basins separated by north to northwest trending block-faulted mountains characterize the land within Tucson AMA. Tucson AMA is comprised of two sub-basins: the Upper Santa Cruz Valley Sub Basin (USCVSB) north of the Pima/Santa Cruz County line, and the Avra Valley Sub Basin (AVSB).

Temperatures and precipitation vary based on season and elevation. Average high temperatures in the Tucson AMA range from 67 degrees Fahrenheit (°F) in January to 103 °F in July (ADWR, 1999). Rainfall occurs in two seasons; during the winter months from frontal storms and during summer months from convective thunderstorms or "monsoon" storms. Average precipitation ranges from approximately 11 inches per year in low elevations to 28 inches per year in the high elevations of the surrounding mountains (ADWR, 1999). Average annual evapo-transpiration rate is about 77 inches per year (ADWR, 1999).

The principal surface water drainage feature in the USCVSB is the Santa Cruz River which originates in Arizona, then flows south into Mexico before turning west and north and re-entering the United States east of Nogales, Arizona. The Santa Cruz River enters the Tucson AMA at the Santa Cruz County/Pima County line and extends 60 miles north before leaving the Tucson AMA northwest of Red Rock, Arizona. Surface flow occasionally enters the basin from the south from storm flood flows and effluent discharges from the Nogales International Wastewater Treatment Plant located 20 miles south of the county line. Perennial flow occurs along an approximate 23-mile reach of the Santa Cruz River from the discharges of effluent at Pima County's Roger Road Wastewater Treatment Plant and the Ina Road Water Pollution Control Facility. The remainder of the river is ephemeral and only flows in response to precipitation.

Principal tributaries of the Santa Cruz River include the Cañada Del Oro Wash and Rillito Creek. Tributaries to Rillito Creek include Pantano Wash and Tanque Verde Creek which in turn receive surface flow from Sabino Creek, Rincon Creek and Cienega Creek. Cienega Creek, Sabino Creek, Tanque Verde Creek, Agua Caliente Wash and Cañada Del Oro Wash have small perennial reaches in the eastern portions of the USCVSB.

In the southern portion of the AVSB, Altar Wash is the principal surface water drainage feature and becomes Brawley Wash in northern portions. Brawley Wash has a confluence with the Santa Cruz River shortly after leaving the Tucson AMA to the northwest. A small portion of Arivaca Wash is perennial within the AVSB.

3.0 GENERALIZED GEOLOGY

The AVSB and the USCVSB are alluvial basins surrounded by block-faulted mountains. Block faulting occurred as a result of the Basin and Range disturbance that began about 12 million years ago (Anderson, 1987). These mountains include the Santa Catalina, Rincon, and Santa Rita Mountains in the east portion of the USCVSB; and the Silverbell and Baboquivari Mountains in the west portion of the AVSB. The Sierrita, Tucson and Tortolita Mountains divide the two sub-basins. The alluvial basins are composed of a thick sequence of basin-fill sediments.

3.1 BEDROCK GEOLOGY

Bedrock materials of the surrounding mountains consist of andesitic to rhyolitic volcanic rocks, tuff, and agglomerate; diorite; granodioritic and mylonitic gneiss; granite; schist; and interbedded conglomerate, limestone, and sandstone (Davidson, 1973 and Reynolds, 1988). These rocks are from Precambrian to Tertiary age (Davidson, 1973). Depth to bedrock in the two sub-basins is estimated based on gravity modeling (Oppenheimer and Sumner, 1980). Depth to bedrock on the center of the USCVSB is about 11,000 feet. In the AVSB, depth to bedrock is about 9,600 feet.

3.2 BASIN GEOLOGY

The alluvial deposits in the USCVSB are separated into six distinct geologic units, referenced as the Pantano Formation, lower Tinaja beds, middle Tinaja beds, upper Tinaja beds, the Fort Lowell Formation, and stream alluvium. A brief summary of each unit is presented below:

- ***Pantano Formation.*** Overlaying and in fault contact with bedrock materials is the Pantano Formation which consist of conglomerate, sandstone, mudstone, gypsiferous mudstone, and siltstone (Anderson, 1987). This formation is highly faulted and tilted, and was deposited prior to the Basin and Range disturbance. Sediments of the formation are as much as thousands of feet thick (Anderson, 1987).

- ***Lower Tinaja Beds.*** Overlaying the Pantano Formation is the lower Tinaja beds which consist of mudstone and clay with interbedded sand, silt, and gravel. These beds were also deposited prior to the Basin and Range disturbance (Anderson, 1987).

- ***Middle Tinaja Beds.*** Middle Tinaja beds occur only in the central downfaulted portions of the USCVSB. They consist of gypsiferous and anhydritic clayey silt and mudstone (Anderson, 1987).

- ***Upper Tinaja Beds.*** Upper Tinaja beds typically consist of moderately consolidated sand, gravel, clay, and silt and are typically described as

conglomerate or cemented sand and gravel in well drillers' logs. The upper, middle and lower Tinaja beds are up to 5,000 feet thick (Davidson, 1973).

- ***Fort Lowell Formation.*** The Fort Lowell Formation overlays the upper Tinja beds and consists of interbedded layers of clay, silt, sand, gravel, and boulders. The formation is about 300 to 400 feet thick in most of the basin (Davidson, 1973).

- ***Stream Alluvium.*** Unconsolidated fluvial deposits that occupy the stream bed channels of the Santa Cruz River and its tributaries characterize the stream alluvium. The stream alluvium is typically less than 100 feet thick. The stream alluvium typically consists of sand and gravel and has high infiltration capacity (Davidson, 1973).

The AVSB is separated into two distinct units, referenced as the lower and upper alluvium (Hanson, Anderson and Pool, 1990). The lower alluvium is equivalent to the Pantano Formation and Middle and Lower Tinaja beds, and the upper alluvium is equivalent to the Upper Tinaja Beds and the Fort Lowell Formation of the USCVSB.

4.0 HYDROGEOLOGIC CONDITIONS

4.1 GROUNDWATER OCCURRENCE AND MOVEMENT

The hydrogeologic system of the Tucson AMA is generally characterized by periodic recharge along the ephemeral stream channels of the Santa Cruz River and Brawley Wash and their tributaries, ground-water flow to the north-northwest through basin-fill deposits, and discharge to water supply wells and underflow to the Picacho basin to the northwest. Periodic stream flow in the ephemeral drainages occurs in response to precipitation and snow melt from the surrounding mountains. Some perennial reaches occur near the mountain fronts. Infiltration occurs through the high-permeable stream-channel deposits and flows down gradient through moderately to highly permeable basin-fill deposits.

Natural recharge to the aquifer system occurs as a result of infiltration of surface water runoff along the mountain fronts of the mountains, and stream channel recharge along the Santa Cruz River and Brawley Wash and their tributaries. Based on Osterkamp (1973), rates of groundwater recharge at the mountain fronts and stream channels in the Tucson AMA range from 0 to 850 AF per mile of mountain front or stream-channel. Average annual natural recharge in the Tucson AMA is approximately 76,600 AF/yr (ADWR, 1999).

Groundwater levels in the USCVSB have declined as much as 200 feet since 1940 (ADWR, 2003). Cones of depression are evident within Tucson Water's central well field as a result of municipal pumping and the Green Valley/Sahuarita area from agriculture and mining pumping. Typical annual declines have been in the order of 3 to 4 feet (ADWR, 2003). Since the late 1970's and early 1980's there has been some recovery of the water levels of about 80 feet in southern portions of the USCVSB. Water levels in the Cañada del Oro area in northern portions of the USCVSB have been relatively constant despite an increase in groundwater pumping.

Water levels have declined as much as 150 feet in northern portions of the AVSB creating a large cone of depression as a result of agricultural pumping. Similarly, since the late 1970's, water levels have recovered about 60 feet (ADWR, 2003).

4.2 GROUNDWATER QUALITY

Levels of Total Dissolved Solids (TDS) in groundwater in the Tucson AMA range from 101 mg/l to 752 mg/l and averages approximately 259 mg/l (Pima Association of Governments, 1994). In most areas of the Tucson AMA, groundwater is within potable drinking water standards.

5.0 Tucson AMA'S WATER SUPPLY

Total water use in the Tucson AMA in 2000 was about 336,000 acre-feet (AF) per year with groundwater resources being the primary water supply at about 90 percent (ADWR Tucson AMA, 2003). Groundwater produced from exempt wells are not accounted for in this total. Effluent is served to some golf courses, parks and schools and accounted for about 3 percent of the total use (ADWR Tucson AMA, 2003). Central Arizona Project (CAP) water is utilized to recharge the aquifer and for agriculture irrigation (in-lieu of groundwater). In 2000, approximately 49,500 AF of CAP water was recharged to the aquifer and approximately 24,000 AF was utilized for agriculture (Tucson Water, 2003b). Municipal use accounts for about 48 percent of the total water use and agricultural use accounts for about 32 percent (ADWR Tucson AMA, 2003). The remaining water use includes copper mines and other industrial well owners (ADWR Tucson AMA, 2003).

5.1 GROUNDWATER

Groundwater is used to supply potable municipal, industrial and agricultural uses. In 2000, groundwater use totaled almost 301,500 AF (ADWR Tucson AMA, 2003). Approximately 53 percent was produced for municipal uses, 27 percent for agricultural uses and the remaining 20 percent for industrial and mining uses (ADWR Tucson AMA, 2003).

5.2 RECLAIMED WATER

Approximately 70,200 AF of effluent was generated from July 2000 to June of 2001 by the two treatment plants owned and operated by Pima County (Pima County Wastewater Management Department, 2003). Some effluent was used for turf irrigation, but most was discharged into the Santa Cruz River and recharged the local groundwater aquifer.

Roger Road Wastewater Treatment Plant generated about 44,150 AF of effluent from July 2000 to June of 2001 (Pima County Wastewater Management Department, 2003). The City of Tucson reclaimed 10,400 AF of this effluent for use in its reclaimed water system and about another 680 AF for turf irrigation at the Silverbell golf course, leaving about 33,100 AF to be discharged into the Santa Cruz River (Pima County Wastewater Management Department, 2003). City of Tucson delivers the reclaimed water to golf courses, parks, schools including the University of Arizona and Pima Community College and many single-family homes.

Ina Road Water Pollution Control Facility produced about 26,100 AF/yr of effluent from July 2000 to June of 2001 (Pima County Wastewater Management Department, 2003). About 620 AF of effluent generated was used for turf irrigation at Arthur Pack golf course. Approximately 25,500 AF/yr remains and is discharged into the Santa Cruz River (Pima County Wastewater Management Department, 2003).

The City of Tucson stores effluent underground at the Sweetwater Recharge Facilities. Peak recovery of the reclaimed water occurs from May through October during periods of peak turf irrigation demands (Pima Association of Governments, 2003). The

Sweetwater Recharge Facilities has a permitted capacity of 6,500 AF/yr and for the most part operates on an annual put-and-take basis (Tucson Water, 2003). These facilities consist of 28 acres of off-channel spreading basins, six recovery wells, and the Sweetwater Wetlands (a multi-use wetland treatment system) all of which are located on the east and west banks of the Santa Cruz River (Tucson Water, 2003). These facilities utilize spreading basins to enhance infiltration, the vadose-zone profile to improve water quality through soil-aquifer treatment, and designated wells to recover the stored effluent (Pima Association of Governments, 2003). After the effluent is recovered, it is chlorinated and sent to the reclaimed distribution system (Pima Association of Governments, 2003).

The City of Tucson, in partnership with the U.S. Bureau of Reclamation, also recharges and stores effluent along a five-mile reach of the Santa Cruz River downstream from the Roger Road Wastewater Treatment Plant (Tucson Water, 2003). This permitted in-channel recharge facility is called the Santa Cruz River Managed Underground Storage Facility and is used to accrue both annual and long-term storage credits for the effluent passively recharging the aquifer between the Roger Road outfall and Ina Road. As of 2003, the City of Tucson had one recovery well associated with this facility (Tucson Water, 2003).

In addition, the City of Tucson, Town of Oro Valley, Town of Marana, Metropolitan Domestic Water Improvement District, Cortaro-Marana Irrigation District and Cortaro Water User's Association, Avra Valley Irrigation District, Flowing Wells Irrigation District and Pima County have jointly applied to obtain permits to recharge and store in-channel effluent in the Lower Santa Cruz River Managed Recharge Project (ADWR Tucson AMA, 2003). This project will allow participants to annually accrue up to 21,500 AF of effluent storage credits (which takes into account the fifty percent cut to the aquifer for managed facilities) along the Santa Cruz River between Ina Road and Trico Road. It is believed that this permit will be issued sometime in 2003.

In the future, one or more of the above entities may be interested in developing additional constructed in-channel and/or off-channel effluent storage facilities in order to accrue more effluent storage credits. In addition, municipal effluent will eventually be treated and used as a renewable water source for potable supply (Tucson Water, 2003).

5.3 CENTRAL ARIZONA PROJECT WATER

The CAP canal was completed to the Tucson area in the early 1990's to deliver a renewable supply of water from the Colorado River. For the purpose of this study, a TDS concentration 650 mg/l was utilized for this study (Tucson Water, 2003b). In 2000, 24,289 AF of CAP water was delivered and used in-lieu of groundwater for agricultural irrigation (ADWR Tucson AMA, 2003).

The CAP water allocation for the Tucson Basin's water providers and users is 215,333 AF per year and consists primarily of municipal contracts (ADWR, 1999). The City of Tucson has an allocation of 138,920 AF of this total (ADWR, 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 sub-basin at the Clearwater Renewable Resource Facility (Clearwater) (Tucson Water, 2001).

Clearwater consists of a series of recharge basins and recovery wells and 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. From the central pumping station, water is boosted to the Hayden-Udall Water Treatment Plant for chlorine disinfection and pH adjustment (Tucson Water, 2001). The water is then pumped through a tunnel to the 60 million-gallon Clearwell Reservoir. From the Clearwell Reservoir the water is distributed to the main distribution system of the City of Tucson. In the spring of 2001, City of Tucson began delivering about 18 million gallons of blended CAP water a day from the Clearwater facility. By the winter of 2003, expansion of the facility will allow the City of Tucson to deliver up to 54 million gallons per day (Tucson Water, 2001). Of all the permitted CAP water recharge facilities in Tucson AMA, only Clearwater has the "wet-water" capability to recover CAP for municipal supply (Tucson Water, 2003).

CAP water is also currently recharged in the Tucson AMA in three other constructed artificial recharge facilities but none at this time have wet-water recovery capability (Tucson Water, 2003). Recharge facilities include Pima Mine Road Recharge Project, Avra Valley Recharge Project, and the Lower Santa Cruz Recharge Project.

Pima Mine Road Recharge Project, a constructed recharge facility developed through a partnership between the City of Tucson and the Central Arizona Project, originally consisted of a single 14-acre basin, but three new basins were added in 2002 for a combined total basin area of 37 acres (Central Arizona Project, 2003). Operations began in early 1997 as a pilot project and later became a full-scale project to recharge up to 30,000 acre feet per year.

The Avra Valley Recharge Project began operations as a pilot facility in 1996 and was permitted to a full-scale facility in 1998 (Central Arizona Project, 2003). The project consists of 11 acres of spreading basins with a permit to store 11,000 acre-feet of water per year.

The Lower Santa Cruz Recharge Project is a partnership between CAP and the Pima County Flood Control District (Central Arizona Project, 2003). Construction of the full-scale facility began in 1999 and was completed in 2000. This facility consists of 33 acres of spreading basins and can recharge up to 30,000 acre-feet of water per year.

The City of Tucson, Pima County, Metropolitan Domestic Water Improvement District (MDWID), Town of Marana, Town of Oro Valley, ADWR and others have sponsored investigations in the Tucson area to study the feasibility of additional sites for recharge (ADWR Tucson AMA, 2003). These projects will allow greater amounts of contracted CAP water to be recharged into the future.

6.0 GENERALIZED SALT BALANCE

Two generalized salt balances were developed for the Tucson AMA by Tucson Water (2003b). The salt balance for the year 2000 was developed to reflect current conditions and is presented as Figure 3. The salt balance for the year 2015 was developed to reflect conditions when the full allotment of CAP water will be utilized and is presented as Figure 4. The assumptions for each item on the flow chart are included on the pages following each salt balance. Table 6.1 summarizes the salt balance flow charts and is presented below:

TABLE 6.1 GENERALIZED SALT BALANCE FOR THE TUCSON AMA

DESCRIPTION	2000	2015
Average salt inflow from the CAP Aqueduct (million tons per year)	0.0651	0.1904
Average salt inflow from groundwater (million tons per year)	0.0052	0.0052
Average salt inflow due to natural recharge (million tons per year)	0.0313	0.0313
Additional salt sources (million tons per year)	0.0290	0.0343
Total Amount of Salt Entering the Tucson AMA (million tons per year)	**0.1306**	**0.2611**
Average salt outflow in groundwater (million tons per year)	0.0137	0.0137
Average salt outflow in the Santa Cruz River (million tons per year)	0.0093	0.0419
Total Amount of Salt Leaving the Tucson AMA (million tons per year)	**0.0229**	**0.0555**
Net Salt Accumulation in the Tucson AMA (million tons per year)	**0.1076**	**0.2056**

It is estimated that by 2015, salt accumulation in the Tucson AMA will almost double from current (2000) levels. This is predominately due to utilization of the full CAP allotment. In 2000, utilization of the CAP accounted for approximately 50 percent of the salt entering the Tucson AMA; when the full allotment is utilized, the CAP will account for approximately 73 percent of the salt entering the Tucson AMA.

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 and natural recharge accounted for approximately 24 percent. Additional salt sources from human activities (such as the application of fertilizers and municipal and industrial uses) account for approximately 22 percent of the salt entering the Tucson AMA. The amount of additional salt sources was based on values utilized in a salt balance prepared for the Phoenix AMA (CASS, 2002). Approximately 4 percent of the salt that entered the Tucson AMA was from groundwater inflow, however approximately 10 percent of the salt entering the Tucson AMA, left the Tucson AMA as groundwater

outflow. Approximately 18 percent of the salt entering the Tucson AMA, leaves the AMA with groundwater and Santa Cruz River outflow.

By 2015, full allocation of the CAP is anticipated to be utilized and approximately 205,500 tons of salt will accumulate in the Tucson AMA annually. Utilization of the CAP will account for approximately 73 percent of the salt entering the Tucson AMA. 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. The amount of additional salt sources was based on values utilized in a salt balance prepared for the Phoenix AMA (CASS, 2002). 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 the AMA as groundwater and Santa Cruz River outflow.

7.0 REFERENCES

Anderson, S.R., 1987. *Cenozoic Stratigraphy and Geologic History of the Tucson Basin, Pima County, Arizona*. United States Geological Survey (USGS), Water-Resources Investigations Report 87-4190.

Arizona Department of Water Resources, 1999. *Tucson Active Management Area Third Management Plan 2000-2010*.

Arizona Department of Water Resources, 2003. *Tucson Active Management Area*, http://www.water.az.gov/adwr/content/WaterInfo/InsideAMAs/amatucson.html.

Arizona Department of Water Resources, Tucson Active Management Area, (Tucson AMA), 2003. personal communication.

Central Arizona Salinity Study (CASS), 2002. *Salt Balance Phoenix Metro Area Typical Year, Draft*. U.S. Department of Interior Bureau of Reclamation Central Arizona Salinity Study.

Central Arizona Project, 2003, http://www.cap-az.com/.

Cordy, G.E., and Bouwer, Herman, 1999, *Where do the salts go? The potential effects and management of salt accumulation in south-central Arizona*: U.S. Geological Survey Fact Sheet 170–98, 4 p.

City of Tucson, personal communication with Ralph Marra and TimThomure, 2003.

Davidson, E.S., 1973. *Geohydrology and Water Resources of the Tucson Basin, Arizona*. US Geological Survey, Water-Supply Paper 1939-E.

Hanson, R. T., Anderson, T. and Pool, D.R., 1990. *Simulation of Ground-water Flow and potential Land Subsidence, Avra Valley, Arizona*, U.S. Geological Survey Water Resources Investigations Report 90-4178.

Oppenheimer, J.M., and Sumner, J.S., 1980. *Depth-to-Bedrock Map, Basin and Range Province, Arizona*.

Osterkamp. W.R., 1973. *Ground-Water Recharge in the Tucson Area, Arizona*. United States Geological Survey, Map I-844-E.

Pima Association of Governments, October, 1994. *CAP Water Salinity Impacts on Water Resources of the Tucson Basin*.

Pima Association of Governments, 2003. *Regional Effluent Planning Partnership*, http://www.pagnet.org/HostedSites/repp/background.html.

Pima County Wastewater Management Department, 2003. personal communication.

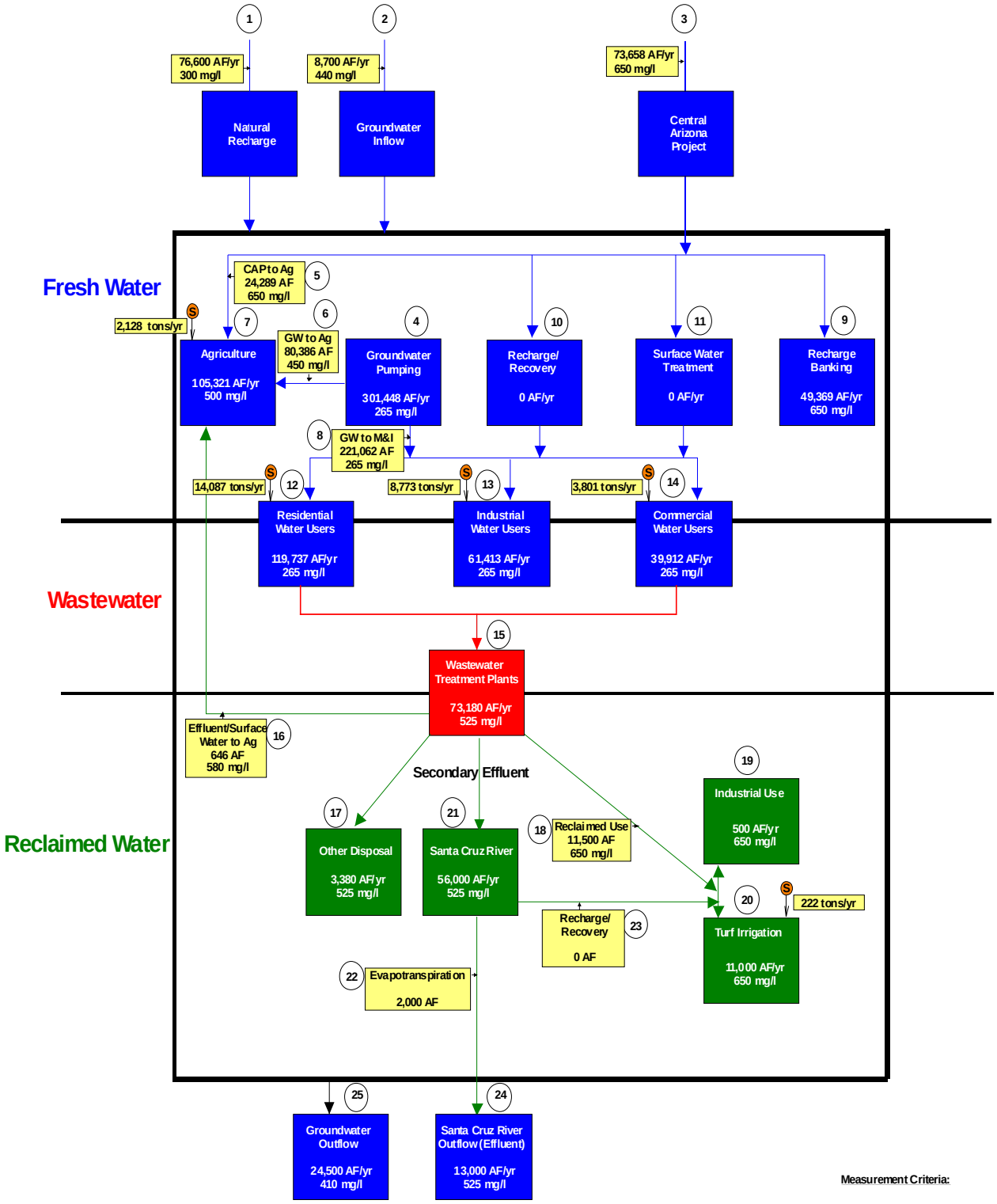
Reynolds, Stephen J., 1988. *Geologic Map of Arizona. Arizona Geological Survey Map 26.* Produced in cooperation with the U.S. Geological Survey. United States Department of the Interior, U.S. Geological Survey.

Tucson Water, 2001. Clearwater, 2001, *Tucson's New Blended Water Resource* http://www.ci.tucson.az.us/water/water_resources/clearwater/clearwater_production/clearwater_production.htm.

Tucson Water, 2002, *Tucson's Water Resources, Current Clearwater Water Production*, http://www.ci.tucson.az.us/water/water_resources/clearwater/clearwater_production/clearwater_production.htm.

Tucson Water, 2003b. Salt Balance (Wet Water) Tucson Active Management Area 2000 and 2015.

FIGURE 3
SALT BALANCE (WET WATER)
TUCSON ACTIVE MANAGEMENT AREA
2000



Measurement Criteria:

mg/l Salinity Concentration

MAF/yr Volumetric Flow Rate

Ⓢ Salt added (26)

(nn) Footnote

Salt Entering The Study Area: 101,573 Tons per Year

Salt Added Within the Study Area: 29,011 Tons per Year

Salt Leaving The Study Area: 22,943 Tons per Year

Salt Accumulated In The Study Area: 107,641 Tons per Year

Tucson AMA SALT BALANCE 2000 FOOTNOTES: Data Source Citations/Explanation

(1) Natural Recharge: This salt-balance component consists of natural stream-channel recharge and mountain-front recharge for the ADWR Tucson Active Management Area (Tucson AMA). The annual volumetric flow rate is based on the ADWR-Tucson AMA Third Management Plan (1999)—Page 2-16. The TDS estimate is from R.L. Laney (U.S. Geological Survey Water-Supply Paper 1939-D (1972) based on the average TDS of groundwater in the Tucson basin; it is assumed that this can credibly serve as the average TDS associated with natural recharge inputs in Tucson AMA.

(2) Groundwater Inflow: The annual volumetric flow rate based on the ADWR-Tucson AMA Third Management Plan (1999)—Page 2-16. However, ADWR plans to update the water budget for Tucson AMA based on the results of its updated groundwater model for Tucson AMA; the documentation is still in draft form and is currently under review. The groundwater inflow across this boundary is estimated to more than double the estimate that is the published in the Third Management Plan (1999). The groundwater TDS estimate along the inflow boundary is a spatially-weighted average based on TDS and electrical conductivity data obtained from ADWR-GWSI, ADEQ, and USGS databases; the electrical conductivity values were converted to TDS by applying an empirically-based factor of 0.64.

(3) Central Arizona Project Water: Volume of CAP used is based on ADWR- Tucson AMA's "2000 AMA Water Use Summary." The average TDS of raw/untreated CAP water is based on a calculation of recent data collected by Tucson Water.

(4) The volume of groundwater pumping in 2000 is based on ADWR-Tucson AMA's "2000 AMA Water Use Summary." The average TDS of pumped groundwater in Tucson AMA is approximated by using the average TDS of groundwater in City wells within and outside of the Tucson Water service area.

(5) The volume of CAP water used by agriculture in Tucson AMA for 2000 is based on ADWR-Tucson AMA's "2000 AMA Water Use Summary." The TDS of CAP water is the same as noted in (3).

(6) The volume of groundwater pumped by agriculture in 2000 is based on ADWR-Tucson AMA's "2000 AMA Water Use Summary." The summary tabulates reported pumping in 2000 losses. The average TDS of groundwater pumped in agricultural areas in Tucson AMA is based on an estimate for eastern Pima County generated by the Pima Association of Governments (September 15, 2003).

(7) The volume of water used by agriculture is the sum of (5), (6), and (16). The composite TDS concentration of the three waters used by agriculture is the volume-weighted average of (5), (6), and (16).

(8) The volume and average TDS of groundwater delivered to residential, industrial, and commercial water users in the Tucson AMA. The volume is derived from ADWR-Tucson AMA's "2000 AMA Water Use Summary". The average TDS of groundwater is the same as (4).

(9) The volume of CAP water put in storage (not recovered) in 2000 is derived from ADWR-Tucson AMA's "2000 AMA Water Use Summary", [Total CAP – Ag CAP = Banked CAP]. The TDS estimate is the same as (3).

(10) This input does not apply in 2000 since no CAP water was recovered in the Tucson AMA in 2000.

(11) There was no treatment of CAP water (the only surface water source available) in Tucson AMA in 2000.

(12) Volume (groundwater only in 2000) represents the residential portion of Tucson AMA's overall municipal use in 2000. The overall municipal use (159,649 acre-feet) is documented in ADWR-Tucson AMA's "2000 AMA Water Use Summary." The weighted average percent (75%) which is applied to the overall municipal use was calculated from information in the ADWR-Tucson AMA Third Management Plan (1999), Page 3-15. The TDS estimate is the same as (4).

(13) Volume (groundwater only in 2000) represents the industrial use (plus mining) from data in ADWR-Tucson AMA's "2000 AMA Water Use Summary." The TDS estimate is the same as (4).

(14) Volume (groundwater only in 2000) represents the commercial portion of Tucson AMA's overall municipal use in 2000. The overall municipal use is the same as noted in (12). The weighted average percent (25%) which is applied to the overall municipal use was calculated from Page 3-15 of ADWR-Tucson AMA's Third Management Plan (1999). The TDS estimate is the same as (4).

(15) The approximate total volume of wastewater effluent produced by Pima County treatment plants in 2000 is the sum of that portion of (16) relating to effluent diverted to agriculture (280AF in 2000), (17), (18), and (21). The TDS is a calculation from Tucson Water's Resource Planning Tool (2003).

(16) Volume of 280AF of effluent (reclaimed water) delivered to agriculture in 2000 is from Tucson Water. An additional 366AF of surface water for agriculture is from the ADWR-Tucson AMA's "2000 AMA Water Use Summary." The TDS is a volume weighted average.

(17) Volume refers to effluent discharged by Pima County wastewater treatment plants other than Ina Road Water Pollution Control Facility and the Roger Road Wastewater Treatment Plants; none of this volume leaves the Tucson AMA. The TDS is assumed to be the same as in (15).

(18) The volume represents the amount of reclaimed water put to reuse in 2000 including Tucson Water's reclaimed water system and effluent used at the Silverbell Golf Course and the Arthur Pack Golf Course. The TDS is the average produced by the Reclaimed Water System.

(19) This is the industrial component of (18). The TDS is the same as (18)

(20) This is the turf irrigation component of (18). The TDS is the same as (18)

(21) The volume represents secondary effluent discharged to the Santa Cruz River in 2000 by two Pima County wastewater treatment plants. The TDS is the same as in (15).

(22) Evapotranspiration estimate from effluent flows in the Santa Cruz River is derived from K. Galyean (U.S. Geological Survey Water Resources Investigations Report 96-4021) and further modified by Tucson Water for facility permitting purposes.

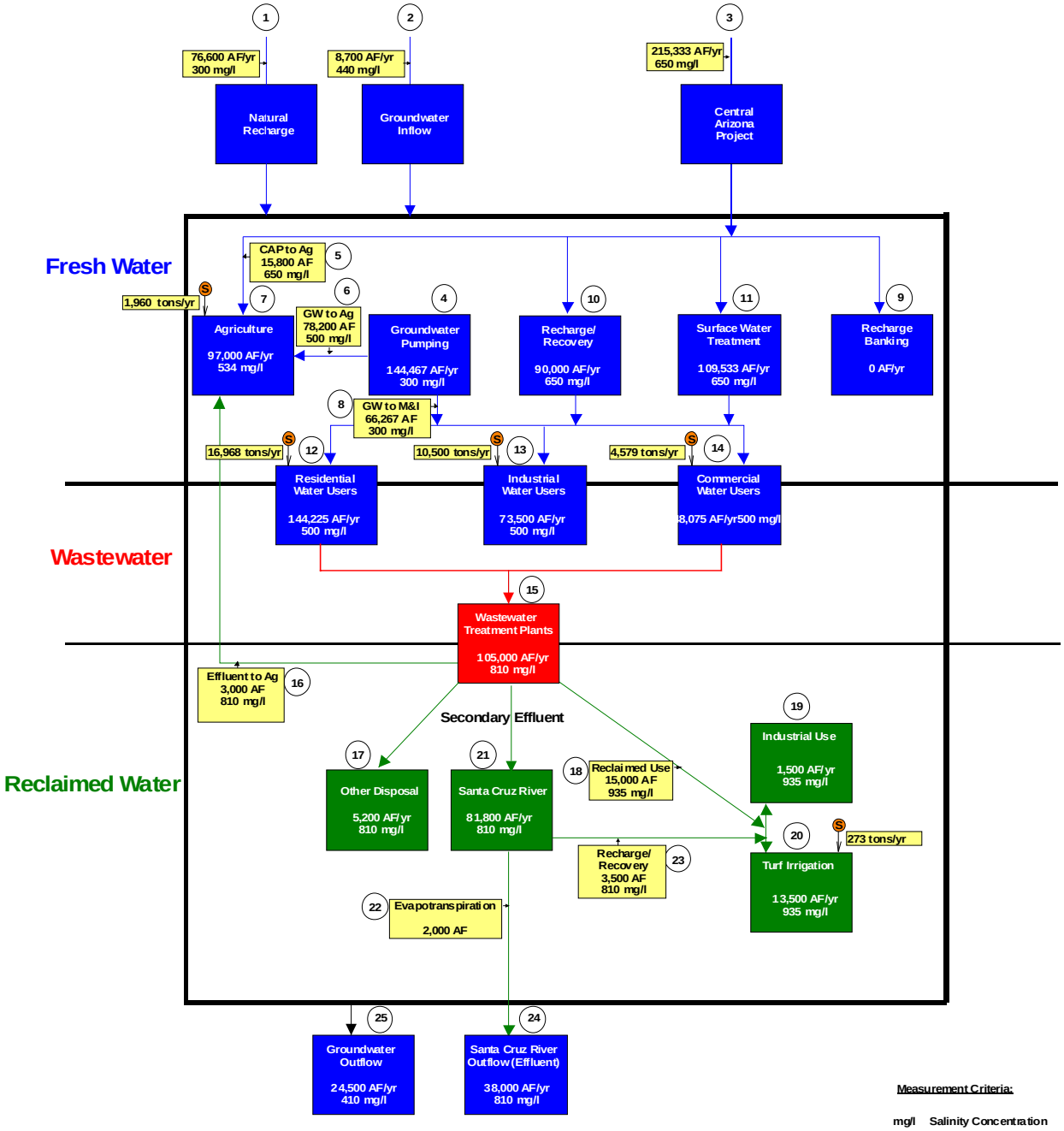
(23) There was no recovery of recharged secondary effluent associated with a managed in-channel underground storage facility permit in 2000.

(24) Volume of in-channel effluent outflow leaving the Tucson AMA as surface water is calculated as follows: (24) = (21) – [(22) + 41,000 acre-feet/yr] where 41,000 acre-feet is the volume of effluent which annually infiltrates in the Santa Cruz River channel between the two treatment plant outfalls and the Tucson AMA boundary as per the Lower Santa Cruz River Managed Recharge Project Application for an Underground Storage Facility Permit (2002) and extended to the Tucson AMA boundary. The TDS is the same as in (15).

(25) The volume of groundwater underflow leaving the Tucson AMA and entering the Pinal AMA at near Picacho as per ADWR-Tucson AMA Third Management Plan (1999), Page 2-16. However, ADWR plans to update the water budget for Tucson AMA based on the results of its updated groundwater model for Tucson AMA; the documentation is still in draft form and is currently under review. The groundwater outflow across this boundary is estimated to be about 25% less than the estimate published in the Third Management Plan. The groundwater TDS estimate along the outflow boundary is a spatially-weighted average based on TDS and electrical conductivity data obtained from ADWR-GWSI, ADEQ, and USGS databases; the electrical conductivity values were converted to TDS by applying an empirically-based factor of 0.64.

(26) Additional salt added due to human activities such as the application of fertilizers and municipal and industrial use. The amount of salt added to each item is based on the *Salt Balance Phoenix Metro Area Typical Year, Draft*, CASS, 2002. The salt added to each Tucson item was based on the volumetric proportion to the corresponding item in the Phoenix Metro Area.

FIGURE 4
SALT BALANCE (WET WATER)
TUCSON ACTIVE MANAGEMENT AREA
2015



Salt Entering The Study Area: 226,813 Tons per Year
Salt Added Within the Study Area: 34,280 Tons per Year
Salt Leaving The Study Area: 55,522 Tons per Year
Salt Accumulated In The Study Area: 205,571 Tons per Year

Tucson AMA SALT BALANCE 2015 FOOTNOTES: Data Source Citations/Explanation

(1) Natural Recharge: This salt-balance component consists of natural stream-channel recharge and mountain-front recharge for the ADWR Tucson Active Management Area (Tucson AMA). The annual volumetric flow rate is based on the ADWR-Tucson AMA Third Management Plan (1999)—Page 2-16 assumed to remain relatively constant. The TDS estimate is from R.L. Laney (U.S. Geological Survey Water-Supply Paper 1939-D (1972) based on the average TDS of groundwater in the Tucson basin; it is assumed that this can credibly serve as the average TDS associated with natural recharge inputs in Tucson AMA and will remain relatively constant.

(2) Groundwater Inflow: The annual volumetric flow rate based on the ADWR-Tucson AMA Third Management Plan (1999)—Page 2-16 assumed to remain relatively constant. However, ADWR plans to update the water budget for Tucson AMA based on the results of its updated groundwater model for Tucson AMA; the documentation is still in draft form and is currently under review. The groundwater inflow across this boundary is estimated to more than double the estimate that is the published in the Third Management Plan (1999). The groundwater TDS estimate along the inflow boundary is a spatially-weighted average based on TDS and electrical conductivity data obtained from ADWR-GWSI, ADEQ, and USGS databases; the electrical conductivity values were converted to TDS by applying an empirically-based factor of 0.64. TDS is assumed to remain relatively constant.

(10) Central Arizona Project Water: Volume of CAP used is assumed to be full utilization of all allocated CAP water within the Tucson AMA as noted in the Draft Hydrologic Report on the Tucson Active Management Area, Central Arizona Salinity Study (May 2003). The average TDS of raw/untreated CAP water is based on a calculation of recent data collected by Tucson Water and is assumed to remain constant due to on-going efforts of the Colorado River Basin Salinity Control Forum.

(11) The volume of groundwater pumping in 2015 is based on ADWR-Tucson AMA Third Management Plan (1999)—Page 11-23, as modified by Tucson Water assumption of full Tucson AMA CAP utilization. The average TDS of pumped groundwater in Tucson AMA is approximated by using the average TDS of groundwater in City wells within and outside of the Tucson Water service area. Significant reduction in Central well field usage causes a rise by 2015.

(12) The volume of CAP water used by agriculture in Tucson AMA for 2015 is based on ADWR-Tucson AMA Third Management Plan (1999)—Page 11-23. The TDS of CAP water is the same as noted in (3).

(13) The volume of groundwater pumped by agriculture in 2000 is based on ADWR-Tucson AMA Third Management Plan (1999)—Page 11-23. The average TDS of groundwater pumped in agricultural areas in Tucson AMA is based on an estimate for eastern Pima County generated by the Pima Association of Governments (September 15,2003) for the year 2000, with assumed incremental increase by 2015.

(14) The volume of water used by agriculture is the sum of (5), (6), and (16). The composite TDS concentration of the three waters used by agriculture is the volume-weighted average of (5), (6), and (16) as included in the ADWR-Tucson AMA Third Management Plan (1999)—Page 11-23.

(15) The volume and average TDS of groundwater delivered to residential, industrial, and commercial water users in the Tucson AMA. The volume is derived from ADWR-Tucson AMA Third Management Plan (1999)—Page 11-23, as modified by Tucson Water assumption of full Tucson AMA CAP utilization. The average TDS of groundwater is the same as (4).

(16) CAP Recharge Banking is not assumed to continue in a "typical year" beyond the year 2015.

(17) Volume refers to effluent discharged by Pima County wastewater treatment plants other than Ina Road Water Pollution Control Facility and the Roger Road Wastewater Treatment Plants; none of this volume leaves the Tucson AMA. The TDS is assumed to be the same as in (15).

(18) The volume represents the projected reclaimed water to be used in 2015 for turf irrigation and industrial uses including Tucson Water's reclaimed water system and effluent used at the Silverbell Golf Course and the Arthur Pack Golf Course. The TDS is projected for the Reclaimed Water System as an increase of 125 mg/L over the 2015 Wastewater TDS, similar to measured concentration for 2000.

(19) The his is the industrial component of (18). The TDS is the same as (18)

(20) This is the turf irrigation component of (18). The TDS is the same as (18)

(21) The volume represents secondary effluent projected to be discharged to the Santa Cruz River in 2015 by two Pima County wastewater treatment plants. The TDS is the same as in (15).

(22) Evapotranspiration estimate from effluent flows in the Santa Cruz River is derived from K. Galyean (U.S. Geological Survey Water Resources Investigations Report 96-4021) and further modified by Tucson Water for facility permitting purposes.

(23) The projected volume of recovered recharged secondary effluent associated with a managed in-channel underground storage facility permit in 2015. The TDS is assumed to be the same as in (15).

(24) Volume of in-channel effluent outflow leaving the Tucson AMA as surface water is calculated as follows: (24) = (21) – [(22) + 41,000 acre-feet/yr] where 41,000 acre-feet is the volume of effluent which annually infiltrates in the Santa Cruz River channel between the two treatment plant outfalls and the Tucson AMA boundary as per the Lower Santa Cruz River Managed Recharge Project Application for an Underground Storage Facility Permit (2002). The TDS is the same as in (15).

(25) The volume of groundwater underflow leaving the Tucson AMA and entering the Pinal AMA at near Picacho as per ADWR-Tucson AMA Third Management Plan (1999), Page 2-16. However, ADWR plans to update the water budget for Tucson AMA based on the results of its updated groundwater model for Tucson AMA; the documentation is still in draft form and is currently under review. The groundwater outflow across this boundary is estimated to be about 25% less than the estimate published in the Third Management Plan. The groundwater TDS estimate along the outflow boundary is a spatially-weighted average based on TDS and electrical conductivity data obtained from ADWR-GWSI, ADEQ, and USGS

databases; the electrical conductivity values were converted to TDS by applying an empirically-based factor of 0.64.

(26) Additional salt added due to human activities such as the application of fertilizers and municipal and industrial use. The amount of salt added to each item is based on the *Salt Balance Phoenix Metro Area Typical Year, Draft*, CASS, 2002. The salt added to each Tucson item was based on the volumetric proportion to the corresponding item in the Phoenix Metro Area.

CENTRAL ARIZONA SALINITY STUDY --- PHASE I

Technical Appendix F

HYDROLOGIC REPORT ON THE HARQUAHALA BASIN

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1.0 INTRODUCTION

The Central Arizona Salinity Study (CASS) is a coalition of water and wastewater agencies evaluating salinity issues in Central Arizona. The mission of CASS is to provide its members with workable alternatives for a quality, cost effective, sustainable, and reliable water supply through partnerships and cooperative efforts in regional salinity planning and management. CASS was formed in November 2001. CASS is a study group and not a legal entity.

Salinity from local and imported sources is increasing the salinity of groundwater in localized areas and the salinity of reclaimed water in Central Arizona. The magnitude of the salinity issue is unclear and water providers in Central Arizona decided to work together to assess the problem and, if necessary, develop regional strategies for managing it. Central Arizona water providers must work together to protect, preserve, and develop these shared resources and to respond to issues of: increasing water quality and water supply regulation; increasing reclaimed water utilization; increasing levels of salinity into water reclamation facilities; developing brine disposal strategies; deteriorating groundwater quality in localized areas; and managing costs.

If no workable solution is implemented, salinity increases may result in greater water and wastewater treatment costs, decreased agricultural production, and some water sources may become unsuitable for their intended uses.

- Increasing salinity levels may reduce the ability of water providers to use groundwater and reclaimed water to meet customer water demands. Some communities may not have enough supply to meet demand. Growth and development in these communities may become limited.

- Water reclamation plants may have water quality permit compliance problems. High salinity levels in reclaimed water supplies may make this resource unsuitable for some of its intended uses. Retrofitting water reclamation plants to manage salinity and dispose of brine may significantly increase wastewater treatment costs.

- Water customer complaints may increase due to increasing salinity of the drinking water supply. Retrofitting potable water treatment plants to manage salinity and dispose of brine may significantly increase water treatment costs.

The following white paper describes hydrologic conditions in the Harquahala Basin. This report is based on literature review of publicly available information, and site-specific fieldwork was not conducted as part of this study. The purpose of the report is to provide a general framework of the physical, geologic, and hydrologic aspects of the basin. The report will also discuss surface water quality and groundwater quality over time, with a primary focus on salinity.

2.0 PHYSICAL SETTING

The Harquahala Basin is located in west-central Arizona within the Sonoran Desert section of the Basin and Range physiographic province (Figure 1). The basin is adjacent to the Phoenix Active Management Area (AMA) to the east, Lower Gila Basin to the south, Ranegras Plain Basin to the west, and McMullen Valley Basin to the north. The Harquahala Basin comprises approximately 765 square miles, and precipitation in the basin averages approximately 6 inches per year (Hedley, 1990). The principal natural surface drainage feature is Centennial Wash, which enters the basin between the Harquahala and Little Harquahala Mountains in the northwest, and exits the basin between Saddle Mountain and the Gila Bend Mountains in the southeast (Figure 2). The land surface elevation ranges from 1,000 feet above mean sea level (amsl) where Centennial Wash exits the basin to over 5,000 feet amsl in the surrounding mountains. The basin supports a sparsely populated agricultural community of approximately 900 people, and the population is projected to increase slightly to 1,000 people by the year 2040 (ADWR, 1993).

3.0 GENERALIZED GEOLOGY

The Harquahala Basin is thought to have formed during the Tertiary Basin and Range Disturbance. During this disturbance, widespread extensional deformation in southern and western Arizona resulted in northwest trending mountain ranges separated by alluvial filled troughs.

3.1 BEDROCK GEOLOGY

The Harquahala Basin is bounded by the Harquahala Mountains on the north, Big Horn Mountains on the northeast, Saddle Mountain on the southeast, Gila Bend Mountains on the south, Eagletail Mountains on the southwest, and Little Harquahala Mountains on the northwest (Figure 2). The bounding mountain ranges are predominantly comprised of Precambrian granitic and metamorphic rocks, Mesozoic and Paleozoic sedimentary rocks, Jurassic to Late Cretaceous granitic rocks and volcanics, and Tertiary volcanics and basalt (Reynolds, 1988. Hedley, 1990). In general, the sedimentary and metamorphic rocks primarily occur in the north/northwest portion of the basin (Harquahala and Little Harquahala Mountains), and the granitic rocks and volcanics dominate the bedrock geology elsewhere in the basin.

3.2 BASIN GEOLOGY

The Harquahala Basin is comprised of a relatively deep, northwest trending alluvial valley that is typical of the Basin and Range physiographic province. Based on gravity modeling (Oppenheimer and Sumner, 1980), the depth to bedrock in the majority of the basin is greater than 1,600 feet below land surface (bls). The gravity modeling also suggests the deepest portion of the basin is near the center, with a depth to bedrock greater than 8,000 feet bls. Graf (1980) reported that the alluvial deposits are less than 300 feet thick near the mountains, and greater than 2,000 feet thick near the center of the basin. Hedley (1990) reported that the alluvial deposits are up to 5,000 feet thick in the center of the basin. Although differences in depth to bedrock values are noted in each study, the alluvial deposits are thickest near the center of the basin, and thin towards the bounding mountain ranges.

Based on the study by Hedley (1990), the basin fill alluvium in the Harquahala Basin is composed of heterogenous deposits of clay, silt, sand and gravel. The most prominent alluvial unit in the basin is an extensive fine-grained (clay-dominated) deposit. The approximate extent of the fine-grained deposit as modified from Graf (1980) is shown on Figure 2. The fine-grained deposit occurs in the majority of the basin, and is known to be absent only in the extreme southeastern portion of the basin. According to Graf (1980), the thickness of the fine-grained deposits increases towards the northwest, and is more than 1,000 feet thick in the center of the basin. Relatively coarse-grained sand and gravel deposits occur in the southeastern portion of the basin, and also underlie the fine-grained deposits in the majority of the basin.

4.0 HYDROGEOLOGIC CONDITIONS

4.1 GROUNDWATER OCCURRENCE AND MOVEMENT

The alluvial basin fill deposits represent the regional aquifer in the Harquahala Basin. Groundwater in the alluvial deposits is generally unconfined, although local semi-confined to confined conditions exist. Based on estimates by the Arizona Department of Water Resources (ADWR) in 1988, the Harquahala Basin contains approximately 15.5 million acre-feet of recoverable groundwater to a depth of 1,200 feet. Natural recharge to the aquifer is minimal, and is estimated at approximately 1,000 acre-feet per year (ac-ft/yr), primarily as underflow from the McMullen Valley Basin (Freethey and Anderson, 1986). Sources of man-induced groundwater recharge include irrigation seepage (varies), losses from the Central Arizona Project (CAP) canal (5,900 ac-ft/yr), and permitted recharge facilities (projected up to 100,000 ac-ft/yr). The primary sources of discharge from the aquifer are groundwater pumpage for crop irrigation (varies) and evapotranspiration (100 ac-ft/yr).

Based on predevelopment hydrologic conditions, groundwater flowed into the Harquahala Basin from the northwest (McMullen Valley Basin inflow), generally mimicked the direction of surface flow (Centennial Wash) to the southeast, and exited the basin as underflow into the Hassayampa Sub-Basin of the Phoenix AMA (Freethey and Anderson, 1986). However, major groundwater development began in the southeast portion of the basin in 1951, eventually altering the groundwater flow regime. By 1954, approximately 6,000 acres of land was being cultivated with groundwater produced from 20 wells (Stulik, 1964). Agricultural development reached its peak in 1966, totaling 39,500 acres under irrigation with approximately 120 wells supplying 200,000 ac-ft of groundwater (Denis, 1971). Due to the extensive pumping, the groundwater flow direction to the southeast reversed in the developed portion of the basin, and by 1957 the flow direction was toward the northwest (Denis, 1971). By 1966, the majority of the groundwater in the basin flowed toward a well developed cone of depression beneath the agricultural area, resulting in little to no groundwater outflow into the Hassayampa Sub-Basin (Denis, 1971. Graf, 1980).

Due to significant groundwater depletion, the Harquahala Basin was designated as an Irrigation Non-expansion Area (INA) by the Director of the ADWR in 1982. Within an INA, the irrigation of any land is prohibited unless the land was irrigated during the five years preceding the date of designation, which amounts to 38,500 acres of farmland in the Harquahala Basin (ADWR, 1993). According to Hedley (1990), groundwater levels in the agricultural portion of the basin declined up to 325 feet from 1951 to 1980. Although groundwater declines are significant, only 0.6 ft of subsidence has occurred in the basin from 1927 to 1981, and evidence of subsidence is limited to two small earth fissures (Schumann and Genualdi, 1986). With the introduction of CAP water in the mid 1980's, groundwater pumpage decreased dramatically, and groundwater levels have risen as much as 70 feet in the southeast portion of the basin (Hedley, 1990).

4.2 GROUNDWATER QUALITY

The Arizona State Land Department conducted the initial water quality study in the Harquahala Basin, sampling 23 wells from 1952 to 1955. Based on sampling results from this study, total dissolved solids (TDS) concentrations ranged from 432 to 864 milligrams per liter (mg/l), and averaged 608 mg/l (Metzger, 1957). The relatively small range in TDS concentrations and minor groundwater development at the time suggests that the TDS values are likely representative of ambient (predevelopment) groundwater quality conditions. Metzger (1957) also noted that the TDS content represented no water quality problems in the basin with respect to potential irrigation uses. As follow up to this study, the Arizona State Land Department conducted another water quality study in 1966, which included the sampling of 21 wells. Based on sampling results from this study, TDS concentrations ranged from 429 to 810 mg/l, and averaged 616 mg/l (Denis, 1971). Although significant groundwater development occurred in the Harquahala Basin by 1966, TDS concentrations compare readily with the initial water quality study, suggesting that the regional aquifer was not impacted from salinity due to agricultural irrigation at this time.

The ADWR conducted two additional studies that included comprehensive water quality sampling in the Harquahala Basin. The study by Graf (1980) included the sampling of 61 wells from 1979 to 1980. Graf noted that TDS concentrations ranged from 438 to 2,340 mg/l, and averaged 762 mg/l. The study by Graf also indicated that an extensive perched water system had developed beneath the southeast agricultural area, due to downward percolation of irrigation water above the extensive fine-grained unit (Figure 2). The study by Hedley (1990) involved the sampling of 89 wells from 1984 to 1989, and TDS concentrations ranged from 429 to 1,800 mg/l (average 700 mg/l). Hedley also noted the extensive perched water zone beneath the southeast agricultural area, and indicated that cascading water from the perched zone was cross-contaminating the regional aquifer via wells.

A comparison of TDS concentrations over time in the Harquahala Basin, based on the previously discussed water quality studies, is presented in Table 1 and is graphically displayed on Figure 3. In general, the studies conducted by Metzger (1957) and Denis (1971) suggest that the regional aquifer was not impacted from agricultural irrigation, and that the sample results likely reflect ambient groundwater quality in the basin. By contrast, the ADWR studies noted the formation of an extensive perched water system with significantly increased TDS concentrations compared to the regional aquifer. Furthermore, cross-contamination through wells (cascading water from the perched system to the underlying regional system) has degraded water quality locally (Hedley, 1990. Graf, 1980). This is also indicated by the abrupt increase in maximum TDS concentrations noted in the ADWR studies, which compare readily to the average perched water system TDS concentrations.

TABLE 1. TDS CONCENTRATIONS IN THE HARQUAHALA BASIN

SOURCE AND SAMPLE YEARS	MINIMUM (mg/l)	MAXIMUM (mg/l)	AVERAGE (mg/l)
Arizona State Land Department (Metzger, 1957) Samples collected from 1952 to 1955	432	864	608
Arizona State Land Department (Denis, 1971) Samples collected in 1966	429	810	616
Arizona Department of Water Resources (Graf, 1980) Samples collected from 1979 to 1980	438	2,340	762 (2,421)
Arizona Department of Water Resources (Hedley, 1990) Samples collected from 1984 to 1989	429	1,800	700 (2,036)
Note: TDS concentrations represent the regional aquifer system, with the exception of TDS concentrations shown in parentheses that represent the perched water system.			

5.0 SURFACE WATER CONDITIONS

5.1 SURFACE WATER OCCURRENCE

The principal natural surface drainage feature is Centennial Wash, which enters the basin between the Harquahala and Little Harquahala Mountains in the northwest, and exits the basin between Saddle Mountain and the Gila Bend Mountains in the southeast (Figure 2). Centennial Wash and its tributaries are ephemeral, and flow only in response to local precipitation. Due to the arid climate in the basin (approximately 6 inches per year precipitation), flows in Centennial wash are extremely low, and unreliable for crop irrigation (Denis, 1971). Also, due to the extremely low flows, no United States Geological Survey (USGS) stream gauging sites are located within the basin to measure annual flow. Freethey and Anderson (1986) reported that perennial stream losses (inflow) and stream base flow (outflow) for Centennial Wash were essentially zero, and subsequently not included in the predevelopment groundwater budget for the basin. Therefore, the surface flows in Centennial Wash and its tributaries are considered to be negligible for the purposes of this study.

The only reliable surface water source in the Harquahala Basin is the CAP canal, which traverses from west to east across the basin (Figure 2). The CAP canal began delivering water for crop irrigation in the mid 1980's, substantially reducing the reliance on groundwater pumping in the basin. The relationship between groundwater pumping and CAP deliveries in the Harquahala Basin is illustrated on Figure 4. According to rates determined by the Central Arizona Water Conservation District, as reported by ADWR (1988), approximately 5,900 ac-ft/yr is recharged into the basin due to seepage along the canal.

5.2 SURFACE WATER QUALITY

Surface water quality is only available for the CAP canal in the Harquahala Basin. There are no USGS water quality stations in the basin, and therefore no publicly available water quality information for Centennial Wash and its tributaries exists. Based on previous studies in the Salt River Valley, the TDS concentration of CAP water delivered in the Harquahala Basin is assumed to be 560 mg/l.

6.0 GENERALIZED SALT BALANCE

Based on ADWR groundwater pumpage data and CAP water deliveries in the Harquahala Basin, a generalized salt balance was calculated for the Harquahala Basin. The salt balance is divided into three distinct time frames on the basis of irrigation water sources and CAP water usage. The period from 1951 to 1985 represents extensive groundwater development and pumping, almost exclusively for agricultural irrigation. By contrast, the period from 1986 to 2002 represents the introduction of CAP water for irrigation, and significant reductions in groundwater pumpage. Future conditions include the Vidler Recharge Facility in the basin and continued irrigation with CAP water. Results of the salt balance are presented in Table 2 and graphically illustrated on Figure 5. Assumptions utilized in the salt balance are listed below:

TABLE 2. GENERALIZED SALT BALANCE FOR THE HARQUAHALA BASIN

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

- The difference in natural recharge to the basin and groundwater outflow from the basin is negligible.
- All groundwater pumpage is utilized for agricultural irrigation.
- The TDS concentration of CAP deliveries and canal seepage is 560 mg/l.
- Wastewater (septic) infiltration and irrigation return flows are not included in the salt balance, as they originate and terminate within the basin.
- Future salt loading assumes current agricultural practices (1986 to 2002) continue into the future, and that the Vidler Recharge Facility operates at the permitted capacity (100,000 ac-ft/yr).
- The Harquahala Basin is essentially a “closed” basin, and there is no salt removal.

Prior to the introduction of CAP water, the only reliable source of water in the Harquahala Basin was groundwater from wells, and virtually all of the groundwater pumped was utilized for agricultural purposes (Graf, 1980). According to the ADWR Assessment in 1993, municipal and industrial water demands in the basin are essentially negligible (1,000 ac-ft/yr), and represent 1 percent of the average water pumpage in the basin (104,000 ac-ft/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. Based on previous salt contribution calculations from

irrigation in the Salt River Valley, the crop irrigation in the Harquahala Basin would result in approximately 0.002 million tons of salt per year.

Utilization of CAP water for irrigation purposes in the mid 1980's essentially replaced groundwater pumping in the basin. Compared to average pumping from 1951 to 1985 (104,000 ac-ft/yr), groundwater production decreased dramatically to approximately 8,500 ac-ft/yr from 1986 to 2002. During this time, average CAP water deliveries were approximately 81,000 ac-ft/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 at 0.002 million tons per year. However, CAP water represents a new water source inflow for the basin, resulting in additional salts of approximately 0.066 million tons per year. The additional salts were calculated based on the quantity of CAP deliveries (including seepage) and an average TDS concentration of 560 mg/l. Recharge facilities also represent additional inflow of CAP water into the basin. The Vidler Recharge Facility began pilot operations in 1998, and had recharged approximately 17,000 ac-ft of water by 2002 based on reported water deliveries (CAP, 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 ac-ft/yr of CAP water. For the purposes of the annual salt accumulation graph (Figure 5), the year 2010 was arbitrarily chosen to represent the future. 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 ADWR Assessment (1993).

The annual salt accumulation in the Harquahala Basin is relatively low (0.069 million tons per year) compared to recently completed salt balances in nearby basins. By comparison, the Gila Bend Basin averages approximately 0.5 million tons per year of salt, and the Salt River Valley 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. The agricultural area encompasses approximately 40,000 acres, and the downward percolation of irrigation water in this area has caused a perched water system to form 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.

7.0 REFERENCES

Arizona Department of Water Resources: Harquahala Basin. www.water.az.gov/adwr/Content/WaterInfo/OutsideAMAs/LowerColorado/Basins/harquahala.html.

Arizona Department of Water Resources, April 1993. Draft Water Resources Assessment, Inventory and Analysis of Water Resources Issues.

Central Arizona Project. Water Deliveries by Turnout Report for Calendar Years 1987 through 2002.

Daniel, D.L., January 1981. Arizona Department of Water Resources: Maps Showing Total Dissolved Solids Content of Groundwater in Arizona.

Denis, E.E., April 1971. Arizona State Land Department: Ground-Water Conditions in the Harquahala Plains, Maricopa and Yuma Counties, Arizona.

Freethey, Geoffrey W. and Anderson, T.W., 1986. United States Department of the Interior, U.S. Geological Survey: Predevelopment Hydrologic Conditions in the Alluvial Basins of Arizona and Adjacent Parts of California and New Mexico.

Graf, C.G., 1980. Arizona Department of Water Resources: Maps Showing Ground-Water Conditions in the Harquahala Plains Area, Maricopa and Yuma Counties, Arizona—1980.

Hedley, J.D., January 1990. Arizona Department of Water Resources: Maps Showing Groundwater Conditions in the Harquahala Irrigation Non-Expansion Area and Tiger Wash Basin, Maricopa and La Paz Counties, Arizona—1989.

Metzger, D.G., September 1957. Arizona State Land Department: Geology and Ground-Water Resources of the Harquahala Plains Area, Maricopa and Yuma Counties, Arizona.

Oppenheimer, J.M., and Sumner, J.S., 1980. Depth-to-Bedrock Map, Basin and Range Province, Arizona.

Reynolds, Stephen J., 1988. Geologic Map of Arizona. Arizona Geological Survey Map 26. Produced in cooperation with the U.S. Geological Survey.

Schumann, Herbert H, and Genualdi, Robert B, 1986. Map of Land Subsidence, Earth Fissures, and Water-Level Change in Southern Arizona.

Stulik, R.S., September 1964. Arizona State Land Department: Effects of Ground-Water Withdrawal, 1954-63, in the Lower Harquahala Plains, Maricopa County, Arizona.

United States Department of the Interior, U.S. Geological Survey, 2002. Water Resources Data, Arizona, Water Year 2002. Water-Data Report AZ-01-1.

United States Geological Survey: www.waterdata.usgs.gov/nwis/annual.

Sebenik P.G., May 1981. Arizona Department of Water Resources: Maps Showing Ground-Water Conditions in the Gila Bend Basin Area, Maricopa County, Arizona—1979.

CENTRAL ARIZONA SALINITY STUDY --- PHASE I

Technical Appendix G

HYDROLOGIC REPORT ON THE PINAL ACTIVE MANAGEMENT AREA

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1.0 INTRODUCTION

The Central Arizona Salinity Study (CASS) is a coalition of water and wastewater agencies evaluating salinity issues in Central Arizona. The mission of CASS is to provide its members with workable alternatives for a quality, cost effective, sustainable, and reliable water supply through partnerships and cooperative efforts in regional salinity planning and management. CASS was formed in November 2001. CASS is a study group and not a legal entity.

Salinity from local and imported sources is increasing the salinity of groundwater in localized areas and the salinity of reclaimed water in Central Arizona. The magnitude of the salinity issue is unclear and water providers in Central Arizona decided to work together to assess the problem and, if necessary, develop regional strategies for managing it. Central Arizona water providers must work together to protect, preserve, and develop these shared resources and to respond to issues of: increasing water quality and water supply regulation; increasing reclaimed water utilization; increasing levels of salinity into water reclamation facilities; developing brine disposal strategies; deteriorating groundwater quality in localized areas; and managing costs.

If no workable solution is implemented, salinity increases may result in greater water and wastewater treatment costs, decreased agricultural production, and some water sources may become unsuitable for their intended uses.

- Increasing salinity levels may reduce the ability of water providers to use groundwater and reclaimed water to meet customer water demands. Some communities may not have enough supply to meet demand. Growth and development in these communities may become limited.

- Water reclamation plants may have water quality permit compliance problems. High salinity levels in reclaimed water supplies may make this resource unsuitable for some of its intended uses. Retrofitting water reclamation plants to manage salinity and dispose of brine may significantly increase wastewater treatment costs.

- Water customer complaints may increase due to increasing salinity of the drinking water supply. Retrofitting potable water treatment plants to manage salinity and dispose of brine may significantly increase water treatment costs.

The following white paper describes hydrologic conditions in the Pinal Active Management Area (AMA). This report is based on literature review of publicly available information. Site-specific fieldwork was not conducted as part of this study. The purpose of the report is to provide a general framework of the physical, geologic, and hydrologic aspects of the basin. The report will also discuss groundwater quality and surface water quality over time, with a primary focus on salinity.

2.0 PHYSICAL SETTING

The Pinal AMA is located in south-central Arizona within the Sonoran Desert section of the Basin and Range physiographic province (Figure 1). The boundary of the Pinal AMA is generally consistent with the boundary of the Lower Santa Cruz basin. The Maricopa-Stanfield, Eloy, Vekol, Santa Rosa, and Aguirre Valley sub-basins comprise the Pinal AMA (Figure 2). Water use in the AMA has been primarily in the Maricopa-Stanfield and Eloy sub-basins in the northern portion of the AMA. Due to a lack of development, little or no data is available for the Vekol, Santa Rosa, and Aguirre Valley sub-basins (ADWR, 2003). The general focus of this study has been on the Maricopa-Stanfield and Eloy sub-basins, thus they are referred to in this report as the principal sub-basins.

The Pinal AMA is adjacent to the Phoenix AMA to the north, Donnelly Wash Basin and the Tucson AMA to the east, San Simon Wash Basin to the south, and the Gila Bend Basin to the west. The Pinal AMA comprises approximately 4,100 square miles, land surface elevation ranges from 1,000 feet to 4,000 feet above mean sea level (amsl), and precipitation averages between approximately 6.5 and 8.5 inches per year (ADWR, 2000). The average daily mean temperature at a weather station at the Casa Grande National Monument is 69.4 degrees Fahrenheit (Western Regional Climate Center, 2003).

Principal surface drainage features include the Gila and Santa Cruz Rivers. Within the principal sub-basins, these rivers are generally dry except after a significant storm event (Hammett, 1992). However, the San Carlos Project delivers Gila River water for irrigation within the Pinal AMA, and Pima County wastewater treatment plants contributes intermittent flow to a portion of the Santa Cruz River (ADWR, 1993). The Gila River enters the northeast corner of the AMA and generally extends westward into the Phoenix AMA, then re-enters the northwest corner of the Pinal AMA. The Santa Cruz River enters the east side of the AMA near Picacho Peak and extends northwest as a broad wash area that discharges into the Gila River in the northwest corner of the AMA (Figure 2).

The Central Arizona Project (CAP) aqueduct flows through the eastern portion of the Eloy Sub-basin. Since 1987, water from the CAP has been utilized for irrigation uses within the Pinal AMA (ADWR, 2000). CAP deliveries are made to the Maricopa-Stanfield Irrigation and Drainage District (MSIDD), the Central Arizona Irrigation and Drainage District (CAIDD), the Hohokam Irrigation and Drainage District (HIDD), the Ak Chin Indian Community, the City of Eloy, and Arizona Water Company in Casa Grande (ADWR, 2003).

3.0 GENERALIZED GEOLOGY

Basins within the Pinal AMA are thought to have formed during the Tertiary Basin and Range Disturbance. During this disturbance, widespread extensional deformation in southern and western Arizona resulted in northwest trending mountain ranges separated by alluvial filled troughs.

3.1 BEDROCK GEOLOGY

The principal sub-basins of the Pinal AMA are bounded by South Mountain, Sacaton, and Santan Mountains on the north; Tortilla and Picacho Mountains on the east; Silver Bell, Sawtooth, Tat Momoli, and Tabletop Mountains on the south; and the Sierra Estrella and Palo Verde Mountains on the west (Figure 2). The mountain ranges to the south and east are predominantly comprised of Tertiary volcanic and granitoid rocks. The mountain ranges on the northern and western boundaries of the principal sub-basins are predominately Tertiary granitoid rocks and Precambrian granitoid and metamorphic rocks (Reynolds, 1988).

3.2 BASIN GEOLOGY

The Pinal AMA is comprised of north trending structural troughs that include five sub-basins separated by low mountains. Based on gravity modeling, the depth to bedrock is less than 1,600 feet below land surface (bls) in the majority of the Pinal AMA (Oppenheimer and Sumner, 1980). However, gravity modeling also suggests a deep portion in each sub-basin. The deepest sub-basins include the Maricopa-Stanfield (estimated between 6,400 and 8,000 feet deep), the Santa Rosa (between 8,000 and 9,600 feet deep), and the Eloy sub-basin (between 9,600 and 11,200 feet deep). The Aguirre sub-basin is between 3,200 and 4,800 feet deep and two small basins in the Vekol sub-basin are between 1,600 and 3,200 feet deep.

Based on the study by Hammet (1989), the alluvial deposits in the principal sub-basins are separated into three distinct units, referenced as the stream alluvium, upper basin fill, and lower basin fill. A brief summary of each unit is presented below:

- ***Stream Alluvium.*** Unconsolidated fluvial deposits that are late Pliocene to Holocene in age characterize the stream alluvium. The extent of the stream alluvium deposits is restricted to the Santa Cruz and Gila Rivers and its tributaries and washes.

- ***Upper Basin Fill.*** The upper basin fill is characterized by unconsolidated to moderately cemented gravel, sand, silt, and clay. The finest fill deposits are found near the centers of the sub-basins. The upper basin fill deposits were likely deposited in an integrated (through-flowing) drainage basin. Agriculture primarily utilizes groundwater in the Upper Basin Fill for irrigation.
- ***Lower Basin Fill.*** The lower basin fill primarily consists of conglomerate and a fine-grained unit. The fine-grained unit is predominately silt and clay near the centers of

the sub-basins. However, this fine-grained unit becomes coarser at the margins of the sub-basins and includes sand and gravel lenses that are utilized for water production.

4.0 HYDROGEOLOGIC CONDITIONS

4.1 GROUNDWATER OCCURRENCE

Based on estimates by the Arizona Department of Water Resources (ADWR, 2003), the principal sub-basins contain approximately 34 million acre-feet of recoverable groundwater to a depth of 1,200 feet. Since 1989, groundwater storage in the AMA has increased due to significant flood events and reduced groundwater reliance. The primary source of groundwater recharge (inflow) to the principal sub-basins is infiltration of irrigation water from the San Carlos and Central Arizona Projects. Additional sources of recharge include groundwater flow from adjacent sub-basins and infiltration of storm water from the Gila and Santa Cruz Rivers and its tributaries. Loss of water from the principal sub-basins is primarily a result of groundwater and surface water outflow

Based on predevelopment hydrologic condition, groundwater in the principal sub-basins of the Pinal AMA generally flowed west to northwest (Freethey and Anderson, 1986), roughly following flow directions of the Gila and Santa Cruz Rivers. The estimated pre-development volume of water stored in the principal sub-basins (to a depth of 1,200 feet) was approximately 63 million acre-feet. The groundwater system was in dynamic equilibrium with slight to non-existent vertical hydraulic gradients (Hamett, 1992). Beginning in the 1930s, major groundwater development significantly changed these conditions.

Between the 1930s and 1987, more than 47 million acre-feet of water had been pumped in the Pinal AMA (United States Geologic Survey (USGS), 1986). As a result, cones of depression formed at pumping centers near the cities of Stanfield and Eloy. By 1986, water levels in the Stanfield and Eloy areas had declined more than 550 and 350 feet, respectively (Hamett, 1992). Because of extensive pumping, approximately 120 square miles of land in the area of the pumping centers subsided, a maximum of approximately 12 feet in the Eloy area (Laney, 1978). Earth fissures formed predominately at the margins of the land subsidence zones and are extensive in the Eloy area (Schumann, 1974).

Since deliveries of CAP water began in 1987, water levels in the Stanfield and Eloy areas have increased due to decreased reliance of groundwater and implementation of efficient water-use practices. Between 1989 and 1998, water levels have risen 50 to 150 feet in the Stanfield area and 50 to 175 feet in the Eloy area (ADWR, 2003).

Based on data collected in the late 1980s, two major perched water systems are identified in the principal sub-basins, formed as a result of irrigation return flow. The perched zones are located in the Casa Grande area and in an area extending from Coolidge to between Sawtooth and Picacho Mountains (Hammett, 1992). The Casa Grande perched zone is generally the result of irrigation, however after significant storm events, the Santa Cruz River also provides recharge to the zone. Depths to water in the Casa Grande perched zones range from less than 10 feet to approximately 100 feet (ADWR, 2003). The zone extending south from Coolidge is partially perched, and depths to water range between 50 and 300 feet (Hammett, 1992)

4.2 GROUNDWATER MOVEMENT

The ADWR (2000) has identified post-development inter-basin groundwater flow with respect to the principal sub-basins of the Pinal AMA (Figure 2). Major groundwater inflow has contributed

to the principal sub-basins from the west by the South Picacho Peak inflow (~29,000 acre-feet per year) and from the north by the Maricopa-Stanfield inflow (~24,600 acre-feet per year). Groundwater inflow, from Waterman Wash to the west and Aguirre Valley to the south, total approximately 3,500 acre-feet per year. Groundwater outflows include the SanTan-Sacaton and Florence outflows to the north, totaling approximately 10,500 acre-feet per year. Based on the difference between inflows and outflows, approximately 46,600 acre-feet per year of groundwater flows into the principal sub-basins.

Prior to development, groundwater inflows and outflows from the principal sub-basins were generally equal. Groundwater development, beginning in the 1930s, significantly changed this condition, especially in the northwestern portion of the principal sub-basins. Due to the cones of depression, groundwater that had previously flowed out of the basin to the northwest had reversed directions and resulted in the Maricopa-Stanfield groundwater inflow.

4.3 GROUNDWATER QUALITY

According to ADWR (2003), groundwater quality in the principal sub-basins is sufficient for agricultural, industrial, and residential uses, and no major water quality concerns were identified. Based on water level and water quality data collected in the late 1980s, Hammett (1992) identified upper and lower water zones that generally correlate to the upper and lower basin fill units. In addition, a perched water zone was identified.

Total dissolved solids (TDS) concentrations are a general measure of water quality and specific conductivity is directly related to TDS concentration. TDS concentrations can be estimated by multiplying the conductivities measured in groundwater samples by 0.60.

In the upper water zone, specific conductivities range between 1,000 and 2,000 μS/cm (approximately 600 to 1,200 mg/l TDS) in the northern portion of the Eloy sub-basin and the margins of the Maricopa-Stanfield sub-basin. Water quality generally improves in the upper zone in the southern portions of the Eloy sub-basin and in the Stanfield area where specific conductivities are generally below 1,000 μS/cm (below approximately 600 mg/l TDS). Water quality distribution throughout the lower water zone is similar to the upper water zone, except in the northern portion of the Eloy sub-basin and margins of the Maricopa-Stanfield sub-basin, where specific conductivities are between approximately 3,000 and 7,000 μS/cm (approximately 1,800 and 4,200 mg/l TDS).

The perched water system is generally the result of agricultural practices and is reflected in water quality. Specific conductivities in the perched zone located in the Casa Grande area range between 2,000 and 4,000 μS/cm (approximately 1,200 to 2,400 mg/l TDS). In the perched zone that extends south from Coolidge, specific conductivities generally range between 1,300 and 2,300 μS/cm (780 to 1,380 mg/l TDS), however values up to 4,700 μS/cm (2,820 mg/l TDS) were recorded.

4.4 INTER-BASIN GROUNDWATER FLOWS AND TDS CONCENTRATIONS

The TDS concentrations of groundwater inflow and outflow were estimated from water quality parameters recorded in wells in the general areas of the inter-basin inflows and outflows. Three to seven conductivity measurements were used to estimate an average TDS concentration for each flow (Hammett, 1989 and Reeter, 1986) and are presented in Table 1. Assumptions utilized to determine average values are listed below:

TABLE 1. AVERAGE ANNUAL INTER-BASIN GROUNDWATER FLOW AND TDS CONCENTRATIONS

DESCRIPTION	FLOW (acre-feet per year)	AVERAGE TDS CONCENTRAION (mg/l)
South Picacho Peak Groundwater Inflow	29,000	290
Maricopa-Stanfield Groundwater Inflow	24,600	2,292
Aguirre Groundwater Inflow	2,900	393
Waterman Wash Groundwater Inflow	600	580
Santan-Sacaton Groundwater Outflow	7,500	1,604
Florence Groundwater Outflow	3,000	884
Total Groundwater Inflow	46,600	

- Groundwater flow, ADWR (2000).
- Groundwater inflow and outflow and TDS concentrations remain constant.
- Average TDS concentrations based on specific conductivity values in the flow areas.

4.5 SALT ACCUMULATION DUE TO AGRICULTURE

Between 1984 and 1998, Pinal AMA agriculture utilized between 800,000 and 1,200,000 acre-feet of water per year (ADWR, 2000). For purposes of this study, an annual average of 1,000,000 acre-feet of water was utilized for irrigation in the AMA. Based on previous salt contribution calculations from irrigation in the Salt River Valley, crop irrigation in the Pinal AMA would result in approximately 0.0200 million tons of salt per year.

5.0 SURFACE WATER CONDITIONS

5.1 SURFACE WATER OCCURRENCE

Surface water features in the Pinal AMA include the Gila and Santa Cruz Rivers and the CAP aqueduct. The Gila and Santa Cruz Rivers are generally dry, except after significant storm events that result in surface water inflow and outflow from the principal sub-basins, and in areas where flow is contributed by wastewater treatment facilities. Annual surface water inflow and outflow from the principal sub-basins are shown on Figures 3 and 4.

The Gila River is generally dry due to a diversion at the eastern edge of the Eloy Sub-basin. The diversion provides irrigation water for the San Carlos Irrigation Project. Between 1934 and 1984, the San Carlos Irrigation Project has provided an average of approximately 218,000 acre-feet of Gila River water per year to the AMA, however yearly deliveries vary depending on the flow of the Gila River (ADWR, 1993). For example, between 1985 and 2000, the diversion has delivered between approximately 60,000 and 425,000 acre-feet per year (USGS, 2002). Some of this water is utilized by the Gila River Indian Community in the Phoenix AMA. However for this study, it is assumed that surface water use outside the Pinal AMA is negligible

The Santa Cruz River is generally dry in the Pinal AMA, however, inflow does occur due to the discharge of treated effluent from Pima County wastewater treatment plants. In addition, intermittent inflow and outflow generally occurs due to storm events (Figure 5). The Ina Road Waste Pollution Control Facility has been utilizing the Santa Cruz River for effluent discharge since 1978 (personal communication, 2003). The flow of the Santa Cruz River is measured by a USGS surface water station (#09486500), located approximately 22 miles upstream from the Pinal AMA. Between 1940 and 1977, an average of 26,000 acre-feet per year was recorded at this station. Flow increased to an average of 68,000 acre-feet per year (between 1978 and 2000) after construction of the Ina Road Plant. Minor diversions utilize this water in the Tucson AMA, however most of this flow evaporates or infiltrates (ADWR, 1993).

For the purposes of this study, an estimate of the amount of Santa Cruz river flow into the Pinal AMA was calculated. A USGS surface water station (#09486520) is located approximately 6 miles upstream from the Pinal AMA. Since 1996, flow at this station has been approximately 45 percent of the flow recorded upstream near the Ina Road facility. Based on the change in flow over distance between surface water stations and the border of the Pinal AMA, the flow of the Santa Cruz River to the Pinal AMA is estimated to be approximately 9 percent of the flow measured at USGS Surface Water Station #09486500. Additional inflow such as irrigation tailwater is considered negligible for this study.

The CAP aqueduct flows in the eastern portion of the Eloy Sub-basin, and began providing water to the AMA in 1987 (ADWR, 2003). Between 1989 and 1994, CAP deliveries to customers in the Pinal AMA averaged approximately 343,000 acre-feet per year (ADWR, 2003). Non-Indian irrigation districts were the predominant users of the CAP deliveries, Indian deliveries accounted for approximately 20 percent, and municipal use accounted for less than 1 percent.

5.2 SURFACE WATER QUALITY

Surface water quality data was aquired from USGS surface water stations on the Gila and Santa Cruz Rivers (USGS, 2003). Water quality data for the Gila River was obtained from a station near Kelvin, Arizona, approximately 19 miles upstream of the Pinal AMA. Gila River TDS concentrations and flow data were analyzed for the period between 1950 and 2000. Flow varied from less than 1 cubic foot per second (cfs) to 12,200 cfs, and TDS concentraions ranged between 184 and 4,330 mg/l. In general, during high river stages, TDS concentraions were low; during low-flow periods, TDS concentrainos were higher. This general relationship is shown on Figure 5 over a typical four year period. The average TDS concentration for the total Gila River flow between 1950 and 1987 was 653 mg/l. Between 1988 and 2000, the average TDS concentration was 596 mg/l.

Water quality data for the Santa Cruz river is limited in the study area. However, TDS concentration data is available from two USGS surface water stations (Figure 6). For this study, USGS Surface Water Station #09486500 (near the Ina Road Facility) represents water quality of Santa Cruz river inflow. One measurement of 335 mg/l TDS was recorded prior to completion of the Ina Road Facility and represents the TDS concentration of Santa Cruz River inflow between 1950 and 1977. The average TDS concentration of numerous samples collected in 1996 and 1997 is 527 mg/l, and this value represents the TDS concentration of Santa Cruz inflow between 1978 and 2000.

Numerous water quality samples were collected between 1976 and 1981 at USGS Surface Water Station #09489000 which was located on the Santa Cruz River, near the confluence with the Gila River in the northwest portion of the Maricopa-Stanfield sub-basin. The average TDS concentration of these samples is 362 mg/l. For purposes of this study, a TDS concentration of 362 mg/l is utilized for the surface water outflow of both the Santa Cruz and Gila Rivers.

5.3 HISTORICAL SURFACE WATER FLOWS AND TDS CONCENTRATIONS

The time period from 1950 to 2000 can be divided into two distinct intervals on the basis of annual surface water flow into the Pinal AMA. The interval from 1950 to 1987 represents the period of extensive groundwater pumping and Gila River diversions prior to major utilization of CAP water. The delivery of CAP water to the AMA is reflected in the 1988 to 2000 interval. The relationship between average annual surface flows and TDS concentrations is illustrated in Table 2, and assumptions utilized to determine average values are listed below:

TABLE 2. AVERAGE ANNUAL FLOW AND TDS CONCENTRATIONS IN SURFACE WATERS OF THE PINAL AMA

DESCRIPTION	1950 TO 1987	1988 TO 2000
Average annual Gila River diversions (acre-feet)	218,115	318,032
Average TDS concentrations in the Gila River diversions (mg/l)	653	596
Average annual Gila River outflow (acre-feet)	24,570	98,688
Average TDS concentrations in the Gila River outflow (mg/l)	362	362
Average annual Santa Cruz River inflows (acre-feet)	3,286	6,195
Average TDS concentrations in the Santa Cruz River inflow (mg/l)	391	527
Average annual Santa Cruz River outflows (acre-feet)	15,682	10,342
Average TDS concentrations in the Santa Cruz River outflow (mg/l)	362	362
Average annual CAP deliveries (acre-feet)		342,850
Average TDS concentrations of the CAP (mg/l)		640

- Gila River 1950 to 1987, average diversion between 1934 and 1984 (ADWR, 1993).
- Gila River 1988 to 200 diversions, USGS (2003).
- Entire Gila River delivery was used in the Pinal AMA.
- TDS values for the Gila River are averages of the entire flow for each interval at a USGS surface water station near Kelvin, Arizona.
- Gila River outflow, USGS Surface Water Stations Nos. 09479500 and 09479350 (2003).
- Santa Cruz outflow, USGS Surface Water Station #09489000 (2003).
- TDS concentration of Gila River outflow is equal to Santa Cruz River outflow.
- Santa Cruz inflow is estimated to be 9.1 percent of the flow measured by a USGS surface water station near the Ina Road Facility.
- TDS values for the Santa Cruz River inflow and outflow are averages of available USGS data.
- CAP deliveries, average of available data from the ADWR (2003).

The apparent increase in Gila River outflow between 1988 and 2000 is mainly due to a significant storm event in 1993 (Figure 3). The increase in Santa Cruz River inflow in the 1988 to 2000 interval is due in part to discharge from the Ina Road Facility.

6.0 GENERALIZED SALT BALANCE

Based on surface and groundwater data presented in Sections 4.0 and 5.0, a generalized salt balance was calculated for the principal sub-basins of the Pinal AMA. Results of the salt balance are presented in Table 3, and assumptions utilized in the salt balance are listed below:

TABLE 3. GENERALIZED SALT BALANCE FOR THE PRINCIPAL SUB-BASINS OF THE PINAL AMA

DESCRIPTION	1950 TO 1987	1988 TO 2000
Average salt inflow from the Gila River (millions tons per year)	0.1937	0.2578
Average salt outflow from the Gila River (millions tons per year)	0.0121	0.0486
Average salt inflow from the Santa Cruz River (millions tons per year)	0.0017	0.0044
Average salt outflow from the Santa Cruz River (millions tons per year)	0.0077	0.0051
Average salt inflow from the CAP Aqueduct (millions tons per year)		0.2984
Average salt inflow from groundwater inflow (millions tons per year)	0.0683	0.0683
Average salt inflow from agricultural practices (millions tons per year)	0.0200	0.0200
Average salt accumulation in the principal sub-basins (millions tons per year)	0.2639	0.5952

- Assumptions for Tables 1 and 2 apply to Table 3.
- Average Pinal AMA water demand of 1,000,000 acre-feet per year.

Prior to utilization of the CAP Aqueduct, the primary source of salt contribution in the principal sub-basins was from the utilization of Gila River (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 sub-basins.

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

7.0 REFERENCES

Arizona Department of Water Resources, 2003: Pinal Active Management Area. www.water.az.gov/adwr/Content/WaterInfo/InsideAMAs/amapinal.html.

Arizona Department of Water Resources, 2000: Pinal Active Management Area's Virtual Tour. http://www.water.az.gov/adwr/Content/Publications/files/Pinal_AMA_Tour.ppt.

Arizona Department of Water Resources, April 1993. Draft Water Resources Assessment, Inventory and Analysis of Water Resources Issues.

Freethey, Geoffrey W. and Anderson, T.W., 1986. United States Department of the Interior, U.S. Geological Survey: Predevelopment Hydrologic Conditions in the Alluvial Basins of Arizona and Adjacent Parts of California and New Mexico.

Hammett, B.A., 1992. Maps Showing Groundwater Conditions in the Eloy and Maricopa-Stanfield Sub-basins of the Pinal Active Management Area, Pinal, Pima, and Maricopa Counties, Arizona—1989.

Laney, R.L., Raymond, R.H., and Winikka, C.C., 1978, Maps showing water-level declines, land subsidence, and earthen fissures in south-central Arizona: U.S. Geological Survey Water-Resources Investigations 78-83.

Oppenheimer, J.M., and Sumner, J.S., 1980. Depth-to-Bedrock Map, Basin and Range Province, Arizona.

Personal communication, 2003, with an operator at the Pima County Ina Road Water Pollution Control Facility.

Reynolds, Stephen J., 1988. Geologic Map of Arizona. Arizona Geological Survey Map 26. Produced in cooperation with the U.S. Geological Survey.

Reeter, R.W. and Remick, W.H., 1986, Maps showing groundwater conditions in the West Salt River, East Salt River, Lake Pleasant, Carefree and Fountain Hills Sub-basins of the Phoenix Active Management Area, Maricopa, Pinal, and Yavapai Counties, Arizona—1983. Arizona Department of Water Resources Hydrologic Map Series Report No. 12

Schumann, Herbert H, 1974. Land Subsidence and Earth Fissures in Alluvial Deposits in the Phoenix Area, Arizona.

U.S. Geological Survey, 1986. *Annual Summary of groundwater conditions in Arizona, spring 1984 to spring 1985:* U.S. Geological Survey Open-File Report 86-422W.

United States Department of the Interior, U.S. Geological Survey, 2002. *Water Resources Data, Arizona, Water Year 2002*. Water-Data Report AZ-01-1.

United States Geological Survey, 2003: www.waterdata.usgs.gov/nwis/annual.

Western Regional Climate Center, 2003. www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?azcasm.

CENTRAL ARIZONA SALINITY STUDY—PHASE I

Technical Appendix H

Salinity in the Salt River Valley, Arizona: A Historic Perspective

February 2003

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Abbreviations

Acre-feet per year – Af/Yr
AMA – Active Management Area
CAP – Central Arizona Project
CASS – Central Arizona Salinity Study
LCU – Lower Conglomerate Unit
MFGU – Middle Fine-grained Unit
mg/l – Milligrams per liter
myo – Million years old
SRP – Salt River Project
TDS – Total dissolved solids
UAU – Upper Alluvial Unit

1.0 Introduction

Salinity has been an issue in the central Arizona area since irrigated agriculture was initiated but recently an increase in overall salinity has been noted in the surface water, groundwater and reclaimed water resources in the area. Salinity is a general term for a range of minerals dissolved in water or deposited in the soils. These minerals give a salty taste to water and thus the term salinity is used to describe the conglomeration of dissolved minerals. Some of these minerals occur naturally within central Arizona and can be found in the geologic deposits or in the rivers that flow into the area. The importation of Colorado River water and use of water treatment processes such as water softening and demineralization has increased the amount of salinity in the central Arizona area. Initial assessments have verified that a large portion of the total natural and imported salinity remains in the area trapped in the groundwater or in the soils and recycled in the wastewater/reclaimed water reuse process.

The U.S. Bureau of Reclamation and a large group of stakeholders initiated the Central Arizona Salinity Study (CASS) to identify the sources of salinity, develop a salt balance, determine the economic impact on the area and to develop recommendations to reduce the salinity and the corresponding economic impacts. As a part of this study, the Bureau of Reclamation funded a series of white papers to address specific salinity issues. This white paper addresses the historic sources and patterns of salinity within the central Arizona area.

The area of investigation in this white paper includes the general central Arizona area shown on Figure 1-1. The inset map shows the location of the two Active Management Areas (AMA) in central Arizona; the Phoenix AMA and the Pinal AMA. The larger map area shows the Sub-basins within the two AMAs within this white paper study area. The entire area of the CASS study is larger than this white paper study area because it includes the Gila Bend area to the southwest and the Tucson area.

1.1 Purpose

Salinity in central Arizona has been a natural occurrence and can be traced back through geologic history. The purpose of this white paper is to present the historic perspective of salinity to assist others in evaluating the current impacts and to project future impacts. This historic perspective will discuss the geologic history of the central Arizona area and some of the natural sources of salinity. It will also discuss the changes in groundwater salinity that has occurred over time and how irrigation practices and the importation of Colorado River water has changed the historic salt balance.

2.0 Regional Geology

When viewed in the geologic perspective, the minerals that are present in the sediments, soils and groundwater in central Arizona were imported from other areas. Sources of salinity can be identified throughout the drainage areas in formations that are as much as 225 million years old (myo). A review of a geologic map of the southwest shows there are Mesozoic Era formations throughout eastern and northern Arizona (Oetking, 1967). Presumably, these formations were more extensive in the geologic past before erosion shaped them to their present configuration. Many of these formations were formed in marine environments where the sandstones, shales, siltstones and limestones deposited. The sodium, calcium, potassium, chloride and carbonate ions trapped in these formations yielded the minerals to surface water and groundwater as the formations eroded. Rivers transported the minerals into the central Arizona area. The geologic map also shows there are large areas of Tertiary Period volcanic rocks east and south of the central Arizona area. These rock units would yield a wide range of minerals including sulfate compounds to the water as the rocks eroded. These minerals were also transported to central Arizona.

The transportation of salinity into central Arizona from these geologic formations continues to the present. The early explorers were very descriptive in naming features and the Salt River was named because of its salty taste attributed to the high concentration of total dissolved solids (TDS) contained in its water when compared to other rivers in the area. The primary source of these salts is a series of salt springs on the Fort Apache Indian Reservation east of the white paper study area.

2.1 Bedrock and Structural Geology

The character of the central Arizona area seen today began to form during the middle Tertiary Period about 30 to 20 myo when tectonic forces stretched the crust and a series of faults formed the basin and range physiographic province. Portions of the bedrock moved up relative to the basins that dropped down. The surface blocks of bedrock remnants form the mountains ranges seen throughout central Arizona. The basins became repositories for the materials eroded from the local bedrock and transported from other areas by the rivers flowing into the basins. Figure 2-1 shows the physiography of the central Arizona basins and ranges.

The bedrock mountains surrounding the basins in central Arizona are predominately Precambrian Era (greater than 550 myo) granite, gneiss and schist and Tertiary Period granite and volcanic rocks (Wilson, et.al. 1957). Most granite, gneiss and schist rock units do not yield the minerals commonly associated with the TDS salinity. Some volcanic rock units can yield sulfate compounds and these can contribute to salinity.

2.2 Sedimentary Geology

The sediments eroded from the mountains surrounding the basins and transported into the basins have been divided into three regional sedimentary units; the Lower Conglomerate Unit (LCU), Middle Fine-grained Unit (MFGU) and Upper Alluvial Unit (UAU).

2.2.1 Lower Conglomerate Unit

The LCU is classified as a fanglomerate, is primarily composed of pebble to cobble sized fragments of rocks from the surrounding mountains. The LCU also contains a significant amount of sand. These sediments indicate there was a high-energy environment capable of transporting these large materials. The presence of cobbles indicates the materials were not transported great distances because they would have been broken down into smaller fragments. The lack of fine-grained sediments in most of the LCU indicates there could have been a flow through system where there was sufficient energy in the water to transport the fine-grained materials out of the basin leaving the larger and heavier sediments behind. There could have been local closed basin areas where the transportation of sediments was over a short distance and thus the sediments are coarse-grained because the period of erosion during transport was limited. The upper portion of the LCU transitions into fine-grained sediments and these indicate there was a low energy, closed basin depositional environment at that time.

The LCU can form an aquifer unit and the water quality varies from good to marginal depending on the specific local conditions. In some places the LCU groundwater has been impacted by minerals such as fluoride or arsenic due to natural processes. In other areas the LCU has high TDS groundwater because it has been impacted by percolation from overlying sediments or minerals in the fine-grained sediments. The nature of the sediments in the majority of the LCU do not indicate that a depositional environment was present that would result in the formation of materials and layers within the LCU that would yield salinity to groundwater.

2.2.2 Middle Fine-Grained Unit

The MFGU is sometimes called the Middle Alluvial Unit but that name does not describe the sedimentary character of the unity. The MFGU represents a very different depositional environment than the LCU. The MFGU sediments are primarily fine-grained clay and silt sediments deposited during the middle to late Tertiary Period and are about 10 to 5 myo. The fine-grained sediments indicate a very low energy depositional environment existed during that period. It is possible that the volcanic activity that occurred during this time period blocked the drainage paths and produced closed basins with lakes. As the lake sediments accumulated the grade of the land surface became flatter and the energy available to transport sediments was further reduced. The result was a condition that looks like the Great Salt Lake basin or Death Valley. Because drainage in the basins was cut off, the water evaporated and evaporite minerals such as halite (salt), gypsum and anhydrite were deposited in playa lake beds. These evaporite sequences dominate the lower and middle parts of the MFGU and clay layers dominate the upper part.

The MFGU overlies the LCU and due to the fine-grained nature of the MFGU, it generally forms a seal trapping groundwater in the LCU. Most of the recharge to the LCU occurs around the edges of the basins and any additions to the salinity of the groundwater in the LCU is introduced in the peripheral area or where it is in contact with the base of the MFGU sediments.

The MFGU does contain evaporite deposits that represent potential sources of groundwater salinity. There is a large salt dome in the West Salt River Valley Sub-basin that demonstrates

that portion of the basin area contained a large lacustrine or playa environment for a very long period. The Luke Salt Dome will be discussed in Section 3 of this white paper. The playa lake deposits have been identified in the MFGU throughout the central Arizona area (Bureau of Reclamation, 1976).

Not all of the groundwater in the MFGU is poor quality. There are coarse-grained layers within the upper part of the MFGU that form an excellent aquifer capable of yield good quality groundwater in high rate pumping wells.

2.2.3 Upper Alluvial Unit

The youngest unit is the UAU and it overlies the MFGU throughout most of the areas of the central Arizona basins. Along the basin margins where the MFGU is absent, the UAU overlies the LCU. Deposition of the UAU began about 3 myo and continues today. The UAU is the surface unit of the basins. The UAU represents another change in the depositional environment in the central Arizona basins. The UAU contains a mixture of sediments that range in size from cobbles to clay and the layers within the UAU vary in sediment composition, thickness and areal extent.

The original groundwater within the UAU was impacted by the salinity of the Salt River and this is discussed in Section 4 of this white paper. Human activities have increased the area of the UAU impacted by salinity and this is discussed in Section 5.

2.2.4 Geologic Cross-Section

Figure 2-2 presents a generalized typical cross-section of the geology through a central Arizona basin. It shows the regional relationship of bedrock with the basin faults and the three sedimentary units. It also shows the stratigraphic position of the Luke Salt Dome.

3.0 Luke Salt Dome

The Luke Salt Dome is a massive deposit of halite (sodium chloride) located in the west Salt River Valley area near Luke Air Force Base (Figure 3-1). The Arizona Geological Survey estimated this salt body may be at least 6,000 feet thick and as much as 10,000 feet thick and contains 15 cubic miles of salt (Rauzi, 2002).

Salt is not deposited in a dome shaped form but rather in flat layers similar to what can be seen in Death Valley, California. When the salt layers are buried by additional layers of sediment and the thickness and weight of the overlying sediments increases, the salt begins to slowly flow. Salt is less dense than the sediments and once a weak spot is formed in the sediments, the salt begins to form an upward bulge. This process continues and the weight of the sediments forces the salt to form a dome. As the salt rises, the sediments above the dome also begin to bulge up. In the west Salt River Valley just west of Luke Air Force Base, there are some small hills near Dysart Road and Bethany Home Road that represent this uplift of sediments above the salt dome.

The deposition of 15 cubic miles of salt required a long period to form. Using present day information developed as a part of the CASS study a conservative time period can be estimated. The CASS data for the average year shows the following information:

- Salt River and Verde River at Granite Reef Diversion Dam – inflow 770,000 Acre-feet per year (Af/Yr) and a salinity of 480 milligrams per liter (mg/l).
- Gila River at Ashurst Hayden Dam – inflow 90,000 Af/yr and a salinity of 550 mg/l.
- Agua Fria River at Waddell Dam – 50,000 Af/Yr and a salinity of 400 mg/l.

The present day average conditions may not reflect the conditions during the Miocene when the salts were being deposited. The deposition of salts and the fine-grained sediments indicate it may have been dryer and thus the inflow rates would be less than today. However, the present day conditions can provide a general order of magnitude for this volume of salt to be deposited. These three rivers bring roughly 610,000 tons of TDS into the Phoenix valley each year. This is equal to a volume of 9 million cubic feet or 0.00006 cubic miles of salts. If the Luke Salt Dome contains at least 15 cubic miles of salt, it would have required about 250,000 years to bring that volume of salts into the valley based on current conditions. If the climate was dryer, the time for deposition would be longer. This calculation demonstrates that the importation and deposition of salt related minerals has been a long-term condition in the central Arizona area.

The Luke Salt Dome impacts some of the groundwater in the west Salt River Valley area but not the majority of the groundwater. Most of the salt is contained in the clay sediments of the MFGU and this seals it away from overlying sediments that contain groundwater. However, near the Dysart Road and Bethany Home Road area where the salt dome is a few hundred feet below the surface it does impact the groundwater and the TDS can reach 40,000 mg/l.

The Luke Salt Dome also contributes to the geologic hazards in the area, not because of the salt contamination but rather due to the structure and location of the dome. Groundwater pumping has been used in the west Salt River Valley around the Luke Air Force Base for decades and as a result the water table has declined several hundred feet and formed what is called the Luke Sink, an area of water table depression. Associated with this water table decline is land subsidence caused when alluvial sediments are dewatered and the weight of overlying sediments caused the

pore spaces to collapse. The result is a regional lowering of the land surface due to subsidence. When there is a structure in the land subsidence area, like the Luke Salt Dome, compaction is not equal because the thickness of sediments above the structure is thinner than the thickness of sediments around the structure. The differential compaction can produce earth fissures and these rapidly erode into fissure gullies. There are fissures and fissure gullies around the Luke Salt Dome. This demonstrates that the impact of historic salinity in the central Arizona area are not only related to groundwater quality.

The Salt Dome does have economic benefits. Morton Thiokol operates a salt mine in Glendale. Water is pumped down into the dome where it dissolves the salt. The fluid is pumped to the surface into evaporation ponds where the salt is deposited and harvested for sale. Liquefied petroleum gas is pumped into the cavities as a part of a gas storage project.

4.0 Historic Salt River

The configuration of the historic Salt River did not always appear as it does today. During the deposition of the UAU, which began about 3 myo, the river channel changed location. The reasons for these changes are both structural and sedimentary.

The structural reason for potential changes in the Salt River channel location is documented by the terraces mapped along the rivers. Terraces formed as sediments were deposited adjacent to the historic river. Mapping shows that the terraces that formed along the Salt River, as well as the Agua Fria, New River and Queen Creek changed over time. In the Salt River Valley, the evidence is that the mountains continued to rise changing the base level of the rivers. This is a structural change. As the mountains rose, the river became unstable in the channel it had eroded and it began to erode a new channel into the terrace deposits and formed a new lower level terrace. This was not a one-time event. In the Salt River Valley a series of four historic terraces were mapped in addition to the modern floodplain (Péwé, 1978). These are from oldest to youngest; Sawik, Mesa, Blue Point, and Lehi Terraces. Each time the base level changed it provided the energy for the Salt River to cut a new channel.

Subsurface geologic investigations have verified that the depth to the bedrock of the basement of the central Arizona area varies. In areas between the mountains such as between the Phoenix Mountains and South Mountain or between the Sierra Estrellas and the White Tank Mountains, the bedrock is closer to the surface than in the center of the basins. When the UAU was being deposited, the bedrock may have formed shelves that could block the flow of the rivers. Lee (1905) proposed that the Salt River might have flowed south to join with the Gila River on the south side of South Mountain in the past. This was based on an analysis of the surface physiography and analysis of the sediments penetrated by water wells. The area between South Mountain and the San Tan Mountains is a broad flat plain while the area between the Phoenix Mountains (which includes Papago Buttes, Tempe Butte, and Camelback Mountain) and South Mountain is much narrower and the bedrock is closer to the surface. When the surface of the UAU was lower in the past because there was less sedimentary material in the valley, the Salt River could have flowed in the alternate path hypothetically shown on Figure 4-1 because the path between the Phoenix Mountains and South Mountain was blocked by the bedrock. As the sedimentary material continued to accumulate and the base level changed due to structural actions, the course of the Salt River was altered to follow the path seen today. Péwé suggested that the Salt River changed course after the Sawik and Mesa terrace periods.

Additional evidence that the Salt River may have flowed south of South Mountain is presented on Figure 4-2. The pink and purple colors on the map represent areas where the salinity ranges from 1,000 to more than 3,000 mg/l. These high TDS water areas surround South Mountain. The area of impact of the high TDS water probably is greater today than it was historically, due to the activities of man moving water away from the river for irrigation.

5.0 Groundwater Salinity

The previous sections of this white paper documented the historic salinity in the Salt River valley area before human activity changed the conditions. The primary reason for the change caused by humans was the need to divert water from the river for irrigation of crops. Abandoned Indian canals showed irrigation had occurred centuries before the Salt River Project (SRP) system of dams and canals were built. This had an effect on the pattern of salinity.

In geologic history, the high salinity areas were primarily associated with the location of the Salt River, but with the practice of irrigation the water was moved across the surface of the basins and spread over a wider area. Figure 5-1 shows salinity data plus the locations of SRP canals. This system distributes Salt River water over a wide area of the valley. Figure 5-1 shows the configuration of the SRP canals and the location of high salinity zones. The areas where the TDS ranges from 1,000 to greater than 3,000 mg/l is shown in pink and purple. In many limits of the areas with the higher TDS is generally associated with the lands irrigated by the SRP canals.

When farmers use water with a high TDS for irrigation they must apply more water than is needed to grow the crops. This extra water is used to flush or leach the salts deposited in the soil by the irrigation water to depths below the root zone of the crops. Over time, this leaching percolates down to the aquifer and increases the salinity of the groundwater below the irrigated fields. SRP water deliveries begin in the east part of the Salt River Valley and water is conveyed by the canals to the west. The water used in the east part of the SRP system is almost all surface water. SRP developed a series of wells along the canal system to supplement the available Salt River flow. Wells pump groundwater from beneath the eastern areas and add it to the canal flows. This combined flow is transported west where some of the water is used for irrigation. Again, due to leaching the recharge to the aquifer from the fields has a greater salinity than the irrigation water. Wells in this second area add water to the canals and the process is repeated until by the time the flow in the canals reaches the far western part of the SRP system a large proportion of the water is well water. This is how the water is recycled. The leaching water recharges the aquifer with water that has a greater salinity than the source irrigation water. As the water is recycled from the east to the west the salinity increases and is discussed in Section 5.4.

5.1 1905 Conditions

The earliest major report on the water supply of the central Arizona area was prepared by Lee (1905). However, by 1905, modern irrigation had been practiced in the Phoenix area for almost 40 years and historic irrigation had been practiced for centuries. Lee's water quality data is reported as parts per 100,000 and thus all concentrations reported are multiplied by 10 to convert the data to parts per million (equivalent to mg/l) for use in this white paper. Many of the wells described by Lee were really sumps rather than wells. Pits were excavated until water was encountered, then a pump was installed. Many pits were excavated close to the Salt River or where the groundwater was very shallow and influenced by the river. This means the water quality data really reflects the surface water quality rather than groundwater quality. These wells are not used in this white paper for analyses. Some shallow wells located away from the Salt River, Gila River and Agua Fria River probably were pumping shallow groundwater and while the groundwater may have been influence by irrigation leaching, they do reflect groundwater quality. These shallow wells are used in this white paper for analyses. Some deeper wells were drilled but were less than 300 feet deep and thus constructed in the UAU. Wells did not penetrate

the MFGU our LCU. These wells reflect groundwater quality and are used in this white paper analyses.

Figure 5-2 presents the groundwater salinity based on the data in the Lee report. Most of the wells with water quality information were concentrated it a few areas, thus the interpretations of regional groundwater salinity shown on Figure 5-3 is not very detailed. The figure shows areas where the TDS is less than 1,000 mg/l and the concentrations ranged from 320 to almost 1,000 mg/l. Figure 5-2 also shows where the TDS was between 1,000 and 1,500 mg/l and where it is greater than 1,500 mg/l. Some of the analytical results in the highest TDS area ranged as great as 5,000 mg/l. There was insufficient information to attempt to develop TDS contours for concentrations greater than 1,500 mg/l.

The 1905 data shows the greatest TDS concentration was located along the Salt River and the concentration decreased to the west. The area with the best quality water was located on the north side of the Salt River between the two 1,000 mg/l contour lines.

5.2 1973 Conditions

Figure 5-1 presents the salinity data for the 1973 period (Kister, 1974). There was much more information available in 1973 then in 1905 and thus the TDS areas are presented in greater detail. The figure shows that a large portion of the central Arizona area has TDS concentrations greater than 1,000 mg/l and that the groundwater with TDS concentrations less than 1,000 mg/l are located along the edges of the basins away from the Salt River. There is no indication that the salinity of the groundwater increased or the area impacted by TDS greater than 1,000 mg/l increased between 1905 and 1973 just that there was more information available in 1973.

5.3 1976 Conditions

Figure 5-3 presents the groundwater salinity in 1976 (Reclamation, 1976). This information is shown as specific conductance but is converted to mg/l on the legend to be consistent with the information shown on other figures. The information for 1976 is very consistent with the information presented for 1973. The areas of low TDS concentrations are still north and east of the SRP area. The TDS concentration increases to the west and south to more than 3,250 mg/l.

Figure 5-3 also shows the chemical nature of the TDS minerals by classifying the groundwater. The areas influenced by the Salt River, Gila River and SRP irrigation are sodium – calcium chloride waters, similar to the salt in the salt dome.

5.4 1999 to 2002 Conditions

By 1999, conditions had changed again in the Phoenix area. Central Arizona Project (CAP) water was being imported from the Colorado River and used to supplement irrigation water and as a part of the municipal supply for areas outside of the SRP boundary. CAP water averages about 650 mg/l and is a new source of salinity being imported to the central Arizona area.

The majority of CAP water is used for municipal supply. Interior use of CAP water has increased the salinity measured at the wastewater treatment plants and water reclamation plants. This may have an impact on the use of reclaimed water produced by these facilities. Exterior use of CAP water may be building salinity in the soils. Most residential irrigation is for turf and ornamental plants and the homeowners do not add the quantity of water needed for leaching as do farmers. Much of the salinity associated with CAP water may be building in the soil layers just below the plant root zones and will remain in the soil unless a wet period with high rainfall totals flushes the salinity to deeper soil zones.

The use of CAP water outside of the SRP boundary means the area of potential TDS impacts has expanded again. The first expansion from the river corridor was associated with SRP water use and the second is with CAP water use. In 1999, the average TDS of SRP water measured at Granite Reef Diversion Dam was 563 mg/l while the SRP water averaged 518 mg/l at the same location.

The information on Figure 5-4 shows the average TDS concentrations within the SRP area and this is consistent with the information presented on previous figures.

Figure 5-5 presents the TDS concentrations measured in the SRP system in 1999 (SRP, 1999). This information confirms that the salinity of SRP water generally increases from the east to the west. This is very apparent in the portion of the system south of the Salt River where the TDS increases from 518 mg/l measured in the south canal to 823 mg/l at the end of the Western Canal. Water is diverted into the Arizona Canal on the north side of the Salt River and it had a TDS concentration of 518 mg/l at Granite Reef Diversion Dam. The impacts of the higher salinity groundwater shown in Figure 5-1 are evident in this northern part of the SRP system. The Grand Canal is the southern of the two canals and much of it passes through the area where the groundwater averages 1,000 to 3,000 mg/l and thus by the time the water reaches the end of the Grand Canal the TDS concentration is 612 mg/l. The Arizona Canal is north of the Grand Canal and passes through areas where the groundwater TDS is from less than 500 mg/l to 1,000 mg/l. This higher quality groundwater results in better quality canal water and the Arizona Canal TDS averaged 503 mg/l at the Agua Fria River.

Figure 5-5 shows the concentration of three irrigation drainage system discharges, two near the Gila River and one in the east portion of the SRP system. This data shows how the concentration of SRP water is changed as it runs off irrigated fields. In the east valley the concentration of the irrigation water was 681 mg/l but the drain water TDS concentration was 1,347 mg/l. The Western Canal water averaged 823 mg/l and the drain on the south side of the Gila River averaged 888 mg/l. The Grand Canal water averaged 612 mg/l of TDS and the drain averaged 945 mg/l.

6.0 Conclusions

The information developed in this white paper confirms:

- Salinity has been imported into the central Arizona area for millions of years from geologic formations east and north of the area and is not a new problem.
- Geologic conditions in the past fostered the deposition of huge salt deposits that now form a salt dome in the West Salt River Valley. Mining the dome provides and economic benefit but the dome impacts local groundwater quality and contribute to the formation of geologic hazards.
- The Salt River probably flowed south of South Mountain to join with the Gila River but now flows north of South Mountain.
- The earliest documentation of groundwater quality was in 1905 and by then the groundwater may have been impacted by irrigation return flows. Subsequent groundwater quality analyses confirm that the poorest quality groundwater is in a zone that follows the Salt River and Gila River while the areas with the highest quality groundwater are located closer to the mountains.
- The dominant groundwater is a sodium-calcium chloride water.
- Farming activities have contributed to the spread of poor quality, high salinity water from the river corridor to throughout the irrigated area.
- Central Arizona Project water is importing additional salts into the central Arizona area and the CAP water is being used in areas where SRP water was not used. This is potentially increasing the areas impacted where salinity will be accumulating in the groundwater and soils.

References Cited

Bureau of Reclamation, 1976, Geology and Ground-water Resources Report, Maricopa and Pinal Counties, Arizona; U. S. Department of Interior.

Kister, L.R., 1974, Dissolved – Solids Content of Ground Water in the Phoenix Area, Arizona Map I-845-G; U.S. Geological Survey Miscellaneous Investigations Series.

Lee, T.L., 1905, Underground Waters of Salt River Valley, Arizona; U.S. Geological Survey Water-Supply and Irrigation Paper No. 136.

Oetking, P., 1967, Geologic Highway Map of the Southern Rocky Mountain Region; American Association of Petroleum Geologists Map No. 2.

Péwé, T.L., 1978, Terraces of the Lower Salt River Valley in Relation to the Late Cenozoic History of the Phoenix Basin, Arizona; in Guidebook to the Geology of Central Arizona, 74th Cordilleran Section Meeting, Geological Society of America.

Rauzi, S. L., 2002, Arizona Has Salt; Arizona Geology Spring 2002 – Vol. 32, No. 1.

Salt River Project, 1999, Annual Water Quality Report; SRP.

Wilson, E.D., Moore, R.T., and Peirce, H.W., 1957, Geologic Map of Maricopa County, Arizona; Arizona Bureau of Mines.

CENTRAL ARIZONA SALINITY STUDY – PHASE I

Technical Appendix I

CAP, SRP and SCIIP

Introduction

The CAP, SRP and SCIIP are irrigation projects which use and control the main surface water supplies for the primary study area which consists of the Phoenix Metro area and the Gila River Indian Community. The primary surface water sources are the Colorado River brought into central Arizona by the CAP, the Salt & Verde Rivers dammed, controlled and delivered to the Phoenix metro area by SRP and the Gila River, dammed and delivered to Gila River Indians and also Pinal County agriculture by SCIIP.

The Central Arizona Project

The Central Arizona Project (CAP) was designed by the Bureau of Reclamation and constructed in cooperation with the Central Arizona Water Conservation District, CAWCD. CAWCD, now referred to as CAP, was created to operate and maintain the CAP and to repay the federal treasury the reimbursable costs for building the project.

The CAP aqueduct is 336 miles long and was designed to deliver annually 1.5 million acre-feet of Colorado River water to central and southern Arizona. The aqueduct is expected to deliver an average of 1.5 million acre-feet but is capable of delivering up to 1.9 million acre-feet of Arizona's total annual entitlement of 2.8 million acre-feet of Colorado River water. The CAP's operating features—pumping plants, New Waddell Dam, check structures and turnouts are remotely controlled from the project headquarters located in north Phoenix via a computer assisted control and communications system. The operators monitor the systems performance and adjust it as necessary, correcting flow and other parameters. As the water flows through the aqueduct, it is controlled by check structures and carried under rivers and major washes by inverted siphons and through mountains via tunnels. Turnouts deliver water to agriculture and municipal distribution systems. Besides the major components, the CAP has many other associated features, these include: roads, bridges, wildlife crossings, over chutes, under chutes and recreational trails. Transmission lines and switchyards carry electric power to project features. Earthen dikes paralleling the aqueduct protect it from floods. The entire aqueduct is fenced for the protection of people and wildlife.

During the winter months when electricity is cheap, Colorado River water is pumped through the CAP aqueduct by four separate pumping plants from the river to near Phoenix. The water is diverted and is pumped into Lake Pleasant by the pump/generating station located at New Waddell Dam. During the summer months when electricity costs are higher, the water stored in Lake Pleasant is then released and electricity is generated at the pump/generating station, the released water supplies Phoenix and other down stream users. Maintenance can then be performed on the pump plants along the main CAP aqueduct between the Colorado River and Phoenix.

Figure 1 illustrates the CAP water service area and the aqueduct alignment that supplies water to that area.

Figure 1: Central Arizona Project

The Central Arizona Project water was allocated by the Arizona Department of Water Resources to 85 municipal and industrial users, 12 Indian communities, and 23 non-Indian agriculture districts. Currently the Central Arizona Project has subcontracts with 56 of the municipal and industrial users, 10 Indian communities, and 10 non-Indian agriculture districts.

CAP Subcontracts, Policies, Pricing & Strategies

There are three components of CAP water prices: capital, operation and maintenance (O&M), and energy. CAP subcontracts extend through the year 2050 and contain provisions which state that the capital component of the CAP water price must be paid whether the water is used or not. This provides considerable incentive to begin using the CAP water as soon as possible. The capital component is $54 per acre-foot from the year 2000 on.

The energy component of CAP water prices covers the cost of energy required to pump the water from Lake Havasu on the Colorado River to the customer's turnout on the CAP aqueduct. CAP's pricing includes a "postage stamp" energy rate for CAP water use. This means that the energy component of the CAP price is the same for all customers regardless of their location on the system. The price of energy available to CAP is strongly based on energy contracts which are effective until the year 2011. Thus, the energy component of CAP water prices could change significantly in 2011.

In 1993, the CAP Board of Directors established the Forward Pricing Program which provided more stability and predictability for its customers regarding pricing of CAP water. Under this program, CAWCD reviews forward prices annually, formally establishes the current year's prices, and sets a schedule for the succeeding five years.

CAP has also established an incentive recharge program which provides excess CAP water to M&I subcontractors at a reduced rate. The water must be used to earn long-term storage credits at an underground storage facility.

CAP is currently working on establishing a policy for wheeling non-project water through the aqueduct system. The policy will undoubtedly include the requirement that non-project water maintains a lower priority than all project uses and that wheeling cannot negatively impact CAP users. Other provisions of the policy that are not so clear include: the source of energy which may be used to wheel non-project water, the price for wheeling, and the priority relating to other non-project uses of the CAP system.

State Demonstration Projects

1990 legislation gave CAWCD the responsibility of developing State Demonstration recharge projects and the authority to assess an ad Val Orem tax to fund those projects. The tax (4 cents per $100 assessed valuation) was assessed in Maricopa and Pima Counties from 1991 through 1996. Legislation dictated that the funds were to be used for the benefit of the county in which they were collected. Funds collected in Maricopa County totaled about $28 million. About $15 million still remains in the fund and CAWCD is actively pursuing development of direct recharge projects with those funds. CAWCD's primary focus in Maricopa County was development of the Agua Fria Recharge Project northwest of the Phoenix metropolitan area. This project has the capability of storing 100,000 acre-feet per year. Recharge operations began in 2001.

ADWR policies governing CAP water use

The State of Arizona has a policy to encourage the use of renewable water supplies such as CAP water. ADWR is relying upon the assured and adequate water supply rules to encourage M&I water providers to use their CAP allotments.
State law allows for the storage of surplus CAP water underground through either direct or indirect (groundwater savings) projects. The water, when recovered, retains its legal identity as CAP water. Long-term storage CAP credits may be used by water providers to demonstrate an

assured water supply. The ability to recharge CAP water provides an alternative to municipal water providers to store and deliver CAP water without developing water treatment facilities.

In the Assured Water Supply Rules adopted in 1995, water providers deemed to have an Assured Water Supply were given a three-year "grace period" during which time they could continue mining groundwater with no penalty. After the grace period, they must comply with the AWS Rules and begin making an effort to rely on renewable supplies, including their CAP allocations.

CAP water transfers & leases

ADWR is authorized to review proposed transfers of CAP water. A transfer is defined by ADWR to include the assignment, sale, lease or relinquishment of a CAP M&I subcontract for more than one year. After ADWR's review, the recommendations are submitted to the Secretary of Interior for final decision. Due to the importance of CAP water to the future of Arizona, ADWR, in conjunction with the Central Arizona Water Conservation District have adopted policies and procedures on CAP transfers. The adopted state policies have also been approved by the U. S. Department of Interior.

In the case of a transfer of CAP water the first priority will be given to entities that succeed the interest to a water provider and which will provide water to the same service area. The second priority will go to entities (including the CAGRD or county augmentation districts) which will use the CAP water to mitigate adverse impacts caused by future groundwater withdrawals by the transferring entity. The third priority goes to entities that can demonstrate future adverse impacts caused by the withdrawal of groundwater that resulted from the transfer of CAP water. Fourth priority goes to entities in the same AMA which demonstrate the need for additional assured water supplies to meet committed demand. Fifth priority goes to entities in the same AMA which demonstrate the need for additional assured water supplies up to the year 2035. The sixth priority goes to entities in the same AMA which demonstrate the need for additional water supplies for the period after 2035. Seventh priority goes to replenishment districts in the same AMA as the transferring entity to meet projected obligations in the year 2035. The final priority goes to entities in other AMA's consistent with the aforementioned priorities.

According to policy passed by the CAWCD Board, any transfer of a CAP M&I subcontract allocation must be accomplished with no profit to the relinquishing entity. All financial transactions must be fully disclosed. The only payment to the relinquishing entity will be made by CAWCD and will consist of reimbursement of CAP capital charges that were paid by that entity plus 5% of that amount as compensation for costs associated with the CAP subcontract. [Reimbursement for the Arizona State Land Department will be as provided in A.R.S. § 37-106.01(c)]. A "cost of money" payment will also be made. Such payment will consist of interest beginning on the date the original payment was received by CAWCD using a simple annual interest rate equal to the weighted average rate earned by CAWCD for that calendar year less 1%. No payment will be made for capital payments associated with any water delivered from October 1, 1993 through the date of relinquishment.

The entity that receives the subcontract allocation will be required to pay CAWCD 1) the amount CAWCD paid to the relinquishing entity with interest from the date payment was made by CAWCD; 2) any outstanding payments due under the subcontract with interest from the due date; and 3) any charges paid by CAWCD to the United States associated with the transfer. Interest paid by the receiving entity will be simple annual interest at a rate equal to the weighted average rate earned by CAWCD for each calendar year or portion of a calendar year.

In those instances where the assignment and transfer is made to a successor-in-interest that will serve the original subcontract service area, payment for certain administrative, legal, or engineering fees may be permitted. CAWCD will review and approve these situations on a case by case basis and will facilitate those financial transactions directly between the involved entities.

Arizona Water Bank

The Arizona Water Banking Authority was created in 1996 to store unused CAP water for future use. The stored CAP water can be used as long-term storage credits to: 1) firm existing water supplies for municipal users during Colorado River shortages or CAP service interruptions; 2) help meet the water management objectives of the Arizona Groundwater Code; 3) assist in the settlement of American Indian water rights claims; and 4) exchange water to assist Colorado River communities.

Salt River Project

The Salt River Project (SRP), located near Phoenix, Arizona, includes a service area of about 240,000 acres spanning portions of Maricopa, Gila and Pinal Counties in central Arizona. The service area is furnished a full irrigation water supply from the Salt and Verde Rivers and from approximately 250 ground water wells. SRP surface water supplies originate from the 13,000 square mile Salt River and Verde River watersheds. SRP operates 4 dams and reservoirs along the Salt River and 2 dams and reservoirs along the Verde River. Theodore Roosevelt Dam, the first major structure constructed by Reclamation on the Salt River Project, is located 76 miles northeast of Phoenix and 30 miles northwest of Globe, Arizona. The dam, completed in 1911, was subsequently modified between 1989 and 1996. The modification raised the dam by 77 feet in elevation, increasing water storage capacity by 20 percent and adding flood control space. Other dams operated by SRP include Horse Mesa, Mormon Flat and Stewart Mountain Dam all located along the Salt River. Horseshoe and Bartlett Dams are located along the Verde River. Total storage capacity of the Salt River reservoirs is more than 2.4 million acre-feet. The storage capacity of the Verde River reservoirs is over 300 thousand acre-feet.
The power system includes five hydroelectric plants, three steam power plants and a combined-cycle plant. In addition, SRP has partial participation in other power plants including the Palo Verde Nuclear Generating Station.

Irrigation flow is regulated by Bartlett Dam on the Verde River and Stewart Mountain Dam on the Salt River. Water is released from the Verde River during the winter months in anticipation of the spring runoff. During the summer months water is released from the Salt River system. The logic behind this river operating method is that the Verde Dams do not have flood space or

the capacity as the dams on the Salt River and must make space available for the spring runoff. The Granite Reef Diversion Dam is located 3 miles down stream of the confluence of the 2 rivers and diverts water north into the Arizona Canal and South into the South Canal for delivery to the SRP water service area. SRP also relies on approximately 250 wells to augment surface water deliveries. SRP's water service area is approximately 250,000 acres and includes an extensive network of canals. Illustrated in Figure 2 is the SRP water service area.

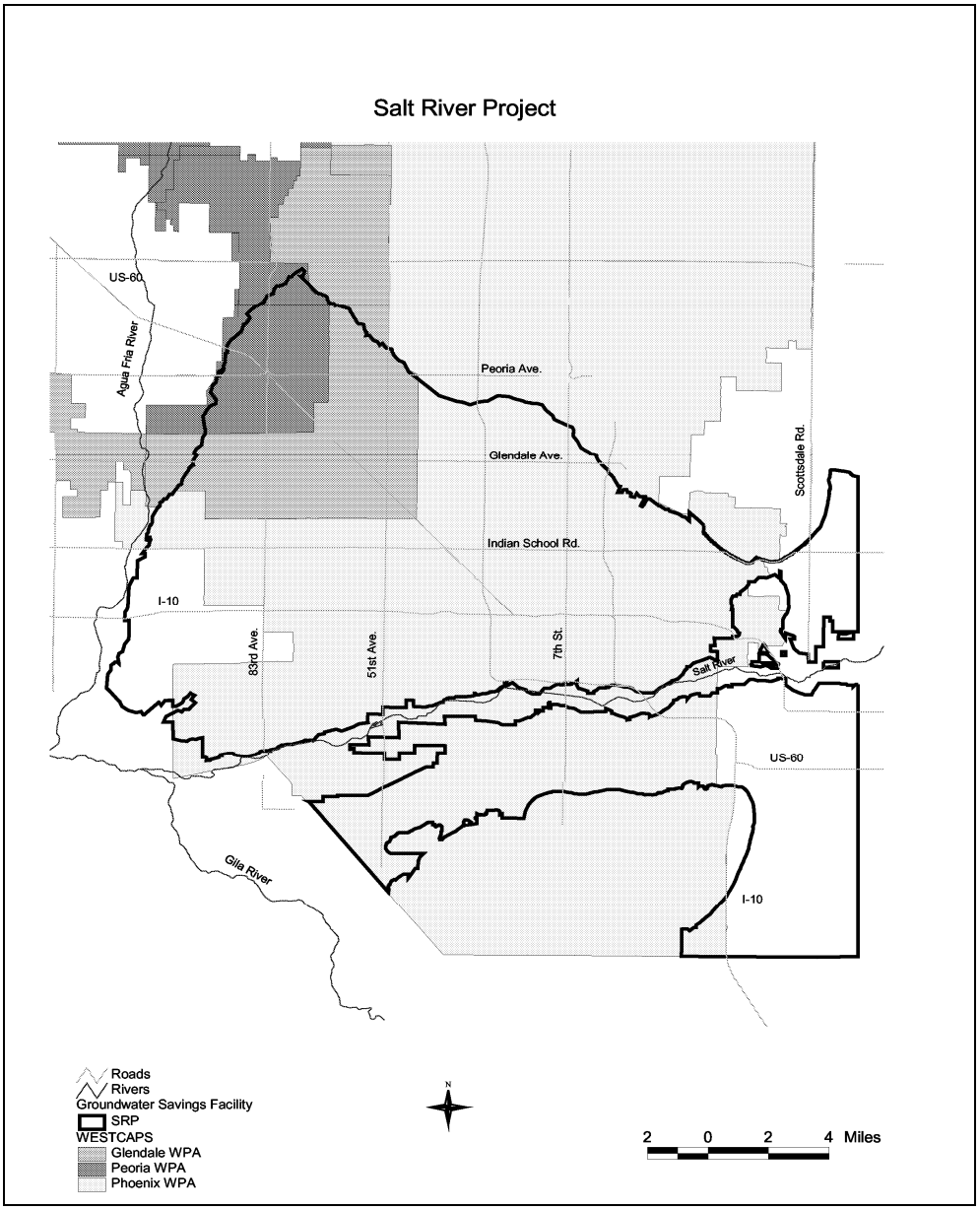


Figure 2: Salt River Project Water Service Area

The Kent Decree

The Kent Decree established the relative rights of Project lands to the water of the Salt and Verde rivers. The decree formally stated the principle of normal flow rights and reaffirmed the

long-standing legal principle of prior appropriation. The purpose of the Kent Decree was to establish which lands had normal flow rights prior to delivery of stored water from Roosevelt Dam.

In the Kent Decree, all local valley rights to the normal flow of the Salt and Verde were set chronologically from 1869 through 1909 based on continuous beneficial use of water. For example, land which used water in 1869 had the first right to water in the river, then land which used water in 1870, and so on up to 1909. Three classes of lands were established based on their initial date of appropriation and "reasonably constant" beneficial use thereafter: Class A lands included all lands under "reasonably constant" cultivation from their first year of use up to the year 1903. Class B lands included those which had been intermittently irrigated but which were not in cultivation in 1903. Class C lands specified those areas which had never been irrigated from the flow in the Salt River at or above Joint Head Dam.

Class A lands were decreed to have rights to normal flow. Their priority was based on their first year of cultivation. Normal flow water is in addition to rights to stored and developed water, which all Association members share equally. Class B lands were decreed to have no rights to normal flow but were entitled to stored and developed water. Class C lands are also not entitled to normal flow but are entitled to stored and developed water. The Kent Decree did make a distinction between Class B and Class C lands. For the period of one year, Class B lands along with Class A lands would be given preference over Class C lands in their claim for stored water. The significance of this stipulation was in 1903 (when the Association was formed) the anticipated available water supply from Roosevelt Dam could not supply all the lands applying for it. Once members of the Association, however, all three classes had equal rights to stored and developed water.

1929 and 1948 Pump Rights

In 1929 and 1948, the Association instituted programs that provided shareholders with the opportunity to augment their water supplies by investing in the construction of a total of seventy-nine deep wells within the Salt River Reservoir District (SRRD). These programs were offered primarily in response to: the need for additional water supplies for specific shareholders; and, the drought conditions of the late 1940's, where runoff in the Salt and Verde watersheds was significantly below average. Only those shareholders who invested in the programs were able to use this augmentation device.

Pump right water service is limited to one acre foot per acre per year per program (1929, 1948), and must be used within the SRRD boundaries. Although pump right water can be used on non-member land, ownership of such rights is tied to the member lands to which they were originally attached. As a result, as Association land urbanizes, and shareholder water entitlements are moved to on-Project municipality water accounts, such municipalities are given access to pump rights under the conditions described in the 1929 and 1948 contracts. Therefore, on-Project municipality access to pump right water is limited to the amount of member land within their respective water service areas. Currently, about 90,051 acres of pump right have been moved to on-Project municipality water accounts, while 84,324 acres remain in agricultural accounts.

Because pump right water is currently the most expensive type of water available to shareholders (currently $35 per AF), it is the last water source called upon.

There are four factors which may impact the use of pump rights: drought, water quality, state and federal regulations, and operational needs. Drought continues to be the main factor in maintaining pump right wells. This supply offers shareholders who have such rights an alternate water supply should surface water supplies be affected by drought conditions. However, water quality and state and federal regulations, primarily the Groundwater Management Act and the Clean Water Act, may limit the use of this water supply in the future.

Those wells which were constructed pursuant to the 1929 and 1948 programs are also used to assist the Association with operational problems (i.e., canal capacity constraints), and notwithstanding the above mentioned limitations, it is envisioned that these wells will continue to be used in this capacity.

Pump right wells are maintained by SRP as part of SRP's overall groundwater management strategy. Since these contractual arrangements are in perpetuity, SRP will continue to maintain these wells for pump right lands, as required in the 1929 and 1948 contracts. However, SRP does not guarantee the quality or amount of water available from pump right wells, since those shareholders who invested in the programs agreed to share in the benefits and risks of the programs.

Water Transportation Agreement

The Water Transportation Agreement (WTA) provides for the wheeling of non-SRP water in SRP canals. Non-SRP water includes CAP water, modified Roosevelt Dam water (New Conservation Space, or NCS water), Cliff Dam replacement water, and others as agreed by the parties.

The major principles embodied in the WTA are (1) transportation priority (SRP entitlement water has higher priority), (2) fees (current fee is $10 per acre foot plus annual administration fee of about $2,000), and (3) water quality (SRP does not guarantee the quality of water delivered. The term of the WTAs is 50 years to coincide with CAP subcontract terms.

GRUSP/CSIF

In 1994, SRP, Chandler, Gilbert, Mesa, Phoenix, Scottsdale, and Tempe signed an intergovernmental agreement (IGA) for the construction and operation of the state’s largest underground water storage facility. In May 1994, the Granite Reef Underground Storage Project (GRUSP) became operational. SRP is the operating agent for GRUSP. The current storage capacity of GRUSP is about 120,000 acre feet per year (subject to operational conditions). The permitted capacity is 200,000 acre feet per year.

In the IGA, each participant is provided the right to utilize its ownership entitlement in GRUSP for its own use (i.e., storage of water), use by other participants, or use by non-participants. For use by non-participants, the participants agreed to pool any unscheduled entitlement for leasing

purposes, and share in any costs and revenues associated with such leasing. The lease agreement, which was developed by SRP, was approved by the GRUSP participants. Any non-participant use of GRUSP must be approved by the GRUSP participants.

The major provisions of the lease agreement include (1) priority of use (GRUSP participants have first right of use on a monthly basis), (2) water quality, and (3) fees (currently $8 per acre foot, plus $5 per acre foot for use of the CAP/SRP Interconnection Facility [CSIF] by non-CSIF participants, and about $2,700 annual administration fee). A WTA (or similar agreement) is also required.

In 1997, the Arizona Water Banking Authority (AWBA) signed a long-term lease agreement for use of GRUSP. The five-year agreement allows for the use of at least 50,000 acre feet of space per year (if operationally available).

San Carlos Indian Irrigation Project

Congress authorized the construction of the Coolidge Dam on the Gila River in Arizona in 1924 as part of the San Carlos Irrigation Project (SCIIP). The dam provides irrigation water to the Pima Indian Reservation as well as to the public and private lands in the area. The dam created a reservoir sufficient to irrigate 80 percent of the SCIIP lands with the balance receiving water from other sources, most notably ground water.

The 1928 Act authorized the Secretary of the Interior (Secretary) to construct a hydroelectric power plant at the dam. Construction costs for the power plant were to be repaid as part of SCIIP. The O& M costs for the power plant were to be paid through the sale of power. The Secretary was authorized to sell “surplus” power and apply the “net revenues” from such sales to reimbursement of the costs of developing power, reimbursement of the costs of SCIIP, and O&M costs of SCIIP.

The cost of operating and maintaining SCIIP, except for the electric generation plant and the transmission lines, was to be paid for by the SCIIPP land owners. The electric generation plant ended operation in 1983.

CENTRAL ARIZONA SALINITY STUDY --- PHASE I

Technical Appendix J

ECONOMIC ASSESSMENT MODEL

Introduction

One of the most important aspects of the salinity study has got to be: Why are we concerned with salinity? The answer of course is that high salinity water is an economic burden to society. In hopes of finding out just how much of a burden, the Technical Committee decided to analyze the economic impact of importing salts into Central Arizona.

In the late 1980's, the Milleken Chapman Research Group, Inc. created a computer model to estimate the economic impacts of salinity in the Colorado River. The model development was funded by the Bureau of Reclamation in hopes of quantifying the efforts of the Colorado River Basin Salinity Control Advisory Council (Council). The Council's function is to "…advise the Secretaries of the Departments of the Interior and Agriculture…on all matters relating to efficient and timely planning and execution of salinity control measures…specified in the Colorado River Basin Salinity Control Act." Most of the salinity control measures implemented have been improvements in agricultural water efficiency. These salinity control measures include such things as installing concrete linings in canals and the retrofitting flood irrigation systems to drip or sprinkler irrigation systems. These projects were reducing the salt load into the Colorado River, but the economic impact of reducing salinity into the Colorado River was unknown. Thus the impetus for creating the original computer model was to make an economic analysis of the work by the Council

The original model estimates the economic impact due to salinity through the entire Lower Colorado River Basin. It does this by looking at five specific areas where high salinity Colorado River water is impacting society. These areas are residential, commercial, industrial, agriculture and water utilities. The original model did a fairly good job of looking at the big picture, but what was lacking in the model was detailed knowledge at the local level.

The Metropolitan Water District of Southern California (MWD) as part of their Salinity Management Study, upgraded the original computer model to better calculate the economic impacts of changes in salinity in the MWD service area. MWD, using their intimate knowledge of salinity problems and water systems in their service area, made modifications to the original model. Their modified model did a much better job at analyzing the salinity impacts in southern California. Some changes incorporated included accounting for salinity impacts by both State Water Project and Colorado River water, local water treatment policies, water recycling policies and improvements of the data about southern California water use. MWD also re-evaluated the formulas and functions used in the model. The basic formulas were considered sound and were not

altered. The cost functions were revised to reflect costs in California. MWD also did extensive surveys of consumers, commercial establishments and industrial manufacturers to get a better picture of water consumption. The work done by MWD to improve the model was extensive and thorough. But they were only concerned about their water service sector. The rest of the Lower Colorado River Basin continued to use the original model's design and programming.

The Technical Committee decided to use the MWD model as a starting point for the economic study for CASS and then modify it to reflect Central Arizona's water and salinity issues. The basic formulas were not changed in the model. These had been reviewed by MWD and found to be adequate. The major changes implemented for the CASS economic model had to do with improving the data and better simulating the water use in Arizona. Such thing as including the salinity contribution of the Salt, Verde and Gila Rivers, including the poor quality ground water in certain parts of the study area, the cost to replace salinity damaged evaporative coolers, and the cost of leaching salt from the root zone of crops were added to the model. Some of the MWD model was discarded because it did not fit in with the water and salinity issues in Arizona. Such things as disposal costs of cooling tower blow down water (there is no additional cost to the industry based on salinity level of water disposed into the sewer), costs of replacing galvanized pipe (there is not enough galvanized pipe in Central Arizona to make this an issue), and desalinization of effluent before recharging (this is not required in Arizona) were eliminated from the model. The biggest improvement to the model was the gathering of good solid data to include into the model. This economic analysis had the best data on Central Arizona ever used in the model.

How the model works

The model gages the economic impact of salinity by analyzing five specific areas where salinity has impacted society. These areas are residential, commercial, industrial, agriculture and water utilities. In each of these sectors different methods are used to come up with a value of the economic impact based on the salinity level of the water used by that sector. For example, the irrigation districts use poorer quality water then residential consumers because the irrigation districts use effluent and also use poor quality groundwater.

The model does not calculate an absolute value of the economic impacts due to salinity. The model starts from a base line then calculates an increase in economic impacts when salinity rises or calculates a decrease in economic impacts when salinity declines in the waters used in the study area. The base line for this study was the creation of a typical year. The typical year uses typical or average salinity levels of Central Arizona's water sources and water supply. The typical year will be described in better detail later in this chapter.

Population and Water Usage

The 2000 census data was used to estimate the population in each of the sub-areas of the entire study area. Refer to the map of the study area in other portions of this report for the boundaries of each sub-area. The number of households was calculated by dividing population by 2.7.

CENSUS 2000 POPULATION DATA		
Sub-area	**Population**	**# of Households**
1) Harquahala	500	185
2) Phoenix Metro Area	3,095,577	1,143,245
3) Gila Bend	1,980	733
4) Pinal	135,383	50,142
5) Tucson Metro	843,737	312,495
6) GRIC	11,257	4,169

Population and Households for the Study Area
Table E-1

The water use data that was used for the modeling was gathered from many sources. Most of the water use data came from the Arizona Department of Water Resources (ADWR) and the associated Active Management Areas (AMA). But other sources of information were the Salt River Project (SRP), the Central Arizona Water Conservation District (CAWCD), the United States Geological Service (USGS), the City of Phoenix and other local sources. Initially, all the water use data was for the year 2000. When this was presented to the Technical Committee it was rejected for use in the analysis because the year 2000 was a drought year. Some of the problems pointed out were that the SRP river system was very under utilized that year and ground water use was higher than normal. Also, the salinity level in the Salt River was very high (763 mg/l) because of the low flows. The Technical Committee recommended a “typical year” be created. A typical year was created by holding the year 2000 water demands constant and using an average or median value for water supply and salinity levels.

A median value was used for water delivered by SRP from the Salt and Verde Rivers. SRP supplied this value. This was an acceptable choice because a median value discounts flood years and drought years. Other data, such as the surface water from the Gila River used by the Gila River Indian Community was an average value, since that was the data available. Several compromises had to be made to make the water supply match the year 2000 demands. The water supply data and water use data are reasonably accurate for a “typical year” and work well enough for the accuracy level delivered from the economic model. Table E-2 shows the water used in different sectors of society for the typical year.

WATER USE BY SECTOR "typical year"				
	All values in acre-feet			
Sub-area	Residential	Commercial	Industrial	Agricultural
1) Harquahala	70	22	0	131,908
2) Phoenix Metro Area	678,657	212,966	142,877	923,000
3) Gila Bend	251	79	0	284,670
4) Pinal	18,335	5,730	8,735	765,000
5) Tucson Metro	137,434	42,924	55,142	130,000
6) GRIC	990	340	0	116,670
Total	835,737	262,061	206,754	2,351,248

Table E-2

Table E-3 shows the water use by "source" for a typical year. Surface water is all river water except for the CAP. Surface water includes the Salt River, the Verde River, the Agua Fria River and the Gila River. CAP water is from the Colorado River delivered via the Central Arizona Project canals. These numbers include losses due to evaporation and seepage. The GRIC irrigation system is notorious for losses, losing up to 40% of the water before it is delivered to the fields. The Tucson Metro numbers reflect the current CAP usage including recharged water but CAP usage will increase as the City of Tucson's Clearwater Recharge facility expands operation.

WATER USE BY SOURCE (typical year)				
	All values in acre-feet			
Sub-area	Ground	Surface	CAP	effluent
1) Harquahala	27,000	0	105,000	0
2) Phoenix Metro Area	410,000	752,000	752,000	130,000
3) Gila Bend Agricultural Area	200,000	85,000	0	0
4) Pinal	310,000	130,000	363,000	5,800
5) Tucson Metro	325,000	0	74,000	12,500
6) GRIC	41,000	54,000	54,000	6,900
Total	1,313,000	1,021,000	1,348,000	155,200

Table E-3

Surface water salinity levels for the typical year were averages for the rivers for the last 25 years. The data was supplied by reports issued by USGS, SRP and the Salinity Control Board. The ground water salinity level was the average water quality in wells located in each sub-area from measurements taken between 1992 and 2000. The Phoenix metro area had two separate ground water qualities calculated: municipal and agricultural. This was done because of the very high TDS in the southwest part of the study area was skewing the groundwater quality. This water is not used for drinking but only for agriculture irrigation. Therefore, the wells located in the agricultural districts in the southwest and southeast of the Phoenix metro area were averaged for irrigation water quality only. The wells located in the rest of the Phoenix metro study area were averaged

for the ground water quality delivered for municipal purposes. Note in Table E-4, the very good quality ground water located in the Tucson Metro area.

Typical Salinity in Source Water (mg/L) "Typical Year"				
Sub-area	**Groundwater**	**CAP Water**	**Surface H2O**	**Effluent**
1) Harquahala	733	649	0	0
2) Phoenix Metro Area	738	649	475	951
3) Gila Bend	1,823	0	2,368	0
4) Pinal	919	649	554	950
5) Tucson Metro	278	649	0	550
6) GRIC	2,334	649	554	1,286
7) Phoenix Agriculture	2,105	649	475	951

Table E-4

The salinity level used for the analysis was a weighted average of the volumes and salinity level of the ground water, the CAP, the surface water and the effluent in any given sub-area. Table E-5 shows the typical year salinity level used in the model.

Sub-Area	Weighted TDS (mg/l)
1) Harquahala	666
2) Phoenix Metro Area	621
3) Gila Bend	1986
4) Pinal	741
5) Tucson Metro	316
6) GRIC	994
7) Phoenix Agriculture	907

Weighted TDS for Sub-Areas
Table E-5

Residential

The economic impact on residential users of water with high salinity levels has been classified into two categories:

1. Reduced life of water-using appliances.
2. Avoidance of salinity impacts by purchase of dispensed water or home water softening systems.

The economic impacts of a reduced life for water using appliances are calculated by determining the life span of the appliance at different salinity levels. At higher salinity levels the life of the appliance is reduced therefore the annualized cost of purchasing the appliance is increased. For example, a $500 appliance lasting 5 years has a $100 annual cost. If that same appliance last only 3 years due to using water with a higher salinity

level the annual cost is $166.67. Therefore, the result of increased salinity in the water would be an annual economic impact to the resident of $66.67. Since we are considering a large population and appliances are purchased at a relative constant rate the concept works well. Table E-6 is a summary of the appliances and the formulas that were used to determine the economic impacts to residents in Central Arizona.

ECONOMIC IMPACTS OF REDUCED LIFE OF WATER USING APPLIANCES AND PLUMBING (2000 Price Level)			
Appliance/Plumbing Item	**Percent of Residences with Appliance**	**Cost**	**Life Span in Years (y) as a Function of TDS in mg/L**
Galvanized steel water supply pipes	0	NA	$y = 12 + \exp(3.4 - 0.0018 * TDS)$
Water Heater	100	$302.45	$y = 14.63 - 0.013 * TDS + 0.689(10^{-5}) * TDS^2 – 0.11(10^{-8}) * TDS^3$
Faucet	100	$408.59	$y = 11.55 - 0.00305 * TDS$
Garbage Disposal	43%	$109.61	$y = 9.23 - 0.00387 * TDS + 1.13(10^{-6}) * TDS^2$
Clothes Washer	95%	$629.20	$Y = 14.42 - 0.011 * TDS + 0.46(10^{-5}) * TDS^2$
Dish Washer	60%	$431.98	$Y = 14.42 - 0.011 * TDS + 0.46(10^{-5}) * TDS^2$
Evaporative Coolers	43%	$1159.00	$y = 20 / \exp(0.0001761 * TDS)$

Table E-6

Galvanized steel water supply pipes were dropped as an impact after research indicated that galvanized pipes for individual homes are no longer installed and the last of the public water supply pipelines will be replaced with in the next 5 years. It was felt this impact was no longer valid or would be no longer valid with in a few years.

Water heaters were considered to be in every single residential unit. The cost of water heaters is an average value of many different brands including both gas and electric water heaters. Data was collected from several major retail stores. The research was web based.

Faucet prices were calculated as an average of many different brands for the bathroom, kitchen and shower. The total number of faucets in a typical house was estimated to be 5: 2 bathroom faucets, 1 kitchen faucet, 1 shower faucet and 1 bathtub faucet.

Garbage Disposals were considered to be in 43% of the residential households, this percentage came from a national survey from the Association of Home Appliance Manufacturers. The price came from an average of many different models.

Clothes Washers were considered to be in 95% of the households, this percentage also came from a national survey from the Association of Home Appliance Manufacturers.

This value seems reasonable for Arizona. The price was calculated as an average from many different models.

Dish Washers were considered to be in 60% of the households, this percentage came from a national survey from the Association of Home Appliance Manufactures. The price was calculated as an average from many different models.

Evaporative Coolers were considered to be on 43% of the homes in Central Arizona either alone or in conjunction with refrigerated air conditioning. This percentage came from an article in the *Journal AWWA*, Vol. 90, No. 4 (April 1998). The price was an average of many different models.

The functions that calculate the life span of the appliances with respect to salinity came from the report, *Estimating Economic Impact of Salinity of the Colorado River* prepared by the Milliken Chapman Research Group, Inc. (February 1988). The CASS Technical Committee decided there was no need to revise the functions because they were reviewed by MWD during the course of their salinity study and found to be adequate.

The second category of residential economic impacts is the avoidance costs. Water softening systems and purchasing bottled water are two methods considered in the model. Table E-7 shows the functions and annual costs for these two avoidance costs.

ECONOMIC IMPACTS OF AVOIDANCE OF SALINITY IMPACTS BY PURCHASE OF DISPENSED WATER, HOME FILTRATION SYSTEMS, AND WATER SOFTENERS (2000 Price Level)

Avoidance Method		Annual Cost	Unit or Cost (y) as a Function of TDS in mg/L
Bottled Water	-	$135.93	y = 61.1 + 0.00323 * TDS {y = % of households using bottled water}
Water Softener	-	$319.30	$y = 6.758 + 0.007 * TDS + 3.01(10^{-6}) * TDS^2 + 2.2(10^{-10}) * TDS^3$ {y = % of households using water softening devices}

Table E-7

Bottled Water annual cost was calculated from individual daily consumption of water multiplied by 365 days multiplied by an average cost of bottled water. According to a survey conducted by *Bottled Water Web Consumer Focus*, the national average individual daily consumption of water is 6.1 eight ounce servings of water daily. This is 48.8 ounces or 0.38 gallons daily. In a survey of 45 people in Reclamation's Phoenix Area Office, they indicated that they on average consumed 0.48 gallons of water daily. The survey gave a "reality check" for the *Bottled Water Web Consumer Focus* value. The cost of bottled water was averaged from numerous sources including surveying supermarkets and web based research.

Many water resource planners including members of the CASS Technical Committee are uncomfortable with the idea that there is a direct correlation between purchase of bottled water and salinity. But W. H. Bruvold performed both laboratory taste tests and field surveys confirming that the higher the TDS level the poorer the taste of water. Bottled water is purchased in part because of poor tasting water. Other CASS team members

were concerned with using bottled water consumption as an economic impact because the bottled water industry that promotes drinking bottled water in a highly effective advertising campaign and is not a detriment to society. The function shows that 61.1% of the population drinks bottled water no matter what the TDS value of the local tap water, these people are not included in the economic impacts. It is the increase of people drinking bottled water because of high salinity tap water that is used to calculate a value for the economic impact.

Water Softeners are used to treat hardness by replacing calcium with sodium in the water, which exacerbates salinity problems by adding more salinity to the system. The cost for a water softening system was calculated by annualizing the initial cost and yearly maintenance cost for a typical system.

Commercial

Commercial water users are schools, department stores, hospitals, banks, restaurants, nursing homes and other similar businesses and institutions. Data was not plentiful on the amount of water consumed by the commercial sector. But the City of Tucson Water Department (Tucson Water) provided data that indicated that commercial water use in Tucson is 23.8% of non-industrial municipal water use. This ratio of 23.8% commercial and 76.2 % residential non-industrial water use was used for the entire study area. The MWD report used a value of 26% commercial water use, so the data supplied by Tucson Water seems reasonable. The economic impact calculations for the commercial sector are the same as the earlier model. The only adjustments made were to reflect current pricing and unique attributes to Arizona. Table E-8 shows the estimated water used by the commercial sector in each sub-area.

Commercial water use by Sub-Area (acre-feet/ year)	
Sub-area	**Estimated Water Use Year 2000**
1) Harquahala	22
2) Phoenix Metro Area	212,966
3) Gila Bend	79
4) Pinal	5,730
5) Tucson	42,924
6) GRIC	340

Table E-8

Water use by commercial entities can be broken into the following categories; sanitary, cooling, irrigation, kitchen, laundry and other. The effect that salinity and its associated hardness have on the commercial sector of society is measured by looking at its effect in each of these categories. The Technical Committee agreed that the data on commercial

water use, MWD collected concerning Southern California would be very similar to Central Arizona. The breakdown of commercial water use is reflected in Table E-9.

PERCENT WATER USE FOR EACH USE CATEGORY							
Sub-area	**Sanitary**	**Cooling**	**Irrigation**	**Kitchen**	**Laundry**	**Others**	**Total**
1) Harquahala	29%	12%	32%	7%	8%	12%	100%
2) Phoenix Metro Area	29%	12%	32%	7%	8%	12%	100%
3) Gila Bend	29%	12%	32%	7%	8%	12%	100%
4) Pinal	29%	12%	32%	7%	8%	12%	100%
5) Tucson	29%	12%	32%	7%	8%	12%	100%
6) GRIC	29%	12%	32%	7%	8%	12%	100%

Table E-9

Sanitary costs are similar to residential costs especially if you consider schools, hotels, motels and hospitals but also other commercial establishments. Using the equation for faucet replacement a value can be calculated. Assuming 0.5 acre-feet per household per year and one-half of household use affecting interior faucet, the cost impact is 6.8 cents per acre-foot per mg/l of salinity.

Additional costs are associated with water softening. Softening water costs vary depending upon size, peak flow rate, hardness of the water, and desired hardness. A median value is about $131 per acre-foot. Assuming that one is reducing hardness in water with a salinity of 600 mg/l to the equivalent hardness of water with a salinity of 400 mg/l, the cost of a reduction would be equivalent to $0.65 per acre-foot per mg/l. Hotels, hospitals and various other entities soften water to some degree. Estimating that 20% of the commercial sanitary water is softened, then it can be calculated that the costs are approximately $0.13 per acre-foot per mg/l. These calculations make the total impact for sanitary costs to be $0.20 per acre-foot per mg/l

Cooling water is approximately 12% of total commercial water use. The use of water for cooling is directly affected by salinity. Cooling towers operate by evaporation, which in turn results in a concentration of salt in the water. Make-up water is supplied to replace evaporated water. The concentration of water in the tower is maintained at a desired salinity level by adding water in addition to that evaporated and allowing a like amount of water (blow down water) to be discharged.

A major factor of the effect of increased salinity is the cost of additional water and added chemicals. Currently, Arizona does not have a disposal cost for highly saline water. According to the MWD study an increase in salinity requires a 7% increase in water based on a tower operating salinity of 2,500 mg/l. Water purchased at retail prices is approximately $600 acre-foot and $157 acre-foot for chemicals. Therefore a cost function would be: Cost = acre-feet * .07/100 * 757 * increase in TDS per mg/l. Or Cost = acre-feet * .53 * increase in TDS per mg/l.

Irrigation water is approximately 32% of the water used by the commercial sector. This is water used to keep the common green areas watered. The wide spread use of plastic pipe for irrigation systems have reduced the impact of salinity. Also, landscape architects and nurseries tend to supply plants that are tolerant of the environment in which they will be planted, and this environment would include the water supply. Salinity impacts for growing grass and irrigating common green areas is not noticeable. The salinity function is zero.

Kitchens account for about 7% of the water used by commercial entities. Restaurants, hotels, hospitals, schools and nursing homes would be the primary users in this sub-category. Surveys indicate that approximately 2/3rds of the water used by commercial kitchens would be softened. Prime water softening uses are in dishwashers and steam tables where softened water reduces scaling and spotting. As calculated above, softened water costs approximately $0.65 per acre-foot per mg/l. Estimating, that only ½ of the water is softened used in commercial kitchens, the cost factor is then $0.33 per acre-foot per mg/l.

Laundries account for 8% of the water used. This includes commercial laundries, coin operated laundries and laundries for hospitals, nursing homes, etc. Commercial laundries and hospitals will soften their water but most coin operated laundries the water is not softened. The economic impact that MWD chose to use in their study was the full $0.65 per acre-foot per mg/l because it was felt that although all laundries did not soften water there were other economic impacts such as increased soap use which were felt by users.

The "Other" category accounts for 12% of the water use. This includes water use such as car washing, ice machines, pools in hotels and things not fitting into the neat categories previously discussed. The cost function used for other is a weighted average of the previous categories.

Table E-10 shows all the cost functions used for commercial water use in the model.

TDS IMPACT FUNCTION FOR EACH CATEGORY						
Use Category	**Sanitary**	**Cooling**	**Irrigation**	**Kitchen**	**Laundry**	**Others**
TDS Function ($/AF per mg/L)	$0.20	$0.53	$0.00	$0.33	$0.65	$0.22

Table E-10

Industrial

High salinity water has a significant economic impact on industry in Central Arizona. Some industries require water which is better quality than the quality of water delivered to them. Food and beverage manufacturing require water which has undergone reverse osmosis to remove the TDS but other industries only need to soften the water by removing the calcium and magnesium components. The high tech industries, such as

microchip manufacturing, need ultra-pure water for its manufacturing process. Each of these processes are expensive and costs rise with the increased removal rates.

The imported water coming into Central Arizona is not only high in dissolved solids it also can change drastically in dissolved solid content over a few days time. For example, this can happen when the Salt River Project switches water supplies from the Verde River (average TDS 269 mg/l) used in winter to the Salt River (average TDS 576 mg/l) used during the summer.

The Arizona Department of Water Resources (ADWR) supplied some industrial water use numbers, but the model needed additional information to cover the entire industrial spectrum. ADWR had industrial water use numbers for dairy farms, cattle feedlots, mining and sand & gravel companies, which for the most part supplied their own water through wells. The model calculates economic impacts for high tech industries, manufacturing industries, food manufacturing, etc. These industries for the most part are buying retail water from private water suppliers or city supplies and were not included in data received from ADWR. Economic census data was used to calculate the industrial water use in Arizona.

The water use by the industrial sector was calculated by first estimating the number of industrial establishments in each sub-area and their size. Information on Central Arizona's industry and the number of employees was gathered from the 1997 Economic Census Data assembled by the U.S. Census Bureau. Water use per employee in gallons per day was also available. With those numbers it was simple arithmetic to come up with annual use in acre-feet per year. The dairy farms, cattle feedlots, mining companies and sand & gravel companies water consumption supplied by ADWR was added to the calculated industrial use to come up with a total for each sub-area. The total use was partitioned into the following use categories; process water, boiler water, cooling water, sanitation and irrigation water for each industry. Each of the use categories have a cost function associated with it.

Tables E-11, E-12 and E-13 for Pinal, Pima and Maricopa Counties respectively, give the industries, the number of establishments of that industry, the total number of employees, the water use per day per employee and then annual water use. The second part of each table has industry data supplied by ADWR.

Pinal County Industry	Establish.	Employees	Water use per employee gallons/day/employee	Annual use gallons/yr	Annual use Ac-ft/yr
Food mfg	8	825	714	147,262,500	452
Paper mfg	1	825	2,174	448,387,500	1,376
Primary Metal mfg	5	2,318	909	526,765,500	1,616
Fabricated metal prod.	10	626	246	38,499,000	118
sub-total	24	4,594			3,562
Dairies					2,088
Power Plants					0
Sand & Gravel					277
Feedlot					2,647
Mining					161
sub-total					5,173
Total					**8,735**

Table E-11

Pima County Industry	Establish.	Employees	Water use per employee gallons/day/employee	Annual use gallons/yr	Annual use Ac-ft/yr
Food mfg	44	654	714	116,739,000	358
Beverage mfg	9	575	1,282	184,287,500	565
Plastics & rubber prod	39	1,100	625	171,875,000	527
Non-metallic mineral	59	1,796	375	168,375,000	517
Fabricated metal prod	123	3,768	246	231,732,000	711
Machinery mfg	52	1,988	357	177,429,000	544
Comp & electronic	56	3,904	227	221,552,000	680
Transportation equip	19	7,499	300	562,425,000	1,726
sub-total	250	17,159			5,629
Dairies					115
Power Plants					5,214
Sand & Gravel					5,455
Feedlot					0
Mining					38,729
sub-total					49,513
Total					**55,142**

Table E-12

Maricopa County Industry	Establish.	Employees	Water use per employee gallons/day/employee	Annual use gallons/yr	Annual use Ac-ft/yr
Food mfg	154	7,499	714	1,338,571,500	4,107
Beverage mfg	17	1,749	1,282	560,554,500	1,720
Textile product mills	75	749	315	58,983,750	181
Apparel mfg	52	1,749	24	10,494,000	32
Wood product mfg	122	6,169	794	1,224,546,500	3,757
Paper mfg	31	1,749	2,174	950,581,500	2,917
Chemical mfg	124	5,798	1,818	2,635,191,000	8,086
Plastics & rubber prod	167	6,391	625	998,593,750	3,064
Nonmetallic mineral	133	3,749	375	351,468,750	1,078
Primary metal mfg	32	3,749	909	851,960,250	2,614
Fabricated metal prod	605	14,329	246	881,233,500	2,704
Machinery mfg	232	7,500	357	669,375,000	2,054
Comp & electronic	270	37,500	227	2,128,125,000	6,530
Electrical equip.	66	3,750	227	212,812,500	653
Transportation equip	172	17,500	300	1,312,500,000	4,027
Furniture prod. Mfg	246	6,526	151	246,356,500	756
sub-total	2,498	126,456			44,282
Dairies	98				9,992
Power Plants	4				78,800
Sand & Gravel	43				9,681
Feedlot	17				122
Mining	0				0
sub-total					98,595
Total					**142,877**

Table E-13

Table E-14 is a breakdown of water uses for each industry into the categories of process water, boiler water, cooling and sanitation & irrigation. Process water can be treated by desalinization, such as reverse osmosis, softening or no treatment depending on what industry is using the water. The high tech industries, such as chip manufacturing, require ultra-pure water. Other industries may require only softening, filtering or no treatment. Boiler feed water for electrical generation requires ultra-pure water but these plants condense virtually all their steam so there is little need for makeup water. In contrast most other industrial boiler feed water represents a relatively large use. Typically, this water will be softened or maybe even desalinated. Cooling water in cooling towers is used for a number of cycles then discarded. The cycles of use depends on what the TDS was to start and to what level of concentration will be allowed and also by law in Arizona. The irrigation and sanitation water uses are minor compared to the other uses.

	Profile of water Use			Sanitation & Irrigation	total
	Process	Boiler	Cooling		
Food mfg	59.00%	5.00%	34.00%	2.00%	100.00%
Beverage mfg	79.40%	11.30%	7.20%	2.10%	100.00%
Textile product mills	81.00%	16.00%	0.00%	3.00%	100.00%
Apparel mfg	81.00%	16.00%	0.00%	3.00%	100.00%
Wood product mfg	81.00%	16.00%	0.00%	3.00%	100.00%
Paper mfg	62.00%	21.00%	9.00%	8.00%	100.00%
Chemical mfg	19.00%	15.00%	62.00%	4.00%	100.00%
Plastics & rubber prod	20.00%	15.00%	61.00%	4.00%	100.00%
Non-metallic mineral	93.00%	0.00%	3.00%	4.00%	100.00%
Primary metal mfg	13.00%	5.00%	24.00%	58.00%	100.00%
Fabricated metal prod	13.00%	5.00%	24.00%	58.00%	100.00%
Machinery mfg	68.00%	4.00%	16.00%	12.00%	100.00%
Comp & electronic	50.00%	2.00%	18.00%	30.00%	100.00%
Electrical equipment	50.00%	2.00%	18.00%	30.00%	100.00%
Transportation equip	68.00%	4.00%	16.00%	12.00%	100.00%
Furniture mfg	81.00%	16.00%	0.00%	3.00%	100.00%
Dairies	10.00%	1.00%	20.00%	69.00%	100.00%
Power plants	19.00%	15.00%	62.00%	4.00%	100.00%
Sand & Gravel	90.00%	0.00%	5.00%	5.00%	100.00%
Feedlot	10.00%	1.00%	20.00%	69.00%	100.00%
Mining	91.00%	3.00%	3.00%	3.00%	100.00%

Table E-14

Tables E-15, E-16 and E-17 for Pinal, Pima and Maricopa Counties respectively, gives the total water use for each county for each process based on Table E-14.

Water in each process Pinal County (acre-feet)					
	Process	Boiler	Cooling	Sanitation & Irrigation	Total
Food mfg	267	23	154	9	452
Paper mfg	853	289	124	110	1,376
Primary Metal mfg	210	81	388	937	1,616
Fabricated metal prod.	15	6	28	69	118
Dairies	209	21	418	1,441	2,088
Power Plants	0	0	0	0	0
Sand & Gravel	249	0	14	14	277
Feedlot	265	26	529	1,826	2,647
Mining	147	5	5	5	161
Total	**2,214**	**450**	**1,659**	**4,411**	**8,735**

Table E-15

Water in each Process Pima County (acre-feet)					
	Process	Boiler	Cooling	Sanitation & Irrigation	Total
Food mfg	211	18	122	7	358
Beverage mfg	449	64	41	12	565
Plastics & rubber prod	105	79	322	21	527
Non-metallic mineral	480	0	15	21	517
Fabricated metal prod	92	36	171	412	711
Machinery mfg	370	22	87	65	544
Comp & electronic	340	14	122	204	680
Transportation equip	1,174	69	276	207	1,726
Dairies	12	1	23	79	115
Power Plants	991	782	3,233	209	5,214
Sand & Gravel	4,910	0	273	273	5,455
Feedlot	0	0	0	0	0
Mining	35,243	1,162	1,162	1,162	38,729
Total	**44,377**	**2,246**	**5,846**	**2,672**	**55,142**

Table E-16

Water in each Process Maricopa County (acre-feet)					
	Process	Boiler	Cooling	Sanitation & Irrigation	total
Food mfg	2,423	205	1,396	82	4,107
Beverage mfg	1,366	194	124	36	1,720
Textile product mills	147	29	0	5	181
Apparel mfg	26	5	0	1	32
Wood product mfg	3,044	601	0	113	3,757
Paper mfg	1,808	613	263	233	2,917
Chemical mfg	1,536	1,213	5,013	323	8,086
Plastics & rubber prod	613	460	1,869	123	3,064
Non-metallic mineral	1,003	0	32	43	1,078
Primary metal mfg	340	131	627	1,516	2,614
Fabricated metal prod	352	135	649	1,568	2,704
Machinery mfg	1,397	82	329	246	2,054
Comp & electronic	3,265	131	1,175	1,959	6,530
Electrical equip.	326	13	118	196	653
Transportation equip	2,739	161	644	483	4,027
Furniture mfg	612	121	0	23	756
Dairies	999	100	1,998	6,894	9,992
Power plants	14,972	11,820	48,856	3,152	78,800
Sand & Gravel	8,713	0	484	484	9,681
Feedlot	12	1	24	84	122
Mining	0	0	0	0	0
Total	**45,692**	**16,015**	**63,603**	**17,566**	**142,877**

Table E-17

The model calculates economic impact for industry in four industrial categories of water use, process water, cooling water, boiler water and sanitary & irrigation water. Process water is further broken down into demineralization, softened and not further treated.

Demineralization costs include reverse osmosis, distillation and electro-dialysis. The cost of reverse osmosis is dropping but still is expensive and varies from about $700 to $1000 per acre-foot for water at about 650 mg/l. Being conservative and using $700 per acre-foot to reduce the water to about 16 mg/l the cost is $1.10 per mg/l. But some de-mineralized process water needed for high tech industry must be ultra-pure and is further treated with distillation or some other process. The costs for additional treatment may increase the costs by another 150%. Estimating that 25% of the de-mineralized water is ultra-pure water this would make the total demineralization costs per mg/l at about $1.53 mg/l per acre-foot.

Water softening costs have previously been calculated in this chapter to be $0.65 per mg/l.

Of course process water that is not treated any further by industry, which is the majority of water used by industry, has no additional costs associated with salinity.

Table E-18 is an estimate of the industrial Process Water that is de-mineralized, softened and not treated by industry.

Industrial Process Water	
Treatment needs	Percent
Demineralization	24%
Softening	24%
No treatment	52%

Table E-18

Cooling towers for industry are usually larger than the ones used for commercial buildings. The use of water for cooling is directly affected by salinity. Cooling towers operate by evaporation, which in turn results in a concentration of salt in the water. Make-up water is supplied to replace evaporated water. The concentration of water in the tower is maintained at a desired salinity level by adding water in addition to that evaporated and allowing a like amount of water (blow down water) to be discharged.

A major factor of the effect of increased salinity is the cost of additional water and added chemicals. Water used for cooling towers for industry can operate at a higher salinity than the smaller towers associated with commercial cooling. According to the MWD study an increase in salinity requires a 4% increase in water based on a tower operating salinity of 3,500 mg/l.

Water purchased at retail prices is approximately $600 acre-foot and $157 acre-foot for chemicals. Therefore a cost function would be: Cost = acre-feet * .04/100 * 757 *

increase in TDS per mg/l. Or Cost = acre-feet * .30 * increase in TDS per mg/l.

Boiler feed water can be broken into three groups: electrical generation, space heating and industrial purposes. Electrical generation plants use ultra-pure water to run through the generators. These are closed systems and very little water is lost. For general space heating in buildings, boilers operate at relatively low temperatures and recycle the steam, once again very little water is needed as make up water. On the other hand, industrial use of boiler feed water can be very high. Make up water can be up to 50% of boiler feed water. Industrial steam is lost by injection into products, cleaning and losses from deterioration of steam condensing equipment. Typically, this water is either softened or de-mineralized by reverse osmosis or electro-dialysis. Allowing for 50% to be softened and 50% to be de-mineralized the costs would be approximately $1.09 per acre-foot per mg/l.

Sanitation & irrigation costs are negligible for industry. Irrigation costs have not been considered because of the same reasoning given for the commercial sector. The same factors that apply to the residential sector are assumed to apply for industrial sanitation uses. The majority of costs come from bottled water consumption and home softening systems. Home softening systems do not apply for industry. Bottled water does apply. The bottled water calculations consider the daily consumption of water, but not broken down between consumed at work or at home. It would be double counting to put that function into the industry also sector.

Table E-19 shows the cost functions used for the industrial sector in the model.

Industrial Water Use Impact Functions						
	Process Water Demineralization	Process Water Softening	Process Water Minor	Cooling Towers	Boiler Feed	Sanitation & Irrigation
Total Industrial Water Impact Functions ($/af per mg/l)	$1.53	$0.65	$0.00	$0.30	$1.09	$0.00

Table E-19

Agricultural

Two factors were taken into consideration to determine the economic impacts on agriculture in Central Arizona because of salinity. The first factor was reduced crop yield. It has been established that as the salinity level increases in the irrigation water the crop yield per acre declines. It is the salt build up in the soil at the root zone that causes the reduction in crop yield. Of course different crops have different tolerances to salinity. Cotton, barley and alfalfa are quite tolerant to salinity and are major crops in Central Arizona. This reduces the impacts that salinity has on agriculture to some degree. The U.S. Salinity Laboratory in Riverside, California developed crop yield curves over the last 25 years. These curves were used in the model to determine the

reduction in crop yield. Because growing conditions can vary dramatically, the crop reduction curves can only approximate the actual change in crop yield. But the curves are sufficient to get a reasonable value for the economic impact on agriculture. The model calculates the economic impact by using the year 2000 as a base year. When the salinity level in the model is increased new crop yield is calculated for each crop type. A dollar amount can then be calculated based on the difference of the yields. Of course there are many, many factors that affect the price of crops on the market. This model only gages the economic impact of changing salinity levels assuming all other factors remained the same. Table E-15 lists the primary crops and approximate acres of those crops grown in the study area for the year 2000. These crop acreages were used for the model.

Crop Type	Harquahala	Phoenix Agriculture	Gila Bend	Pinal	Tucson	GRIC
Cotton	15,920	69,900	14,400	104,357	12,300	3,443
Barley	235	11,200	8,280	16,594	1,000	406
Alfalfa (Hay)	4,041	55,280	17,320	26,325	1,900	2,975
Wheat	600	8,420		18,697	3,900	1,703
Corn	750	600		500		
Broccoli	440	4,000				
Cantaloupe	2,360	9,600				
Watermelon	486	3,900		492		408
Potatoes	130	6,500		2,500		
Head Lettuce					600	
Grapefruit		2,400				250
Oranges		4,600				700
Lemons		1,400				
Tangerines		3,200				
Onions		900				233
Olives						600
Cauliflower		300				
Carrots		1,800				
Honeydews		2,700				
Grapes		2,000		675		
Totals (acres)	24,962	188,700	40,000	170,140	19,700	10,718

Crop Acreage for the Study Area
Table E-20

Table E-21 shows crop value for the study area in the year 2000. These values were used as the base line for the economic analysis.

Crop Type	Harquahala	Phoenix Metro Area	Gila Bend	Pinal	Tucson	GRIC
Cotton	$880.00	$1,019.00	$931.00	$878.00	$932.00	$1,107.00
Barley	$173.00	$274.00		$272.00	$276.00	$370.00
Alfalfa (Hay)	$743.00	$756.00	$752.00	$791.00	$698.00	$733.00
Wheat	$345.00	$325.00	$325.00	$295.00	$283.00	$362.00
Corn	$313.00	$468.00		$477.00		
Broccoli	$3,044.00	$4,853.00				
Cantaloupe	$4,116.00	$2,913.00				
Watermelon	$3,876.00	$2,551.00		$2,786.00		$2,040.00
Potatoes	$3,286.00	$2,947.00		$3,023.00		
Head Lettuce					$5,191.00	
Grapefruit		$380.00				$33.00
Oranges		$1,009.00				$387.00
Lemons		$4,369.00				
Tangerines		$1,299.00				
Onions		$2,067.00				$560.00
Olives						
Cauliflower		$7,678.00				
Carrots		$2,187.00				
Honeydews		$3,725.00				
Grapes		$3,504.00		$3,504.00		

Crop Value per Acre for the year 2000
Table E-21

The second factor considered in the model is the cost of leaching salts from the root zone. The cost calculated was the value of the additional water used for leaching above the water needed for consumptive use by the crops. A weighted average value for the cost of water was calculated from the different sources used by agriculture in the Phoenix metro area. Table E-22 shows the cost of and acre-foot of water for agriculture in the Phoenix metro area.

Cost to pump GW	Cost of SRP ag water	Cost of CAP ag water	Cost of effluent
$33.00	$10.00	$33.00	$8.66

Value of Agricultural Water for Phoenix Metro (Acre-Feet)
Table E-22

Table E-23 and E-24 were used to calculate the weighted average for an acre-foot of water used for agriculture. The cost of SRP water used in the Phoenix metro area was used for the cost of surface water for Pinal, GRIC and Gila Bend. Table E-19 is the weighted average cost used for the model.

	GW	Surface	CAP	effluent
Harquahala	26,908	0	105,000	0
Gila Bend	199,670	85,000	0	0
Pinal	277,200	130,000	352,000	5,800
Tucson	102,000	0	28,000	0
GRIC	23,270	54,000	32,500	6,900
Phoenix Ag	286,600	286,600	286,600	63,200

Agricultural Water use for a Typical Year (Acre-Feet)
Table E-23

Harquahala	**$33.00**
Gila Bend	**$26.13**
Pinal	**$28.91**
Tucson	**$33.00**
GRIC	**$20.92**
Phoenix Ag	**$24.19**

Weighted Average cost of Agricultural Water for a Typical Year (Acre-Feet)
Table E-24

The leaching costs per acre are calculated using Table E-25. The formula used to calculate column "leaching requirement by formula" comes from the Food and Agriculture Organization of the United Nations, FAO Handbook #29. This is the most commonly used formula and was used by ADWR in calculation of leaching requirements in the AMA's. It calculates the leaching requirement needed for the crop based on it's salinity tolerance and the salinity of the water. Table E-20 shows a water quality salinity of 833 uS/cm which is equivalent to 500 mg/l TDS and with a cost associated with agricultural water in the Phoenix metro area. The model calculates a cost for leaching water usage for the base case. It then calculates the cost of additional leaching water usage for a new level of salinity. The difference between those values is the economic impact to the farmer for increases in salinity in the irrigation water.

Crop Type	Crop tolerance uS/cm	Crop water usage (af)	Water quality uS/cm	Leaching requirement by formula (af)	Max leaching (af)	Leaching requirement (af)	Cost of water per (af)	Additional cost per acre
Cotton	7,700	3.43	833	0.08	1.72	0.08	$24.19	$1.88
Barley	8,000	2.08	833	0.05	1.04	0.05	$24.19	$1.09
Alfalfa (Hay)	2,000	6.19	833	0.62	3.10	0.62	$24.19	$14.97
Wheat	6,000	2.15	833	0.06	1.08	0.06	$24.19	$1.53
Corn	1,700	2.12	833	0.26	1.06	0.26	$24.19	$6.25
Broccoli	2,800	1.64	833	0.11	0.82	0.11	$24.19	$2.68
Cantaloupe	1,000	1.56	833	0.39	0.78	0.39	$24.19	$9.43
Watermelon	1,000	1.75	833	0.44	0.88	0.44	$24.19	$10.58
Potatoes	1,700	2.03	833	0.25	1.02	0.25	$24.19	$5.99
Head Lettuce	1,300	0.71	833	0.12	0.36	0.12	$24.19	$2.96
Grapefruit	1,800	3.99	833	0.45	2.00	0.45	$24.19	$10.97
Oranges	1,700	3.26	833	0.40	1.63	0.40	$24.19	$9.62
Lemons	1,700	3.99	833	0.49	2.00	0.49	$24.19	$11.77
Tangerines	1,700	3.26	833	0.40	1.63	0.40	$24.19	$9.62
Onions	850	1.70	833	0.55	0.85	0.55	$24.19	$13.27
Olives	2,500	2.58	833	0.20	1.29	0.20	$24.19	$4.80
Cauliflower	2,800	1.55	833	0.10	0.78	0.10	$24.19	$2.53
Carrots	1,000	1.38	833	0.35	0.69	0.35	$24.19	$8.35
Honeydews	1,000	2.00	833	0.50	1.00	0.50	$24.19	$12.10
Grapes	1,500	3.00	833	0.43	1.50	0.43	$24.19	$10.37

Calculation of Leaching Water Cost per Acre
For Phoenix Metro Area with a water quality of 500 mg/l
Table E-25

Water Utilities, wastewater utilities and distribution pipelines

Salinity impacts to water treatment facilities, waste water facilities and water distribution pipelines are of concern.

Corrosion to waste water facilities is a serious matter. However, this corrosion is associated with sulfides rather than TDS. Because of the problems associated with sulfides, corrosion resistant materials are used in wastewater treatment facilities such as stainless steel. A conclusion can be drawn that wastewater facilities are not noticeably affected by increases in salinity. Wastewater treatment facilities were not included into the model. Although, it can be argued that the physical facility is not affected by salinity, the effluent that is discharged by a wastewater facility has less value if the salinity is too high.

An article in the AWWA Research Foundation, 1985, titled "*Internal Corrosion of Water Distribution Systems*", has a couple of pertinent comments on salinity.

This report states:

> "*Iron pipe corrosion is largely affected by the oxygen content of the water which is unrelated to the salinity*."

Further it states:

> "*Waters of low alkalinity show increased rates of internal corrosion. That is because these waters do not form a protective film of calcium carbonate on the interior surface*."

Since most of the water in Central Arizona is high in calcium carbonate and the previous statement about oxygen being the cause of the corrosion, it was decided not to include the affects of salinity on the water distribution system.

Water treatment facilities were included in the model. For the economic life of water production facilities was developed by Dennis P. Tihansky. The expected life of a water facility can be expressed by the following formula:

$$\text{Expected life in years} = 30.83 - (0.0033 * \text{TDS})$$

A list of all the water treatment facilities in the Phoenix metro area was compiled along with an estimated replacement cost. These were the only water treatment facilities used in the study as most of the sub-areas do not have water treatment facilities because they use groundwater for drinking water purposes. Tucson has a large water treatment facility, the Hayden-Udall water treatment facility, but it is not currently in operation.

The capital costs to replace a facility were calculated using a simple formula of $2.00 per million gallons per day. For example; a water treatment plant that can process 50 million gallons a day would cost $100 million dollars to replace. The model averages the capital cost over the life of the water treatment plant to give a yearly cost. The model then calculates the change of life for each water treatment plant when there is a change in the TDS of the water that that plant processes. It then averages the capital cost over the new calculated life to give a new yearly cost. The difference between the two yearly costs is the economic impact.

City – Water Facility	Size (mgd)	Replacement Cost (millions of dollars)
Phoenix – Deer Valley	160	$ 320
Phoenix – Val Vista	220	$ 440
Phoenix – Squaw Peak	140	$ 280
Phoenix – Verde	60	$ 120
Phoenix – Union Hills	160	$ 320
Phoenix – Lake Pleasant*	80	$ 160
Gilbert - Gilbert	30	$ 60
Glendale – Cholla	30	$ 60
Glendale – Pyramid Peak	40	$ 80
Scottsdale – CAP	55	$ 110
Tempe – Papago	50	$ 100
Tempe – South Tempe	50	$ 100
Chaparral City Water Co. 1	5	$ 10
Chaparral City Water Co. 2	5	$ 10
Peoria – Peoria	16	$ 32
Paradise Valley Water Co.	9	$ 18
Chandler – Chandler	45	$ 90
Total	**1155**	**$2,310**

Water Treatment Facilities in Phoenix Metro Area
Table E-26

Model Analysis

What are we trying to find out in the economic model analysis? The model is too broad or imprecise to give meaningful economic impacts to any one company or even city. It is a regional model that can tell us only the "big picture." The economic analysis can tell us the magnitude of the impacts that society faces if the salinity level of imported waters were to increase. Or on the other hand the analysis can tell us the magnitude of the benefits to society if the importation of salinity can be decreased.

The model does not calculate the absolute value of the economic impact of salinity, rather the model calculates the change of the economic impact to society starting from a base level as salinity levels increase or decrease. That base level for our purposes is the typical year described earlier in this chapter. In the typical year the weighted average salinity of the Salt and Verde Rivers is 475 mg/l, the average salinity for the CAP is 649 mg/l and the average salinity for groundwater is 738 mg/l. The salinity for effluent is a calculated value depending on the salinities of the other waters and societies salt input. The salinity level in the water in the Phoenix Metro area according to the model is a weighted average salinity of the groundwater, the Salt and Verde Rivers, the CAP and the effluent.

Three separate model analyses were done. The first analysis the salinity level in the Salt and Verde Rivers was adjusted by increments of 100 mg/l from a range of 275 mg/l to

1475 mg/l. When the Salt and Verde rivers salinity is adjusted by 100 mg/l the weighted average of the Phoenix Metro and Phoenix agriculture TDS levels adjust to the new input.

The second model analysis was to adjust the salinity level in the CAP. The base year or typical year salinity level for the CAP was 649 mg/l. The salinity level was adjusted by increments of 100 mg/l from 249 mg/l to 1549 mg/l. This is much greater than is ever anticipated the level of salinity would change in the CAP but we were looking for a curve. The model calculates a new weighted average salinity for each step in each sub-area except for Gila Bend. Gila Bend does not receive CAP so is not directly effected by changes in CAP only indirectly. Examine Table E-27. It can be seen that for a salinity change of 100 mg/l of CAP water, the weighted average salinity of the Phoenix Metro area changes by only 34 mg/l.

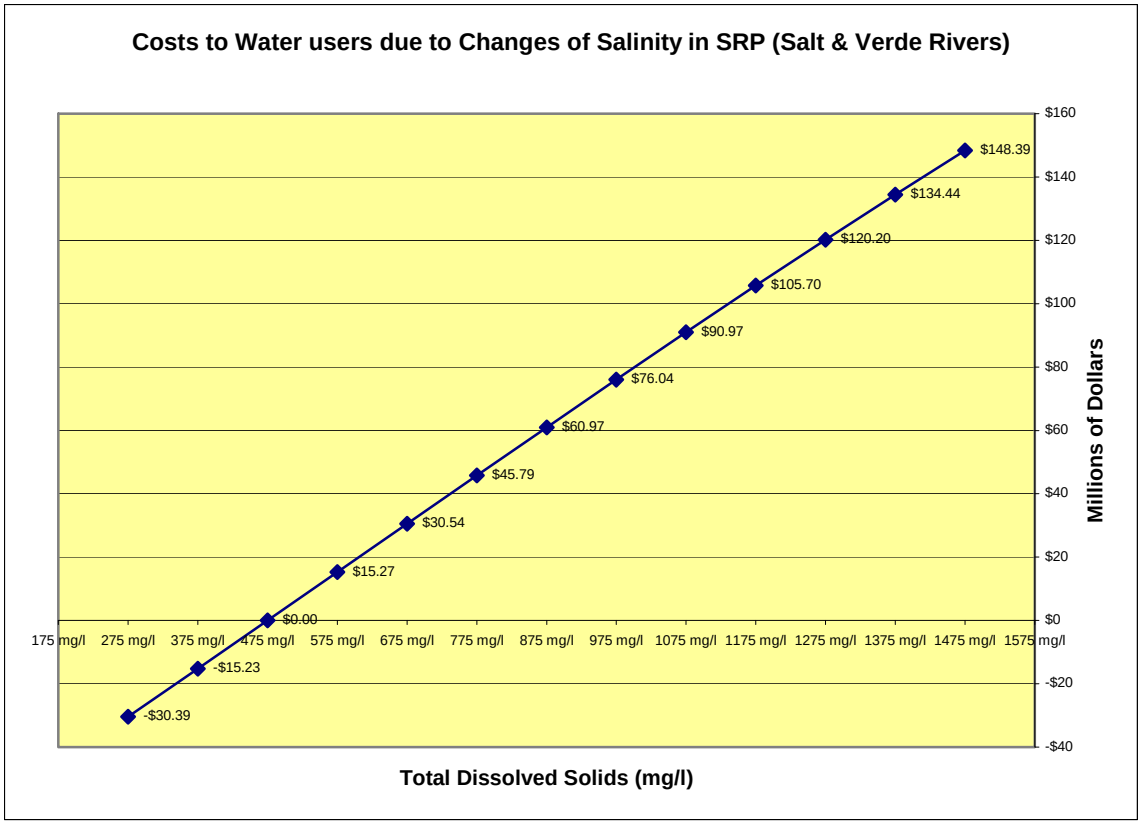
CAP salinity increase versus Weighted average TDS increase					
TDS	**Groundwater**	**Surface water**	**CAP**	**Effluent**	**Weighted Average**
Phoenix Metro	738	475	**649**	951	**621**
Phoenix Metro	738	475	**749**	951	**655**
Phoenix Metro	738	475	**849**	951	**689**
Water Use	**Groundwater**	**Surface water**	**CAP**	**Effluent**	
Phoenix Metro	410,000	750,500	667,000	130,000	

Table E-27

The final model analysis was to adjust the salinity level in the SRP rivers and also the CAP over a range of –200 mg/l to +800 mg/l from the base salinity level of the typical year. Of course, when both the SRP and the CAP salinity levels were changed there was a larger increase in the salinity level of the weighted average then there was when only one of them was increased.

Results of economic analysis

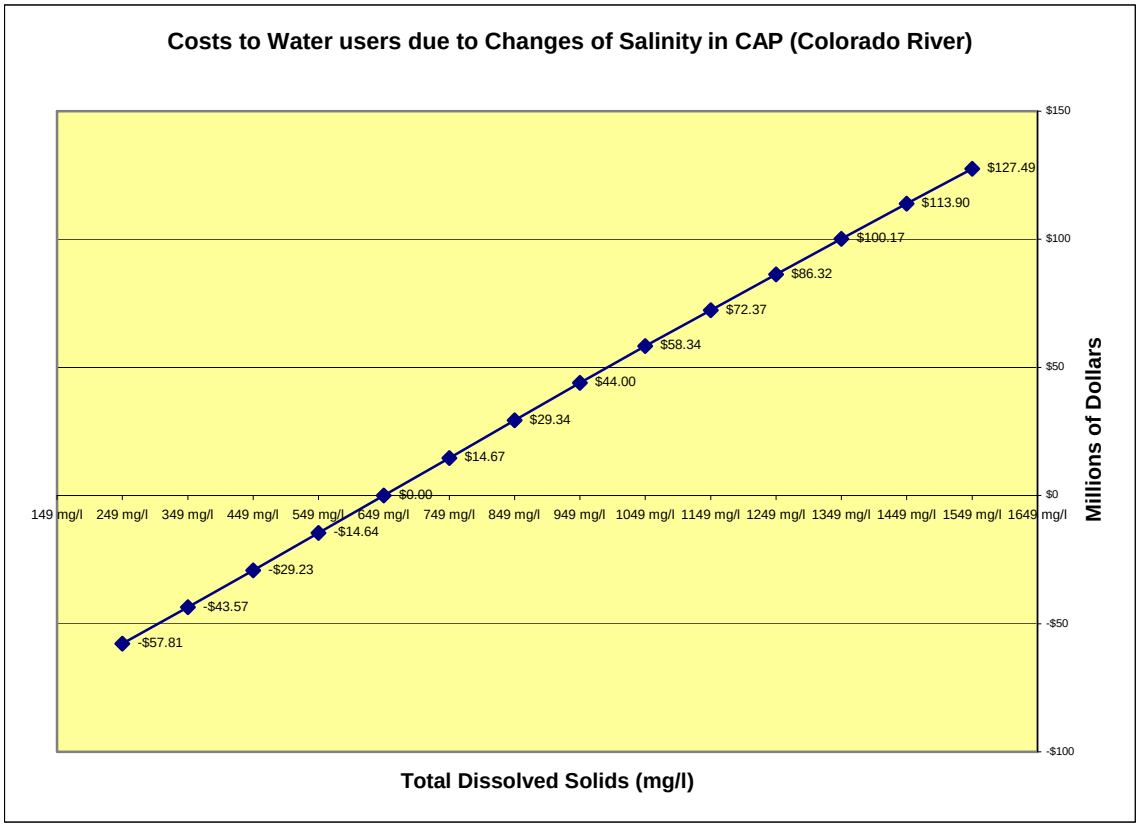
Graph E-1 shows the estimated economic impacts from incremental changes of 100 mg/l TDS in the Salt River and Verde River delivered by the Salt River Project (SRP) from a baseline of 475 mg/l TDS. The graph indicates that the economic impact is slightly above $15 million for each increase or decrease of 100 mg/l TDS. The economic impact is nearly linear with the change of salinity concentration in the Salt and Verde Rivers. These impacts show up only in the Phoenix Metropolitan area because that is the only place where the Salt and Verde River water is used.



Graph E-1

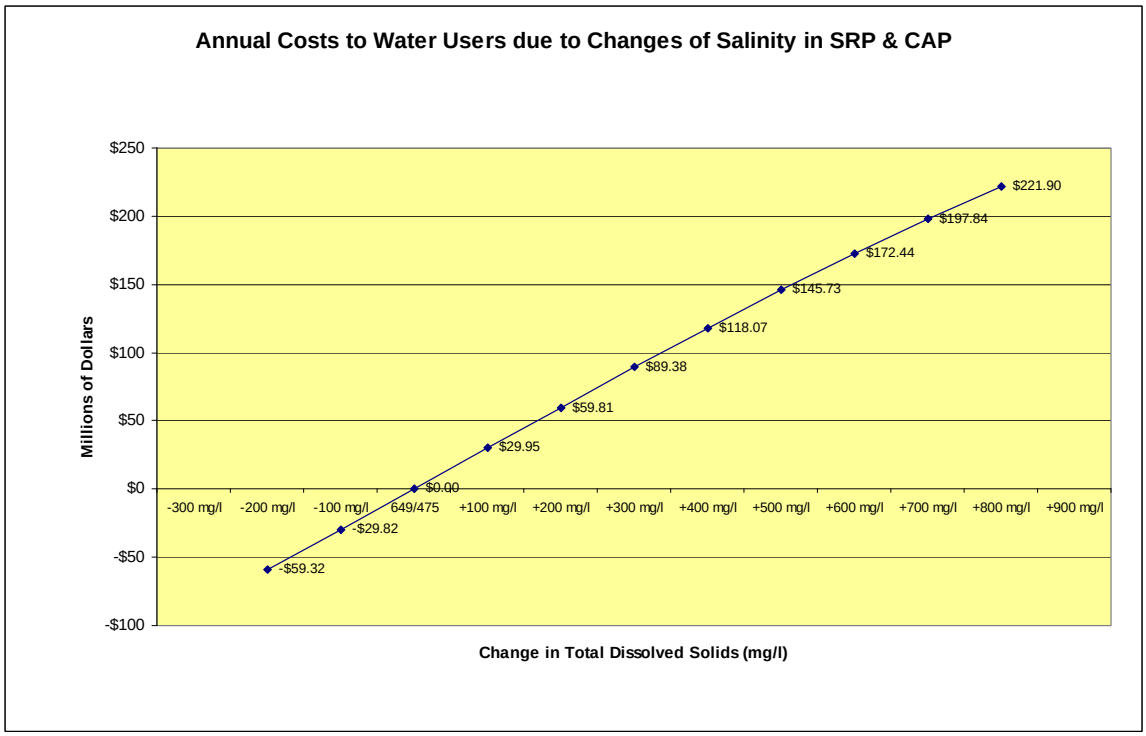
Next the salinity level in the CAP was changed by 100 mg/l TDS increments from a starting point of 649 mg/l TDS. Graph E-2 shows the results of that analysis. The costs are slightly less than $15 million annually for each increase or decrease of 100 mg/l TDS. The graph also indicates that the economic impacts are nearly linear with increasing salinity. The economic impacts due to changes in the salinity level of the CAP effects all the sub-areas except for Gila Bend.

While the economic impacts for CAP and SRP are both near $15 million per incremental change of salinity levels by 100 mg/l, it is just by chance that they are close to each other. In a typical year 1.35 million acre-feet of CAP water is used in the study area and 0.81 million acre-feet of SRP water is used in the study area. Although less SRP water is used, it is used for residential, industrial, commercial and agriculture, all of it in the Phoenix Metropolitan area. CAP water on the other hand is used through out Central Arizona and a greater portion of it is used for agriculture. Agriculture in Arizona is resistant to economic impacts from salinity because so many saline tolerant crops are grown, such as cotton, wheat, and barley. In addition, currently a good portion of CAP water is directly recharged into the ground. Recharged water does not have an economic impact in the model. (In actuality the degrading of the groundwater has an economic impact but it is not considered in the model.) There are many differences in how the CAP and SRP water is used in Central Arizona it just so happens that the economic impacts due to high salinity are nearly equal.



Graph E-2

Graph E-3 shows changes of salinity by 100 mg/l TDS in both the SRP and the CAP waters. As could be expected the impacts are a mathematical combination of the two previous runs, approximately $30 million of annual economic impacts per increase of salinity by 100 mg/l. The impacts are again nearly linear with increasing salinity levels.



Graph E-3

The data used to create the graphs is located in the final section of this chapter. Tables E-28, E-29 and E-30 show the costs incurred by different sectors of society in different areas of Central Arizona. The data shows that the majority of the economic impacts are in the Phoenix Metro area. There are a couple of apparent reasons for this; the Phoenix Metropolitan area uses the most water, has the most residents and the area has the most industry (industrial water processing costs are high). Conversely, Tucson has very minimal impacts because they are not directly using their CAP water at this time except for a small amount of crop irrigation. Tucson has no other surface water and depends on ground water for most of there needs. In the future Tucson will be using CAP water for commercial and residential uses through a recharge and recovery process and the impacts from salinity will increase.

Conclusions

Some conclusions can be reached from the modeling work. One is that if the salinity level of both the SRP and the CAP water is improved by 100 mg/l the savings to society would be about $30 million dollars a year. Residents incur about 45% of the impacts, but industry, commercial establishments and agriculture are also impacted. The economic impact is spread through out society and therefore the individual weight of the impact to any one person, community or business is easy not to great. Another conclusion drawn from the work is that there is not a particular “break point” where economic impacts

rapidly improve or degrade. The results indicate that the impacts are pretty much linear. There is no "magic" range of water quality to shoot for to dramatically reduce the impacts to society. And finally it is very important to notice, as shown in Tables E-28, E-29 and E-30 that the vast majority of the economic impacts to Central Arizona are in the Phoenix Metropolitan area.

The model does not and can not grasp all the economic ramifications of importing high TDS water into Central Arizona. There are economic impacts that are not considered in the model. Such things as abandoned wells due to high TDS in the groundwater and the hidden cost of vast amounts of poor quality groundwater that is available but not able to be economically used are not considered. There are many more intangible impacts which are explored elsewhere in this report. The model is a rudimentary tool but it does give an idea of the magnitude of the annual impacts to society of the importing water high in TDS.

Economic Model Results

Table E-28

A. Sensitivity Analysis Runs. Using Typical Year Data. Baseline to measure damages -

Baseline = SRP TDS Typical Year Data

Economic Impacts to TDS Changes ($ million) 100 TDS Increments

Phoenix TDS =275	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$15,567,801	$4,751,386	$5,856,048	$3,390,076	$823,645	$30,388,956
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$15,567,801	$4,751,386	$5,856,048	$3,390,076	$823,645	$30,388,956

Phoenix TDS =375	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$7,813,738	$2,375,693	$2,928,024	$1,697,657	$414,063	$15,229,175
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$7,813,738	$2,375,693	$2,928,024	$1,697,657	$414,063	$15,229,175

Typical Year Salinity Conditions

Phoenix TDS =475	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$0	$0	$0	$0	$0	$0
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$0	$0	$0	$0	$0	$0

Phoenix TDS =575	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$7,843,470	$2,375,693	$2,928,024	$1,703,199	$418,617	$15,269,003
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$7,843,470	$2,375,693	$2,928,024	$1,703,199	$418,617	$15,269,003

Phoenix TDS =675	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$15,683,763	$4,751,386	$5,856,048	$3,411,447	$841,863	$30,544,506
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$15,683,763	$4,751,386	$5,856,048	$3,411,447	$841,863	$30,544,506

Phoenix TDS =775	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$23,485,357	$7,127,079	$8,784,073	$5,122,123	$1,269,816	$45,788,447
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$23,485,357	$7,127,079	$8,784,073	$5,122,123	$1,269,816	$45,788,447

Phoenix TDS =875	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$31,210,624	$9,502,771	$11,712,097	$6,839,113	$1,702,554	$60,967,159
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$31,210,624	$9,502,771	$11,712,097	$6,839,113	$1,702,554	$60,967,159

Phoenix TDS =975	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$38,820,495	$11,878,464	$14,640,121	$8,562,806	$2,140,159	$76,042,045
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$38,820,495	$11,878,464	$14,640,121	$8,562,806	$2,140,159	$76,042,045

Phoenix TDS =1075	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$46,275,288	$14,254,157	$17,568,145	$10,293,628	$2,582,712	$90,973,931
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$46,275,288	$14,254,157	$17,568,145	$10,293,628	$2,582,712	$90,973,931

Phoenix TDS =1175	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$53,535,688	$16,629,850	$20,496,169	$12,007,323	$3,030,299	$105,699,329
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$53,535,688	$16,629,850	$20,496,169	$12,007,323	$3,030,299	$105,699,329

Phoenix TDS =1275	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$60,563,830	$19,005,543	$23,424,193	$13,721,978	$3,483,006	$120,198,550
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$60,563,830	$19,005,543	$23,424,193	$13,721,978	$3,483,006	$120,198,550

Phoenix TDS =1375	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$67,324,468	$21,381,236	$26,352,218	$15,439,644	$3,940,921	$134,438,486
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$67,324,468	$21,381,236	$26,352,218	$15,439,644	$3,940,921	$134,438,486

Phoenix TDS =1475	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$73,786,167	$23,756,928	$29,280,242	$17,162,070	$4,404,134	$148,389,541
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$73,786,167	$23,756,928	$29,280,242	$17,162,070	$4,404,134	$148,389,541

Table E-29

A. Sensitivity Analysis Runs. Using Typical Year Data. Baseline to measure impacts -

CAP 649 TDS

Benefits from Reduced Salinity 649 TDS to 249 TDS

TDS =249	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$25,363,706	$7,792,313	$9,603,970	$6,644,618	$1,341,496	$50,746,104
2) Gila River IC	$37,843	$8,716	$0	$347,197	$0	$393,756
3) Harquahala	$8,280	$1,629	$0	$1,292,822	$0	$1,302,731
4) Tucson	$0	$0	$0	$9,384	$0	$9,384
5) Pinal	$1,262,686	$235,320	$381,905	$3,475,973	$0	$5,355,885
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$26,672,516	$8,037,979	$9,985,875	$11,769,994	$1,341,496	$57,807,860

TDS =349	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$19,107,238	$5,844,235	$7,202,977	$4,990,539	$1,010,574	$38,155,563
2) Gila River IC	$28,097	$6,537	$0	$246,795	$0	$281,429
3) Harquahala	$6,266	$1,222	$0	$1,082,689	$0	$1,090,177
4) Tucson	$0	$0	$0	$7,056	$0	$7,056
5) Pinal	$946,292	$176,490	$286,429	$2,628,069	$0	$4,037,281
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$20,087,893	$6,028,484	$7,489,406	$8,955,148	$1,010,574	$43,571,506

TDS =449	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$12,785,035	$3,896,157	$4,801,985	$3,331,912	$676,711	$25,491,799
2) Gila River IC	$18,531	$4,358	$0	$164,681	$0	$187,570
3) Harquahala	$4,202	$814	$0	$833,507	$0	$838,523
4) Tucson	$0	$0	$0	$4,730	$0	$4,730
5) Pinal	$629,580	$117,660	$190,953	$1,769,206	$0	$2,707,399
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$13,437,348	$4,018,990	$4,992,938	$6,104,035	$676,711	$29,230,020

TDS =549	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$6,410,875	$1,948,078	$2,400,992	$1,668,488	$339,866	$12,768,300
2) Gila River IC	$9,160	$2,179	$0	$82,381	$0	$93,720
3) Harquahala	$2,106	$407	$0	$421,744	$0	$424,258
4) Tucson	$0	$0	$0	$2,387	$0	$2,387
5) Pinal	$313,730	$58,830	$95,476	$886,039	$0	$1,354,076
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$6,735,871	$2,009,495	$2,496,469	$3,061,040	$339,866	$14,642,740

Typical Year Salinity Conditions

TDS =649	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$0	$0	$0	$0	$0	$0
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$0	$0	$0	$0	$0	$0

Increased Damages from 649 TDS

TDS =749	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$6,430,921	$1,948,078	$2,400,992	$1,673,841	$342,928	$12,796,761
2) Gila River IC	$8,935	$2,179	$0	$82,548	$0	$93,662
3) Harquahala	$2,091	$407	$0	$426,859	$0	$429,358
4) Tucson	$0	$0	$0	$2,402	$0	$2,402
5) Pinal	$310,298	$58,830	$95,476	$887,154	$0	$1,351,758
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$6,752,245	$2,009,495	$2,496,469	$3,072,805	$342,928	$14,673,941

TDS =849	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$12,863,877	$3,896,157	$4,801,985	$3,352,678	$688,960	$25,603,656
2) Gila River IC	$17,631	$4,358	$0	$165,220	$0	$187,210
3) Harquahala	$4,139	$814	$0	$841,916	$0	$846,869
4) Tucson	$0	$0	$0	$4,858	$0	$4,858
5) Pinal	$615,816	$117,660	$190,953	$1,777,332	$0	$2,701,761
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$13,501,463	$4,018,990	$4,992,938	$6,142,004	$688,960	$29,344,354

TDS =949	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$19,279,636	$5,844,235	$7,202,977	$5,033,657	$1,038,137	$38,398,643
2) Gila River IC	$26,078	$6,537	$0	$248,117	$0	$280,733
3) Harquahala	$6,114	$1,222	$0	$1,248,935	$0	$1,256,271
4) Tucson	$0	$0	$0	$13,426	$0	$13,426
5) Pinal	$915,197	$176,490	$286,429	$2,670,304	$0	$4,048,420
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$20,227,025	$6,028,484	$7,489,406	$9,214,439	$1,038,137	$43,997,492

TDS =1049	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$25,657,920	$7,792,313	$9,603,970	$6,720,715	$1,390,504	$51,165,422
2) Gila River IC	$34,265	$8,716	$0	$331,116	$0	$374,098
3) Harquahala	$7,989	$1,629	$0	$1,567,531	$0	$1,577,149
4) Tucson	$0	$0	$0	$35,960	$0	$35,960
5) Pinal	$1,207,102	$235,320	$381,905	$3,359,102	$0	$5,183,430
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$26,907,276	$8,037,979	$9,985,875	$12,014,424	$1,390,504	$58,336,059

TDS =1149	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$31,977,622	$9,740,392	$12,004,962	$8,414,221	$1,746,103	$63,883,301
2) Gila River IC	$42,183	$10,895	$0	$414,347	$0	$467,425
3) Harquahala	$9,738	$2,036	$0	$1,888,475	$0	$1,900,249
4) Tucson	$0	$0	$0	$58,583	$0	$58,583
5) Pinal	$1,490,247	$294,151	$477,382	$3,795,033	$0	$6,056,812
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$33,519,790	$10,047,474	$12,482,344	$14,570,659	$1,746,103	$72,366,371

TDS =1249	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$38,217,081	$11,688,470	$14,405,955	$10,114,575	$2,104,981	$76,531,062
2) Gila River IC	$49,826	$13,075	$0	$497,734	$0	$560,634
3) Harquahala	$11,341	$2,443	$0	$2,212,124	$0	$2,225,908
4) Tucson	$0	$0	$0	$81,195	$0	$81,195
5) Pinal	$1,763,431	$352,981	$572,858	$4,234,473	$0	$6,923,742
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$40,041,678	$12,056,969	$14,978,813	$17,140,101	$2,104,981	$86,322,541

TDS =1349	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$44,354,394	$13,636,549	$16,806,947	$11,801,214	$2,467,181	$89,066,285
2) Gila River IC	$57,189	$15,254	$0	$581,325	$0	$653,768
3) Harquahala	$12,785	$2,851	$0	$2,538,549	$0	$2,554,184
4) Tucson	$0	$0	$0	$112,812	$0	$112,812
5) Pinal	$2,025,574	$411,811	$668,334	$4,677,953	$0	$7,783,672
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$46,449,942	$14,066,464	$17,475,281	$19,711,852	$2,467,181	$100,170,720

TDS =1449	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$50,367,785	$15,584,627	$19,207,940	$13,485,531	$2,832,751	$101,478,633
2) Gila River IC	$64,268	$17,433	$0	$665,092	$0	$746,792
3) Harquahala	$14,066	$3,258	$0	$2,867,055	$0	$2,884,378
4) Tucson	$0	$0	$0	$155,646	$0	$155,646
5) Pinal	$2,275,753	$470,641	$763,811	$5,125,467	$0	$8,635,672
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$52,721,871	$16,075,958	$19,971,750	$22,298,790	$2,832,751	$113,901,121

TDS =1549	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$56,235,996	$17,532,705	$21,608,932	$15,173,508	$3,201,738	$113,752,879
2) Gila River IC	$71,063	$19,612	$0	$749,124	$0	$839,800
3) Harquahala	$15,190	$3,665	$0	$3,196,599	$0	$3,215,454
4) Tucson	$0	$0	$0	$198,540	$0	$198,540
5) Pinal	$2,513,225	$529,471	$859,287	$5,577,142	$0	$9,479,124
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$58,835,474	$18,085,453	$22,468,219	$24,894,913	$3,201,738	$127,485,797

Table E-30

A. Sensitivity Analysis Runs. Using Typical Year Data. Baseline to measure damages -
Baseline = CAP & SRP TDS Typical Year Data

Economic Impacts to TDS Changes ($ million) 100 TDS Increments

Phoenix TDS =449/275	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$28,086,394	$8,647,542	$10,658,033	$6,702,464	$1,485,856	$55,580,289
2) Gila River IC	$18,531	$4,358	$0	$164,681	$0	$187,570
3) Harquahala	$4,202	$814	$0	$833,507	$0	$838,523
4) Tucson	$0	$0	$0	$4,730	$0	$4,730
5) Pinal	$629,580	$117,660	$190,953	$1,769,206	$0	$2,707,399
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$28,738,706	$8,770,375	$10,848,986	$9,474,587	$1,485,856	$59,318,510

Phoenix TDS =549/375	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$14,177,749	$4,323,771	$5,329,017	$3,360,994	$750,250	$27,941,781
2) Gila River IC	$9,160	$2,179	$0	$82,381	$0	$93,720
3) Harquahala	$2,106	$407	$0	$421,744	$0	$424,258
4) Tucson	$0	$0	$0	$2,387	$0	$2,387
5) Pinal	$313,730	$58,830	$95,476	$886,039	$0	$1,354,076
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$14,502,745	$4,385,188	$5,424,493	$4,753,546	$750,250	$29,816,221

Typical Year Salinity Conditions

Phoenix TDS =649/475	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$0	$0	$0	$0	$0	$0
2) Gila River IC	$0	$0	$0	$0	$0	$0
3) Harquahala	$0	$0	$0	$0	$0	$0
4) Tucson	$0	$0	$0	$0	$0	$0
5) Pinal	$0	$0	$0	$0	$0	$0
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$0	$0	$0	$0	$0	$0

Phoenix TDS =749/575	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$14,274,337	$4,323,771	$5,329,017	$3,382,061	$765,335	$28,074,522
2) Gila River IC	$8,935	$2,179	$0	$82,548	$0	$93,662
3) Harquahala	$2,091	$407	$0	$426,859	$0	$429,358
4) Tucson	$0	$0	$0	$2,402	$0	$2,402
5) Pinal	$310,298	$58,830	$95,476	$887,154	$0	$1,351,758
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$14,595,661	$4,385,188	$5,424,493	$4,781,025	$765,335	$29,951,702

Phoenix TDS =849/675	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$28,440,826	$8,647,542	$10,658,033	$6,779,910	$1,546,216	$56,072,527
2) Gila River IC	$17,631	$4,358	$0	$165,220	$0	$187,210
3) Harquahala	$4,139	$814	$0	$841,916	$0	$846,869
4) Tucson	$0	$0	$0	$4,858	$0	$4,858
5) Pinal	$615,816	$117,660	$190,953	$1,777,332	$0	$2,701,761
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$29,078,412	$8,770,375	$10,848,986	$9,569,237	$1,546,216	$59,813,226

Phoenix TDS =949/775	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$42,271,454	$12,971,314	$15,987,050	$10,204,091	$2,343,119	$83,777,028
2) Gila River IC	$26,078	$6,537	$0	$248,117	$0	$280,733
3) Harquahala	$6,114	$1,222	$0	$1,248,935	$0	$1,256,271
4) Tucson	$0	$0	$0	$13,426	$0	$13,426
5) Pinal	$915,197	$176,490	$286,429	$2,670,304	$0	$4,048,420
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$43,218,843	$13,155,563	$16,273,479	$14,384,873	$2,343,119	$89,375,877

Phoenix TDS =1049/875	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$55,528,676	$17,295,085	$21,316,066	$13,603,739	$3,156,545	$110,900,111
2) Gila River IC	$34,265	$8,716	$0	$331,116	$0	$374,098
3) Harquahala	$7,989	$1,629	$0	$1,567,531	$0	$1,577,149
4) Tucson	$0	$0	$0	$35,960	$0	$35,960
5) Pinal	$1,207,102	$235,320	$381,905	$3,359,102	$0	$5,183,430
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$56,778,033	$17,540,751	$21,697,972	$18,897,448	$3,156,545	$118,070,748

Phoenix TDS =1149/975	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$67,984,712	$21,618,856	$26,645,083	$17,013,585	$3,987,012	$137,249,248
2) Gila River IC	$42,183	$10,895	$0	$414,347	$0	$467,425
3) Harquahala	$9,738	$2,036	$0	$1,888,475	$0	$1,900,249
4) Tucson	$0	$0	$0	$58,583	$0	$58,583
5) Pinal	$1,490,247	$294,151	$477,382	$3,795,033	$0	$6,056,812
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$69,526,880	$21,925,938	$27,122,465	$23,170,023	$3,987,012	$145,732,318

Phoenix TDS =1249/1075	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$79,444,196	$25,942,627	$31,974,100	$20,449,711	$4,835,062	$162,645,696
2) Gila River IC	$49,826	$13,075	$0	$497,734	$0	$560,634
3) Harquahala	$11,341	$2,443	$0	$2,212,124	$0	$2,225,908
4) Tucson	$0	$0	$0	$81,195	$0	$81,195
5) Pinal	$1,763,431	$352,981	$572,858	$4,234,473	$0	$6,923,742
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$81,268,794	$26,311,126	$32,546,958	$27,475,236	$4,835,062	$172,437,175

Phoenix TDS =1349/1175	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$89,766,843	$30,266,398	$37,303,116	$23,696,437	$5,701,258	$186,734,052
2) Gila River IC	$57,189	$15,254	$0	$581,325	$0	$653,768
3) Harquahala	$12,785	$2,851	$0	$2,538,549	$0	$2,554,184
4) Tucson	$0	$0	$0	$112,812	$0	$112,812
5) Pinal	$2,025,574	$411,811	$668,334	$4,677,953	$0	$7,783,672
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$91,862,391	$30,696,313	$37,971,451	$31,607,075	$5,701,258	$197,838,487

Phoenix TDS =1449/1275	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$98,885,903	$34,590,170	$42,632,133	$26,787,435	$6,586,189	$209,481,830
2) Gila River IC	$64,268	$17,433	$0	$665,092	$0	$746,792
3) Harquahala	$14,066	$3,258	$0	$2,867,055	$0	$2,884,378
4) Tucson	$0	$0	$0	$155,646	$0	$155,646
5) Pinal	$2,275,753	$470,641	$763,811	$5,125,467	$0	$8,635,672
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$101,239,990	$35,081,501	$43,395,944	$35,600,695	$6,586,189	$221,904,318

Phoenix TDS =1549/1375	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$106,818,509	$38,913,941	$47,961,149	$29,879,013	$7,490,470	$231,063,082
2) Gila River IC	$71,063	$19,612	$0	$749,124	$0	$839,800
3) Harquahala	$15,190	$3,665	$0	$3,196,599	$0	$3,215,454
4) Tucson	$0	$0	$0	$198,540	$0	$198,540
5) Pinal	$2,513,225	$529,471	$859,287	$5,577,142	$0	$9,479,124
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$109,417,988	$39,466,689	$48,820,437	$39,600,417	$7,490,470	$244,796,000

Phoenix TDS =1649/1475	Residential	Commercial	Industrial	Agriculture	Utilities	Total
1) Phoenix Metro Area	$113,665,558	$43,237,712	$53,290,166	$32,971,193	$8,414,743	$251,579,372
2) Gila River IC	$77,575	$21,791	$0	$833,369	$0	$932,735
3) Harquahala	$16,173	$4,072	$0	$3,530,006	$0	$3,550,251
4) Tucson	$0	$0	$0	$241,449	$0	$241,449
5) Pinal	$2,737,460	$588,301	$954,763	$6,031,298	$0	$10,311,822
6) Gila Bend	$0	$0	$0	$0	$0	$0
Total	$116,496,767	$43,851,876	$54,244,929	$43,607,314	$8,414,743	$266,615,630

Bibliography

Anderson, A., Chief Operator of Lone Butte Wastewater Treatment Plant, personal communication on effluent discharge quantity and quality, March 2002.

Arizona Department of Water Resources, Third Management Plan 2000-2010 Phoenix Active Management Area, June 1999

Arizona Department of Water Resources, Third Management Plan 2000-2010 Pinal Active Management Area, June 1999

Arizona Department of Water Resources, Third Management Plan 2000-2010 Tucson Active Management Area, October 1998

Brown, G. Jr., Salinity Laboratory, Relative Salt Tolerance of Herbaceous Crops, 1990.

Brummer, J., U.S. Bureau of Reclamation, Crop Salinity Damage Estimation Procedures, April 1999.

Carlson, B., Chaparral City Water Company, personal communication on water treatment plants, April 2002.

Central Arizona Water Conservation District, Preliminary 2001 Water Rate Schedule, March 2000.

City of Phoenix, Evaporative Cooler, www.ci.phoenix.az.us/water/evapcool.html, March 2002.

Elliot, G., Salt River Project, personal communication on water quality and quantity of Salt and Verde Rivers, February 2002.

Hanely, T., Arizona Department of Water Resources, personal communication on Arizona water Bank recharge, 2000.

Ikeya, D., Arizona Department of Water Resources, personal communication on AMA water use by industry, March 2000.

Metropolitan Water District of Southern California, Salinity Management Study Final Report, June 1999.

Milliken Chapman Research Group, Inc., *Estimating Economic Impact of Salinity of the Colorado River* , February 1988.

Notini, J., Director, Communications & Marketing Association of Home Appliance Manufacturers, personal communication on saturation of home appliances, April 2002.

U.S. Bureau of Reclamation, Crop and Water Data, Form 7-2045, Gila River Farms, 2000.

U.S. Bureau of Reclamation, Crop and Water Data, Form 7-2045, Harquahala Valley Irrigation District, 2000.

U.S. Bureau of Reclamation, Crop and Water Data, Form 7-2045, Salt River Project Water Users Association, 2000.

U.S. Census Bureau, 2000 Census, www.census.gov/main/www/cen2000, February 2002.

U.S. Department of Labor, Bureau of Labor Statistics; www.data.bls.gov/cgi-bin/surveymost.

U.S. Geological Survey, National Water-Use data files, www.water.usgs.gov/watuse/spread95/dictionary95.txt, February 1999.

Wiesenberger, A., Founder BottledWaterWeb.com, personal communication on American consumption of beverages and bottled water, March 2002.

CENTRAL ARIZONA SALINITY STUDY – PHASE I

Technical Appendix K

HUMAN HEALTH IMPACTS FROM SALINITY IN DRINKING WATER

Introduction

Salinity is generally defined as a measure of the dissolved minerals in water and is expressed as Total Dissolved Solids (TDS) in milligrams per liter (mg/L) or parts per million (ppm). TDS is regulated in drinking water by the U.S. Environmental Protection Agency (USEPA) as a "Secondary" standard. Secondary drinking water standards are set at levels at which the water may become objectionable to consumers because of adverse taste, odor, color or appearance. Secondary standards are not directly related to adverse human health effects, but rather to consumer acceptance.

Salinity and Total Dissolved Solids

There are two general categories that are included in TDS: minerals and nutrients, and hardness. Both are summarized below:

Minerals and Nutrients: These include the regulated elements and compounds Aluminum, Chloride, Copper, Iron, Manganese, Sulfate, and Zinc. They also include the unregulated elements Phosphorus, Sodium, Potassium, Iodine, Selenium, and Silicon. Each of the constituents is discussed in the material to follow.

Hardness: Hardness may be defined as the sum of the polyvalent cations present in water. The most common such cations are calcium and magnesium. Hardness is usually expressed in terms of the equivalent quantity of calcium carbonate ($CaCO_3$). There are no distinctly defined levels for what constituents a hard or soft water supply. Generally, water with less than 75 mg/L of hardness express as calcium carbonate is considered soft, and above this value as increasingly hard.

Beginning in about the late 1950's, a series of reports, developed from statistical analyses associating cardiovascular disease and water hardness, were developed indicating an inverse relationship between cardiovascular death rates and water hardness. The tentative results seemed to indicate that the lower the hardness of the water, the higher the death rates. The questions raised by these reports remained unsolved until the National Academy of Sciences recognized that a large body of scientific information indicated a correlation between drinking water and health. This report points out that there is disagreement over the magnitude, or even the existence, of a "water factor" in the risk of cardiovascular disease. The uncertainties include the identity of the specific causal factors, the mode of action, and the specific pathological effects. The heart of the uncertainty involves the various components in hard versus soft water. There are more minerals in hard water and they may have a beneficial impact, whereas soft water is more corrosive and may tend to add potentially harmful corrosion by-products to the water. Several hypotheses have been offered on how components of drinking water may affect cardiovascular function and disease; these generally fall into one of the following classes:

1. That one or more of the principal "bulk" constituents of hardness in tap water are protective. The principle "bulk" constituents are calcium and magnesium.

2. That one or more of the trace elements that tend to be present in hard water are protective. Trace elements that have been hypothesized include lithium, vanadium and chromium.

3. That harmful metals are present in soft water, possibly having been picked up by leaching from the distribution system.

There is no clear answer at this time to define the magnitude or impact of this observation of the relationship between hard water and the apparent reduction in cardiovascular disease rates, hence the continuing uncertainty.

Historical References

Prior to the passage of the federal Safe Drinking Water Act in 1974, drinking water was regulated in some water utilities in the United States by the U. S. Public Health Service (USPHS). These utilities served water to interstate commerce, and were used to supply water to ships, airplanes, trains, and busses that carried passengers between U. S. cities; thus they were subject to the Federal Quarantine Regulations.

The USPHS established "Drinking Water Standards" in 1962, and included language relative to Chloride, Sulfate, and Dissolved Solids.

"*The importance of chloride, sulfate, and dissolved solids as they affect water quality hinges upon their taste and laxative properties. There is evidence that excessive amounts of these constituents cause consumer reactions, which may result in individual treatment or rejection of the supply. Therefore, limiting amounts for these chemical constituents have been included in the Standards.*"

"It is recommended that waters containing more than 250 mg/L of chlorides or sulfates and 500 mg/L of dissolved solids not be used if other less mineralized supplies are available. This is influenced primarily by considerations of taste. Cathartic effects are commonly experienced with water having sulfate concentration of 600 to 1,000 mg/L, particularly if much magnesium or sodium is present. Although waters of such quality are not generally desirable, it is recognized that a considerable number of supplies with dissolved solids in excess of the recommended limits are used without any obvious ill effects."

These original secondary standards are now included in the USEPA National Secondary Drinking Water Regulations at the same concentration levels.

The Contribution of Drinking Water to Mineral Nutrition in Humans

The following material summarizes information on the common mineral constituents in drinking water that may be included in Total Dissolved Solids.

Aluminum: The vast majority of aluminum that occurs in treated water is as a result of the use of alum (Aluminum Sulfate) for coagulation. Aluminum occurs in approximately 30% of the untreated water supplies in the United States and varies in concentration from 1 to 2,800 parts per billion (ug/L) with a mean concentration of 74 ug/L. Aluminum occurs in approximately 50% of the treated water supplies in the range

of 3 to 1,600 ug/L with a mean concentration of 180 ug/L. Aluminum is regulated as a secondary standard in the range of 50 to 200 ug/L primarily because of color and turbidity.

It has been mentioned that aluminum may play a role in the development of Alzheimer's disease; however, work done by various researchers did not find any significant differences in aluminum levels in brain tissue samples from Alzheimer's disease patients and healthy, age matched controls. There is no current direct association between aluminum in drinking water, or any other source, and Alzheimer's disease. An examination for aluminum in the diet will indicate that drinking is a minor source.

Calcium: A recommended daily intake of 800 mg has been established for adults on the basis that the daily excretion of calcium is 320 mg and that only 40% of dietary calcium is absorbed by the average American. There is no clearly defined calcium deficiency syndrome in humans, and calcium is relatively nontoxic when administered orally.

Using a national average calcium concentration of 26 mg/L and a maximum of 145 mg/L, and assuming the average adult drinks two liters of water daily, then the drinking water will contribute an average of 52 mg/day and a maximum of 290 mg/day. On an average basis this will represent 5 to 10 percent of the usual daily intake of calcium.

Calcium levels in the Colorado River average 80 mg/L. This level of calcium concentration put this source in the mid-range of the national occurrence. There is no Secondary drinking water standard for calcium, and there is no move to set an upper limit to protect public health.

Magnesium: The daily need for dietary magnesium is a function of the amounts of calcium, potassium, phosphate, lactose, and protein consumed. For the average healthy American on an average diet the daily magnesium intake requirement varies from 60 to 450 mg/day depending upon age. (The Recommended Dietary Allowance (RDA) for magnesium is thought to be 300 – 400 mg/day). Magnesium that occurs in drinking water contributes from 3 to 4% at the median range, and from 60 to 80% at the high range of concentration of the daily requirement. This is based upon the average concentration that varies from 6 mg/L median to 120 mg/L maximum in treated water supplies. Colorado River water averages 30 mg/L magnesium. Current levels of magnesium in drinking water appear to offer no threat to human health.

Phosphorus: Phosphorus, in the form of phosphate, is common to most foods and varies from a trace amount to more than 600 mg/1000 mg of foodstuff. The highest concentrations occur in nuts, beans, and grains. The average daily requirement is approximately the same as for calcium and the RDA for adults is 800 mg. Because public water supplies contain little phosphorus, and because food provides the vast amount of the RDA, it can be concluded that phosphorus levels in drinking water contribute only a negligible amount to the daily intake.

Sodium: Sodium is an essential element, and is required for nutrient transport. The total intake of sodium is influenced mainly by the use of salts as an additive to food. An examination of the average market basket indicates that from 6,700 to 6,900 mg/day of sodium is consumed in an average diet. Grain and cereal products contain the highest amount of sodium and beverages, including drinking water, only contribute an average of 20 to 30 mg/day. The sodium content of drinking water is extremely variable and one national survey found that drinking water varied from 4 to 80 mg/L with a mean concentration of 28 mg/L. The estimated adequate and safe intake for adults for sodium from 1,100 to 3,300 mg/day; infant requirements

vary from 115 to 750 mg/day. Sodium research needs, especially for infants, include the relationship between sodium and potassium ratios, and the determination of total sodium intake via the diet.

Data suggests that health benefits could accrue to certain segments of the population from a reduction in sodium intake. This applies to individuals on sodium-restricted diets that are limited to less than 2,000 mg/day. With this exception the amount of sodium contributed by drinking water is generally negligible. Sodium is not regulated in drinking water, however the USEPA has included sodium on their Drinking Water Contaminant list (CCL). Specifically, the USEPA has decided to include sodium on the CCL as a research priority to evaluate and revise the current outdated guidance document for sodium. Although the American Heart Association has suggested that sodium in drinking water be limited to 20 mg/L, the USEPA notes that this level is probably low and in need of revision.

Sodium in drinking water is generally naturally occurring; however, excess sodium can be added by the use of home water softeners. Sodium concentrations in the Colorado River average 100 mg/L.

Potassium: According to one national survey potassium in drinking water varies from a trace amount to 8 mg/L with a mean concentration of 2 mg/L. Potassium is present in many foods and is useful as a food additive, often to replace sodium. The RDA for potassium for adults varies from 1,900 to 5,600 mg/day; the requirements for infants vary from 600 to 4,600 depending upon age. Potassium is not regulated in drinking water, and because levels in drinking water are low in relation to food, the contribution of potassium to the daily diet is negligible.

Chloride: Chloride is the most important anion in the maintenance of fluid and electrolyte balance and is necessary to the formation of hydrochloric acid in gastric juices. Chloride is found in practically all-natural waters, and is regulated as a secondary standard by the USEPA at 250 mg/L.

The presence of chloride in drinking water can produce a taste impact that is sometimes objectionable to consumers. Various studies indicate that adverse taste impacts may occur with chloride concentrations from 210 to 310 mg/L.

Current dietary intake of chloride varies largely with the use of salt, and estimates vary from 2,400 to 14,400 mg/day. No RDA for chloride has been established.

Chloride in the Colorado River averages 90 mg/L. The chloride is from naturally occurring sources, although some input from agricultural and other sources is possible. At these levels, drinking water contributes from 7 to 8 percent of the lower estimate of total daily chloride intake. Consumption of chloride in reasonable concentrations is not harmful, but elevated amounts may contribute to adverse taste impacts, and if the chloride is present due to the use of salt, the elevated sodium that results may be harmful to individuals on sodium restricted diets.

Iodine: Sources of iodine include foods, water and medication. In the United State the major contribution of iodine comes from salt, bread, milk, and seafood. Drinking water contains a small and variable amount of iodine. The RDA for iodine for adults varies from 80 to 140 micrograms per day, and assuming water consumption of two liters per day, drinking water provides an average of 0.3 percent of the total intake.

Iron: The amount of iron consumed per day varies widely, and occurs in many foods. The most amount of iron is contained in meats, poultry, fish, cereals, vegetables and bread. Concentrations vary in drinking water, and average 0.240 mg/L with some supplies reported as high as 1.5 to 2 mg/L. The RDA for iron varies from 10 to 18 mg/day depending on age and sex.

Assuming two liters of water consumed per day containing the national mean concentration of iron, this source will supply from 3 to 5 percent of the RDA in adults. Iron is regulated as a secondary standard in drinking water at 0.300 mg/L because of adverse color impacts. Iron, when oxidized, will produce a red or brown staining color that is objectionable to consumers.

Copper: Copper is an essential element and is contained in many foods. A RDA for copper has been established at from 2 to 3 mg/day. Typical copper concentrations in drinking water will provide from 6 to 10 percent of the estimated daily safe intake. Copper is regulated as a secondary standard at 1 mg/L primarily based on adverse color and staining considerations. A Maximum Contaminant Level Goal (MCLG) for copper has been established at 1.3 mg/L based upon health effects, and this amount has been exceeded in some supplies due to corrosion of plumbing materials.

Zinc: The importance of zinc to the human diet has been recognized for many years. An adult requirement for zinc has been set at 15 mg/day, and normal zinc concentrations in drinking water will supply 3 percent of the daily requirement. The highest observed concentration of zinc in drinking water may contribute up to 20 percent of the daily requirement.

Zinc occurs in many foods, and may occur in drinking water from natural sources of from zinc compounds added to water treatment plants for corrosion control purposes. Zinc is regulated as a secondary standard in drinking water at 5 mg/L. Because zinc is an essential element and nutrient for humans, and because there are some indications of zinc deficiency in children, any possibility of detrimental health impacts from zinc in drinking water is considered to be extremely remote.

Selenium: Selenium is an essential element and nutrient for humans. Intake from food sources varies widely due to concentrations from soil, and worldwide total daily intake varies from less than 60 to more than 300 micrograms per day (µg). An estimated adequate and safe intake for adults varies from 50 to 200 (µg). Selenium is regulated as a primary health based standard both as an MCLG and as a Maximum Contaminant Level (MCL) at 0.050 mg/L. Selenium is considered to be a problem for aquatic habitat and in some areas drinking water that meets the human health based standards may present a problem for aquatic habitat or other environmental indicator species.

Most diets in the United States provide approximately 150 micrograms of selenium per day, and the average selenium concentration from drinking water will provide from 1 to 2 percent of this requirement.

Manganese: Manganese naturally occurs in food and water. The average daily intake of manganese ranges from 2 to 9 mg/day, and the average "market basket" survey intake is 4 mg/day. The mean manganese concentration in drinking water is 22 ug/L. There has not been a RDA established for manganese, and the usual intake appears to be adequate for adults. Assuming a daily water intake of 2 liters, manganese in water will contribute an average of 3 percent of the daily intake. Manganese is regulated as secondary standard by the EPA at 0.05 mg/l or 50 ug/l.

Silicon: Silicon has not been established as an essential element and nutrient in humans. Concentrations of silicon, as silica, in drinking water vary from a trace to 72 mg/L in the100 largest cities in the United States.

No information is available on essential dietary levels, but drinking water has not been shown to be an important source or potential public health problem. Silicon is not regulated in drinking water.

Sulfate: Sulfate is found almost universally in natural waters in concentrations ranging from a trace to several thousand milligrams per liter. A survey conducted in 1970 found a range of 1 to 770 mg/L in supplies in the United States with a median concentration of 46 mg/L. The major adverse impact of elevated sulfate levels (around 1000 mg/L) is the laxative effect. Sulfate levels at 500 mg/L will taste bitter but there is a taste threshold for sulfate between 300 and 400 mg/L with some individuals able to detect levels as low as 200 mg/L. A RDA has not been established for sulfate.

Sulfate is regulated as a secondary standard by the USEPA at 250 mg/L based upon both taste and laxative effects.

The Colorado River contains approximately 250 to 260 mg/L sulfate. The USEPA is considering establishing an MCL for sulfate as a primary health based standard, and concentration from 300 to 500 mg/l have been considered.

Summary

The total dissolved solids in the Colorado River is higher than the Secondary standard promulgated by the USEPA. The sodium concentration in the Colorado River is above the 20 mg/L value suggested by the American Heart Association, but within the national normal values observed the national normal values observed in other utilities.

The sulfate concentrations in the Colorado River are near or above the USEPA recommended secondary standards. No other individual constituents of TDS are outside of the reported or regulated national normal values.

Concentrations of TDS in the Colorado River water and concentrations of some of the individual constituents undoubtedly contribute to adverse taste in the drinking water in some locations. While adverse health impacts cannot be demonstrated from consumption of Colorado River water, the high TDS undoubtedly causes some consumers to reject the supply and turn to other sources. This may be viewed as an “adverse impact” to those consumers. This impact must be considered in decision making for blending and selection of sources.

TABLE 1
CONTRIBUTION OF U.S. DRINKING WATER
TO MINERAL NUTRITION OF HUMANS

NUTRIENT AND IN WATER, (mg/L)	TYPICAL LEVEL, (mg/day)
Calcium	26
Magnesium	6
Phosphorus	ND
Sodium	28
Potassium	2
Chloride	21
Copper	0.1
Zinc	<0.2
Selenium	0.001
Manganese	0.025
Silicon	7.1

A question associated with Public Health to research and resolve:

RO home units – Is Bacterial Re-growth a Serious Health Issue for In-home RO units? Is product water disinfection required for In-home RO units?

Low pressure RO systems generally refer to those systems with water feed pressure of less 100 psig. These are the typical countertop or under sink residential systems that rely primarily on the natural water pressure to make the reverse osmosis process; a typical system includes the following Pre-filter, Reverse Osmosis Module, Post Filter, and Diaphragm Pressure Tank. Other RO systems may include GAC filters and sometime a disinfection unit, e.g., ultraviolet light.

Low pressure units typically provide between 2 and 15 gallons per day of water, with an efficiency of 2 to 4 gallons of reject water per gallon of treated water. Water purity can be as high as 95 percent. These systems can be highly affordable, with countertops units starting at about $150, and under sink units starting at about $500. These units produce water for a cost as low as ten cents per gallon once maintenance and water costs are factored in. Maintenance usually requires replacing any pre- or post-filters (typically one to four times per year); and the reverse osmosis cartridge once every two to three years, depending on usage. (1)

Quality of RO Product Water

It has been reported that bacteria can "grow" through membranes. The mechanism by which bacteria pass through a RO membrane is not known and no correlation exists between a dye leak test of the membrane and its bacterial retention efficiency. Researchers at the Center for Disease Control (CDC) conducted extensive investigations on the bacterial contamination of RO systems used in producing purified water dialysis. They reported: 1. certain naturally occurring Gram-negative bacteria can multiply in relatively pure RO water; 2. thorough periodic disinfection of the entire RO system is essential in producing water with acceptable bacterial counts; 3. stagnant water in pipes down stream of the membrane is the major source of bacteria and endotoxin in the product water; and 4. the efficiency of a membrane in rejecting is better in continuous than in intermittent use. The U.S.E.P.A. has listed RO technology as suitable for all small public water systems. It is assumed that the technology is also acceptable for in-home use as well. The U.S.E.P.A. has noted that due to the typical membrane pore sizes and size exclusion capability (in the metallic ion and aqueous salt range); RO filtration is effective for removal of cysts, bacteria and viruses. (2)

Health Significance of Bacterial Re-growth

Bacterial re-growth is common in water and has been observed even in distilled water. In water distribution systems, the Heterotrophic Plate Count (HPC) can occasionally be elevated and there have been concerns that this flora could contain opportunistic pathogens. (3)

It is well established that reports of the incidence of waterborne illness among users of household water treatment products are essentially nil. The Water Quality Association (WQA) white paper

cites over a dozen objective studies on this topic. The data all document the absence of any correlation between use of Point-of-Use (POU) and Point-of-Entry (POE) products and increased rates of illness or the presence of coliform or any disease-causing organisms.

The University of Quebec studies in 1991 and 1997 documented substantial protection from gastrointestinal illness in person with POU water treatment equipment. The first study found there was 34% less illness among those using reverse osmosis. The second Payment study was less dramatic, finding 14 – 40% of gastrointestinal illness to be avoidable by using RO, depending on the age of the people (the 40% higher illness incidence is for the children 2 – 5 years old who used flowing or flushed tap water.) These POU health benefits occurred in spite of "very high levels of heterotrophic bacteria." U.S. Environmental Protection Agency studies have concluded that, "although the heterotrophic plate count (HPC) of the filter units often reached high levels, the bacteria that were found in the product water do not appear to be of health concern. They may however, be a significant factor in preventing pathogenic strains of bacteria from colonizing and persisting in GAC filter cartridges." (4)

Disinfection and Biological Re-growth

Chemical Disinfection

There are several possible ways to disinfect water within a home RO treatment system: Iodine, silver, copper, quaternary, ammonium compounds, and some other chemical agents have been proposed and are sometime used to inactivate waterborne pathogens. However, none of them are considered suitable for long-term use to disinfect drinking water for various important and valid reasons. Iodine is difficult to deliver to water and can adverse health effects, silver and copper are to difficult to deliver to water and primarily only bacteriostatic, and quaternary ammonium compounds are limited in availability, costly and not effective viruses and parasites. However, iodine, either dissolved in water or in the form of an iodinated exchange resin, has been used for short-term water treatment by outdoor recreationists, field military personnel, and persons displaced b natural disasters and human conflicts. Silver is used as a bacteriostatic agent for POU or household water treatment by storing water in vessels composed of silver or passing water through porous or granular filter media impregnated with silver. However, the extent to which silver alone inactivates microbes in water is limited, bacteria may develop silver resistance and many microbes, such as viruses, protozoan cysts and oocysts and bacterial spores, are not inactivated at silver concentrations employed for POU drinking water treatment. These agents are not recommended for routine disinfection of household water. (5)

Disinfection by UV Radiation

The UV radiation technology is simple to use and highly effective for inactivating microbes in drinking water, and it does not introduce chemicals or cause the production of harmful disinfection by-products in the water. While UV lamp disinfection systems have been widely used to disinfect drinking water at the community and household levels, no epidemiological studies of intervention type that document health impacts at the household level have been reported for this technology. There are no reasons to doubt the efficacy of sound UV lamp

disinfection technology to adequately disinfect either household or community drinking water when properly applied.

There are a few concerns that do arise from using UV radiation as a drinking water disinfectant at the household level. It does not provide a chemical disinfectant residual to protect the water from recontamination or microbial regrowth after treatment. A reliable and affordable source of electricity is required to power the UV lamps. The UV lamps require periodic cleaning, especially for systems using submerged lamps, and the have a finite lifespan and must be periodically replaced. The technology is of moderate to high cost when used at the household level. Despite these drawback and limitations, UV irradiation with lamps is a recommended technology for disinfection of house water. (5)

Continuous or Periodic Sanitization

There are two basic approaches for controlling bacterial growth in a water system. One is to maintain a residual level of biocidal agent within the system (continuous dosing). This is similar to the common technique where municipal water treatment facilities inject enough chlorine, or chloramines, into their treated water to provide a residual throughout the United States, and typical minimal target residual is 0.2 mg/L. In the U.S., the most commonly used chemical in point-of-use water treatment systems is chlorine.

The second approach is to periodically sanitize the system. Whether a periodic or continuous approach is used will depend on the quality of the product water required. For instance, those systems producing "ultapure water" where no chemical residual can be tolerated in their product water must employ periodic cleaning and sanitizing instead of continuous dosing of a biostatic chemical. Most systems using continuous dosing will also need a regular, although less frequent cleaning and sanitizing regimen. Even when ultraviolet lights post-treatment with heat or biocide addition in the storage and distribution system is done, the whole system will require periodic sanitization. (6)

Finished Water Storage

The one remaining portion of the RO system where bacterial re-growth may occur is in the finished water storage tank. Re-growth may occur in the finished water storage tank when the water stored is not systematically changed to keep a fresh supply in storage.

One manufacturer, Watt Premier, recommends an annual sanitization of the entire RO unit (including the storage tank) when changing filters. Otherwise, there is no sanitation/disinfection of the water either in or for the finished water storage unit. If additional disinfection is required, the finish water will have to be either boiled or be given the addition of a disinfection product, e.g., household bleach. (7)

Question: Hard water and Water Softening – What is the impact of excess Na+ in the drinking water supply caused by the water softening process?

Hardness in Drinking Water

Hardness is defined as those minerals that dissolve in water which have a divalent (i.e., "positive two") electrical charge. Minerals are composed of either atoms or molecules. An atom or molecule that has dissolved in water is called an "ion". An ion exchange water softener can reduce or eliminate hardness problems.

The primary components of dissolved hardness are calcium (Ca^{++}) and magnesium (Mg^{++}) ions; dissolved iron (Fe^{++}) and manganese (Mn^{++}) ions may also be considered in contributing to the hardness of water. (**Note**: one grain per gallon is equal to 17.1 mg/L.)

Health Effects

The presence or absence of hardness in drinking water is not known to pose a health risk. Hardness is normally considered as an aesthetic water quality factor. The presence of some dissolved mineral material in drinking water is typically what gives water its characteristic and pleasant "taste". (1)

Normal Sodium Consumption

It is estimated that the average person consumes the equivalent of 2 to 3 teaspoons of salt per day from all sources. This is about 8 to 15 grams. Some of this salt is in the food naturally, but most of it is added in processing, preservation, cooking, and at the table. A salt (sodium chloride) intake of 8 to 15 grams is equal to about 3 to 6 grams (3,000 to 6,000 milligrams) of sodium.

Sodium in Softened Water

Since sodium is added to water softened by the cation exchange process (mechanical water softening), the level of sodium in softened water may be of interest to persons on sodium restricted diets.

The table below shows the amount of sodium added to softened water of varying original hardness. The harder the water originally, the more sodium that is added.

Sodium Added to Water from Cation Exchange Softening	
Initial Water Hardness	**Sodium Added By Cation Exchange Softening Of Water**
Grains Per Gallon	Milligrams Na+ / gallon
1	**30**

5	149
6	179
7	209
8	239
9	269
10	298
15	447
20	596
30	894
40	1,191

Contribution of Sodium from Water Softening To Total Sodium Intake

Assuming a daily intake of 5 grams (5,000 milligrams) of sodium in food and the consumption of 3 quarts of water (used for coffee, tea, food preparation and drinking) the contribution of the sodium (Na+) in the water from the home water softening process compared to the total daily intake can be seen in the following table.

Sodium Intake from Softened Water Compared to Total Sodium Intake				
Initial Water Hardness	Salt in Softened Water	Salt From Food	Total Salt Consumed	% Of Total Salt From Softened Water
Grains Per Gallon	Milligrams Na+ / 3 quarts	Milligrams Na+	Milligrams Na+	%
1	23	5,000	5,023	0.4%

5	112	5,000	5,112	2.2%
10	223	5,000	5,223	4.3%
15	335	5,000	5,335	6.5%
20	447	5,000	5,447	8.2%
30	670	5,000	5,670	12.5%
40	893	5,000	5,893	15.2%

Sodium Restricted Diets

Persons who must restrict their sodium intake to 500 milligrams per day should consume water that contains no more than 20 milligrams of sodium per quart. This is assuming that most people consume about three quarts of water per day from all sources (beverages, food preparation, and drinking). 20 milligrams per quart X 3 quarts = 60 milligrams total daily from water.

The 60 milligram level has been suggested since the basic 500 milligram therapeutic diet actually contains about 440 milligrams of sodium from food. This allows 60 milligrams of sodium from water.

If sodium (Na+) is restricted to 1000 milligrams per day, the upper limit for total sodium content of water is about 200 milligrams or about 66 milligrams per quart if three quarts are consumed.

See the following table for original hardness limits of softened water for different levels of water consumption.

Original Hardness Limits of Softened Water Allowable for Sodium Restricted Therapy				
Total Sodium Level Permitted	**Total Sodium Allowed From Water**	**Original Hardness Limits**	**Original Hardness Limits**	**Original Hardness Limits**
Milligrams Na+	Milligrams Na+	Grains Per Gallon If Consumption of Softened Water Is **3 Quarts**	Grains Per Gallon If Consumption of Softened Water Is **2 Quarts**	Grains Per Gallon If Consumption of Softened Water Is **1 Quart**
500 mg.	**60 mg.**	**2.6 gpg**	**4 gpg**	**8 gpg**

1,000 mg.	**200 mg.**	**8.8 gpg**	**13 gpg**	**26 gpg**

If an ion exchange water softener is to be used in a home where a person is on sodium-restricted therapy and water hardness is great enough that excess sodium may be consumed by using softened water, a by-pass can be installed to provide unsoftened water for drinking and cooking.

In some localities the sodium content of the municipal water supply and water from wells may also be higher in sodium than can be allowed.

Persons on sodium-restricted therapy can obtain advice from a physician or dietician. The municipal water department will provide a detailed analysis of the water supply. Detailed analysis of well-water can also be obtained. Contact the municipal water department, the Public Health Service, local water softening dealer, or the Cooperative Extension Service for the name and address of a laboratory which makes this analysis. (2)

The above information has focused upon the impacts of water soften by ion exchange processes upon human health. There is another form of impact caused by using water softening technologies to improve household water quality, i.e., ion exchange resin regeneration and the associated impact upon the community's wastewater treatment system. That issue is the subject to the following discussion.

Water Softening and Regeneration

Water softeners are one of the most effective means of treating hard water, caused by an excess of minerals -- primarily calcium and magnesium -- in the water. There are two basic types of water softeners: self-regenerating water softeners and exchange tank systems.

Residential self-regenerating water softeners are plumbed into the home's water supply and work by eliminating dissolved minerals through a process called ion exchange. Inside each water softener is a mineral tank that is filled with small plastic beads (also known as resin) that are negatively charged. To balance the charge, positively charged sodium ions are present on the beads. A separate brine tank holds a sodium chloride (salt) solution, which is used to regenerate the softener. Under normal usage, hard water is passed through the mineral tank. The calcium and magnesium ions in the hard water have a stronger positive charge than the sodium ions on the resin. Therefore, the calcium and magnesium ions replace the sodium ions on the resin. The water flowing through the softener is now considered "soft" because the majority of the calcium and magnesium in the water has been replaced with sodium.

Eventually there will not be enough sodium left on the resin to effectively soften the water. Then the softener has to be regenerated. This process is usually done during the middle of the night because soft water is not available during the regeneration. To start the regeneration, salt water from the brine tank is sent to the mineral tank. The high levels of sodium in the brine force the calcium and magnesium off the resin, replacing it with sodium. The chloride present in the brine water simply stays in solution. After regenerating the mineral tank, the brine solution is flushed to the sewer. New salt must be added to the brine tank on a regular basis to replace the salt that is used to regenerate the mineral tank. *Because chloride is not used up during the exchange*

process, eventually all of the chloride added to the mineral tank in salt will end up being disposed of to the wastewater collection system as spent brine. (Italics are added for emphasis.) In a recent Chloride Source Study (Study) (3), performed by the County Sanitation Districts of Los Angeles County (District), data was collected to illustrate the distribution of the inputs of chloride from the overall community as wells as from residential water softening systems. In general, Chloride in the studies sewerage system comes from the following sources: Industrial (3%), Commercial (4%), Water Supply (42%), Residential (47%), and Disinfection (4%). The source breakdown of residential chloride includes the following: Human waste (16%), Laundry (12%), Pool backwash (1%), and Self-regenerating water softeners (69%). Based upon the results of this study District established two ordinances to prohibit the installation or assisting in the installation of residential self-regenerating water softeners in the Santa Clarita.

The aim of the ordinances is to reduce the amount of chloride entering the Santa Clara River (River). The River is the last natural river in Southern California. Wastewater generated in the Santa Clarita Valley, from actions such flushing toilets and washing laundry, is sent to the District's water reclamation treatment plants for treatment. The treated water leaving the plants that is not directly reused for landscape irrigation and other applications is sent to the Santa Clara River. If present at high levels in the river, chloride can harm wildlife and have a negative impact on farms that rely on river water for irrigation. Currently, the concentration of chloride in the river is twice the acceptable level established by the state Regional Board.

According to the Study, the largest source of chloride in the Santa Clarita area is residences, particularly residences using self-regenerating water softeners. Residential self-regenerating water softeners account for over half of the chloride coming into the treatment plants. If the discharge of the brine from the self-regenerating water softeners is not controlled, the Districts will have to install very expensive new treatment units at its treatment plants in the Santa Clara valley to remove the chloride.

Another finding from the Study included operational data collected for a typical home self-regenerating water softener is as follows: the concentration of chloride in the brine waste from the softener ranged from 7,000 to 13,000 mg/L, with an average of 10,300 mg/L chloride. The average volume of brine waste discharged was 47 gallons. These results indicate that for each regeneration of the self-generating softener approximately 4 pounds of chloride are used. Although homes with water softeners may be able to use less detergent and thus decrease chloride loadings from cleaning operations, this decreases is not enough to offset the increased chloride loading from regeneration of a self-regenerating water softener.

Exchange tank softeners work in a manner similar to self-regenerating water softeners, but feature a removable mineral tank that is replaced with a fresh mineral tank when the sodium on the resin is depleted. The depleted tanks are regenerated by water conditioning services at off-site facilities.

While the hardness ion, Calcium and Magnesium, are temporarily captured on ion exchange sites, the ions are eventually release back into the wastewater collection system during the water softeners regeneration cycle. Not only are the hardness ions being returned to the collection system, but an additional amount of chloride is being added to the system. The Sodium ion is either going into solution as part of the soften water or remaining on exchange sites as the replacement ion for the hardness ions. As noted above, the average brine waste concentration

from a water softener is 10,300 mg/L. The residual impact of the Chloride in the system may be somewhat diluted with the flow volume in the collection system during the early morning hours. It has been estimated that an ion exchange water softener may add about 500 mg/L TDS to the portion of the community's wastewater that has been softened.

References:

1. "Fundamentals of Water Softening by Ion Exchange," www.culliganmiami.com
2. "Sodium in Your Water", Morton System Saver, www.systemsaver.com/websit/education/water-facts/sodium-in-water.
3. "Santa Clarita Valley Joint Sewerage System, Chloride Source Report", Los Angeles County Sanitation District, October 2002, www.lacsd.org/chloride/images/Chloride_Report.PDF
4. Low Pressure (Residential) Systems: Source: What is…Reverse Osmosis?, www.wqa.org/sitelogic.cfm?ID=872, January, 2003.
5. Biological Regrowth in an RO System Source: Reverse Osmosis, Number 36, Dept. of Health, Education, and Welfare, Public Health Service, Food and Drug Administration, Washington, D.C., 1980; and Small System Compliance Technology List for the Surface Water Treatment Rule, U.S. Environmental Protection Agency, Office of Water, EPA 815-R-97-002, August 1997.
6. Endemic Waterborne Disease in Industrialized Countries Source: Assessment of Risk and Risk Management for Water-Related Infectious Disease, ed. Fewtrell, L., and J. Bartram, World Health Organization, Geneva, Switzerland, circa 1990s.
7. Heterotrophic Plate Count (HPC) Bacteria, The Water Quality Association, www.wqa.org.sitelogic.cfm?ID=195, 1999
8. *Managing Water in the Home: Accelerated Health Gains from Improved Water Supply*, Geneva, Switzerland, World Health Organization, WHO/SDE/WSH/02.07, 2002.
9. Microbial Control and Sanitization of Membrane-Based Pure Water Treatment Systems, Mueller, P & D. Paulson, Filtration News, April 1997. www.osmonics.com/products/Page730.
10. Maintenance, Watt Premier, www.permeierh2o.com/watts

CENTRAL ARIZONA SALINITY STUDY – PHASE I

Technical Appendix L

Reported Impacts of High Salinity Water on Golf Courses in Central Arizona

Erik Filsinger

Golf courses are major users of Arizona's water supplies. Each golf course may consume between 400 to 500 or more acre feet of water annually. Issues associated with the use of water supplies that contain high levels of TDS' and other water contaminants constitute a potentially serious challenge to this important industry.

This water use corresponds to the significant component golf comprises to the Arizona lifestyle and tourism that are key to the economic well being of the State. A study conducted by the National Golf Foundation in the late 1990's showed that the golf industry contributed over $1 billion to the state's economy. The Tournament Player's Club in Scottsdale has stated that the annual Phoenix Open PGA golf tournament generates over $65 million alone.

In addition to direct economic benefits, golf courses provide a recreational amenity that is highly sought after in real estate development. Many of the advertising dollars that attract new residents to Arizona target the Arizona lifestyle and the golf component of that lifestyle. Golf provides not only recreation, but also a greenbelt amenity to many of the new residential communities benefiting from the surge of in-migration to Arizona.

This white paper provides a quick review of the historical regulatory trends in the source of golf course water and then describes some challenges that golf course operators have had to accommodate to when they use a water source whether it be well water or effluent that has poor water characteristics.

It is not intended to be a scientific study conducted to document the extent of the problem. Rather it is a first step to highlight some of the select golf courses that are having problems and to discover the nature of the problem for those facilities having problems. If justified, a subsequent investigation could enumerate the generalization of the issues identified herein.

Regulatory Incentives to Use Renewable Supplies

The Groundwater Act of 1980 began a series of steps to regulate the use of groundwater supplies in Active Management Areas within Arizona. It directed the Arizona Department of Water Resources (DWR) to develop Management Period Plans for achieving Safe Yield by the year 2,025. DWR became the front line of establishing regulatory guidelines on the use of groundwater and as major users of groundwater golf course operators were asked to make a significant attempt at increased conservation. At the same time, the growth in population and tourism placed golf courses on the most

wanted list for recreational facilities and the number of golf courses in Central Arizona grew accordingly.

Golf courses in the “older” areas of the metropolitan areas tended to be served by wells and/or by municipal systems that served a combination of their surface water or well-based supplies. In the SRP areas some of the golf courses were indirectly served water from SRP supplies.

DWR was tasked with developing a series of 10-year management plans, with the First Management Period Plan covering roughly the 1980’s. By the time the Second Management Period Plan was crafted to provide regulatory guidelines in the 1990’s, golf courses were the focus of a major effort to regulate water conservation. The stiff conservation requirements imposed by the Second Management Plan were based in part of scientific research on how much water was required to grow turfgrass in the arid Southwest. It is the belief of some golf course operators that those conservation requirements were below the level of water needed to grow a competitive product. There was an incentive to use 100% renewable supplies because those water sources were not directly regulated by DWR. In addition, there was an incentive to use effluent, in that only 80% of the effluent use counted against conservation limits.

When the Third Management Period Plan was being drafted. DWR and representatives of the golf industry agreed that a regulatory compliance approach was not yielding sufficient savings and a shift in philosophy occurred such that the emphasis was placed on inducing the use of renewable supplies. Effluent counted only as 60% toward conservation limits (a 40 %) reduction. Part of the rationale was an acknowledgement that golf course operators would need to flush the salts from the root zones more frequently.

During the same time period developers made major capital investments in infrastructure to move existing and future golf courses off of groundwater and onto renewable supplies. A leading example of this was the Reclaimed Wastewater Distribution System (RWDS) that was the result of a private-public partnership in north Scottsdale. The RWDS involved a system of reclaiming wastewater from north Scottsdale developments and eventually returning it up to 20 golf courses in the area – a groundwater saving of potentially 10,000 acre feet annually.

Initially the RWDS served CAP water until sufficient effluent supplies were available at the north Scottsdale wastewater treatment facilities. Some golf course operators made slight modifications in their agronomic practices to manage the salt content in this source of water.

Residential and commercial water users add salts to the sewage that flows into the wastewater treatment plants that serves the effluent. The result has been some concentration of salts and other chemicals in the effluent. That combination has proven to be the basis of much of the current challenges facing the golf facilities in the area and forms the basis of some of the analysis that follows herein.

At the same time, some of the urban dispersion has lead to golf courses being developed in areas not served by readily available renewable supplies from effluent or from surface waters. Instead they have been reliant on groundwater, or at least dependent of groundwater until such future time that development occurs is reasonable proximity to provide a source of effluent. Because some of these golf courses are being developed in areas where the groundwater is high in TDS' to begin with, it is also instructive to examine their situation and challenges resulting from the quality of their groundwater.

A further regulatory development has occurred during the approval process for new golf courses within city governments. A number of municipalities are either requiring new golf facilities to irrigate with effluent and/or requiring golf courses to follow the DWR golf course water conservation standards even when Arizona law may not require such.

The net affect is that many if not most golf courses that have been built in the last decade and are likely to be built in metropolitan areas of Central Arizona are targeted to be using supplies of water that are considered renewable supplies or are of a poorer quality because of location.

In order to gain an initial look at the nature of the problems faced by golf courses with operational challenges posed by high salinity water sources, the author of this white paper contacted the Executive Director of Cactus and Pine, the professional organization of golf course superintendents in Arizona. The Executive Director and two past Presidents of Cactus and Pine who are familiar with Arizona golf course operations gave contact names and addresses of 10 golf course facilities that were experiencing some challenges with high salinity water. The golf course superintendents of those facilities were contacted and asked some basic questions about their water source and any problems they were having. Seven responses were received, including one from a Superintendent with oversight responsibility for a total of 7 separate golf facilities himself. Another superintendent oversaw 5 golf courses and a number of other superintendents manage more than 1 golf course.

The initial set of written responses were reviewed and compiled to gain an understanding of the nature of the problem. Several superintendents were recontacted to clarify or expand on their remarks.

Generally, older golf courses that are on well water and municipal systems in the Valley were note included because in the opinion of the golf course superintendents association they did not typify facilities experiencing current problems. Likewise, golf course facilities purely on CAP supplies were not included due to the adaptations that most golf courses have been making to use of that water. Many golf course superintendents consider direct use of the CAP supplies to be one of the better water sources with which they work.

Patterns that emerged from the inquiries serve as the basis for the following discussion. It should be cautioned that these results are not intended to be a scientific sample subject to statistical treatment from which larger generalizations should be made. Nevertheless the

reported information was consistent across facility and across location with regards to the nature of the high salinity water problem and the current treatment programs.

Selected Golf Facilities with Water Quality Problems

To condense the individual discussions into a meaningful presentation the facilities have been grouped into similar types.

North Scottsdale RWDS Facilities. Several golf courses on Scottsdale's RWDS were contacted and provided responses. As a group, these courses are new courses subject to the most stringent DWR water conservation standards. They are also some of the premier golf course facilities internationally and are required to meet the highest standards of play and look. Many were built and served originally with groundwater and/or CAP water, and then have recently been switched to effluent as the primary water source. As noted above, the effluent in large part originates as Scottsdale municipal service water and to a large extent is reused CAP supplies. As a group, these courses may represent the most intriguing problems associated with the current cross-pressures of market demand for goods and services, the requirement to conserve water, the pressure to use renewable supplies, and the challenges associated with specific renewable supplies, especially effluent.

To corroborate the challenges presented by the use of effluent a Tucson facility was also contacted.

Southwest Valley Groundwater. One new golf course facility from the Southwest valley was included because it has been built in an area of high salinity groundwater and has no other water source at the current time than well water. In fact, it was designed with foreknowledge of the poor quality water and is an instructive case study. Similarly another facility in the Southwest Valley was included because it is on high TDS well water. Like the Scottsdale facilities, these golf courses target a high-end market and must meet the expectations of an international clientele.

The North Scottsdale/Tucson Effluent Experience

Golf courses on the RWDS had been using CAP water delivered by Scottsdale through the RWDS pipelines until 1998. Generally the challenges they faced with keeping their facilities in top shape were primarily ones of growing green grass year-round with an absolute minimum of water. Because of the high-end nature of the facilities, these courses overseed in winter with ryegrass and most tend to have bentgrass greens. The base grass is one of a variety of bermudagrass. At the level of the water conservation standards included within the Third Management Period Plan, some portions of browning out of fairways was inevitable and did occur, often in conjunction with mounding and edge effects. However, owners and guests still had the expectation of a lush green carpet.

In September/October of 1998 the RWDS began to supply effluent from the north Scottsdale water campus located at roughly Pima and Union Hills roads. The percentage

of reclaimed effluent supplied through the RWDS system varies greatly throughout the year, with a median split of 70% effluent/30 % CAP water being typical. As capacity at the reclamation plant increases, this figure will increase until effluent becomes the exclusive water source for these facilities.

Generally the golf courses use between 400 and 500 acre feet of irrigation water annually. Because the City of Scottsdale delivers the water, city staff takes regular readings of the chemical constituents in the water.

Problem issues reported from the selected facilities will be outlined and then mitigation steps discussed, but it should be noted that this paper has not attempted to sample the breadth of the problem and it is likely that some facilities are not having problems to the degree reported herein. Please note also that the problems described herein are also reported to some degree according to the subjective experience of the golf course superintendents reporting the problems.

TDS runs between 700 and 1000 ppm. One superintendent felt that TDS readings above 650 slowed grow-in during overseeding. He also felt that at readings near 1,000 ppm the applications of nutrients were less effective. In general, the superintendents who manage golf facilities in central Arizona seem to feel that TDS problems emerge with readings of 1,000 ppm or greater.

While bermudagrass is fairly salt tolerant, the other normal grasses used for either overseeding (ryegrasses) or tees and greens (typically bentgrasses) do less well with high TDS water.

There are reported high readings of sodium/sodium bi-carbonate. At readings near 300 ppm the normal leaching procedures of flushing the salts through the turfgrass and root zone become problematic. Scottsdale WWTP representatives report that the effluent produced at the campus tends to run around 175 ppm Na, with alkalinity usually running less than 150 mg/L.

Nitrates are the biggest concern, especially on the bentgrass greens. If the levels of nitrates being delivered by the RWDS reach 10 ppm or greater serious problems begin to emerge. High nitrate levels cause the growing crown of the bentgrass greens to thicken and cutting the greens to normal playing height leads to scalping the crown; therefore killing the greens. Nitrate levels will vary depending on the treatment protocol employed in the wastewater treatment facilities; a nitrate problem with effluent in one city may not mean a nitrate problem in another city, other things being equal. Scottsdale WWTP representatives state that future expansion plans will address the nitrate issue.

The Tucson experience paralleled that reported for north Scottsdale effluent use. It’s TDS readings are about 700 ppm and its sodium bi-carbonates running about 300 ppm. As will be noted again below, Tucson water rates are much higher than corresponding water rates in the Scottsdale courses (about $435/AF versus $250/AF).

Southwest Valley Well Fed Courses – Water Quality

TDS. The two reporting high-end golf facilities from the Southwest Valley are served by well water. In one case the TDS readings range from 1,900 to 3,000 ppm. In the other case the well water has readings close to 4,000 ppm. Generally there are constant challenges, even with bermudagrass, but certainly with any overseeding and with almost all landscape vegetation associated with the courses. As will be discussed below in more detail, diseases of overseeded turfgrasses are a constant challenge due the high TDS.

Nitrates are of somewhat less concern because effluent reuse is not currently the primary water source.

More discussion will follow in the agronomic procedures employed to be discussed below, but these facilities must use a front-end treatment of the water (sulfur burners and gypsum injection) and in fact one facility hauls water for its greens.

Problems Associated with the High Salinity Water

The following problems appear wherever high salinity water is used for turfgrass irrigation.

TDS

High TDS water tends to limit the ability of certain species of turfgrasses to grow and flourish. Salt build-up in the root zone is endemic and must be flushed. Flushing the salts in principle involves applying more water than normal, dissolving the existing salts in the plant's growing zone, and "flushing" those salts further into the earth. In addition to the related problem of creating a soil profile that is conducive to the movement of the salts, the problems that are cited are due to difficulty moving the water through the plant profile in a way that actually flushes the salts. In practice this frequently leaves major areas of turf saturated.

High TDS water stains the facilities that receive any overspray. Given the market demand for aesthetically pleasing facilities, buildings and cartpaths must be cleaned.

High TDS water creates a shorter useful life for sandtraps. It contributes to the "clumping" and unplayability of sand.

Sodium

One particular element of the TDS's that requires specific attention is sodium. High sodium causes the soil to disperse, filling in the small gaps in the material, leading to a somewhat impermeable layer and poor infiltration for water.

Nitrates

High nitrate levels cause the growing crown of the bentgrass greens to thicken and cutting the greens to normal playing height leads to scalping the crown; therefore killing the greens.

Sulfur

While this chemical is used as a treatment for high TDS problems and to balance water pH, the unintended consequence of its use is a deterioration of certain types of manufactured sand used in bunkers.

Protozoa

The RWDS water now that it is largely effluent has nutrients that feed protozoa and golf course irrigation systems once infected with protozoa can develop severe problems and even shutdowns during the Spring. These living organisms grow and thrive in the effluent and literally clog the mainlines, though this problem can be pretty common in any Arizona surface water source due the presence of organic carbon and nutrients not typically found in groundwater.

Algae, snails, and fresh water clams

Effluent and/or CAP water seems susceptible to additional organisms that must be controlled for effective irrigation to occur, though again this may be common in other surface water sources.

Agronomic practices, chemical additives and other treatments

Regardless of the location, the treatment regimens for specific challenges are similar and have a similar function – to help move the irrigation water through the turfgrass plant profile and generally to improve the drainage characteristics of the facilities.

Sulfur burners or sulfur injection systems tend to be used to place concentration of sulfur into high TDS water to lower the salt content. Sulfur is added to the water supply to counteract the negative affects of the TDS/Sodium. When combined with the local soils, the sulfur facilitates the formation of calcium carbonate (gypsum) and reduce the sodium levels in the soil, helping the water move through the turfgrass profile.

Gypsum is added either by injection into the water supply or as an additive through surface dispersion. (This treatment is also used for the specific TDS, sodium, discussed below)

Wetting agents are used to help push the water through the grass plant profile.

Leaching the soil by flushing the salts out with more water is a standard practice. Most facilities now do it every two weeks, which means a much higher water use.

Almost all facilities have to engage in much higher and intense levels of aerification to break-up the topsoil and enhance the infiltration of the irrigation water in order to try to get the salts to flush through the root zone.

Major capital investments have been made to re-profile the turfgrass growing region of the soil to enhance its percolation. Generally this is done by adding a major of layer of sand to the fairways (around 3 inches). In addition, each year the facilities that are facing the drainage challenges are adding a layer of sand in the topdressing cycle wherein added soil constituents are added to the turfgrass.

In addition, due to the tendency of areas of play to become and stay wet, whole sections of golf courses have had to be redesigned and modified to increase drainage.

A potentially economic side affect of this wetness is that some facilities have to limit the ability of golfers to drive their golfcars on the fairways. This may be seen as a negative on the premier golf experience those golfers expect and will have some economic or intangible impacts on the facility and its owners or members who has designed and promised a different golfing experience.

Special fertilizer devoid of nitrates has to be used when the effluent nitrates are elevated.

Chlorine is added to wet wells to control snails, fresh water clams, midges, and protozoa.

Aggressive treatments with an oxygenating compound (potassium permanganate) kill the protozoa. However, during the crisis period when irrigation lines are shut down, huge numbers of man-hours entailing a significant labor expense must be employed to manually water the shut-down sections of the golf courses.

Fish species are added to golf course lakes to control algae and to increase the impermeability of the lake bottom and to mitigate water loss to the aquifer.

These problems may exist whether the water source is effluent, surface water, or groundwater, depending on the facility and the specifics of the water source itself.

Cost Impacts of High Salinity Water

It should be emphasized that not all golf facilities will experience each and every cost factor because not all of the problems occur at each facility. Indeed, this paper has made no attempt whatsoever to address the breadth or generalizability of the problems to other facilities. However, when a problem arises, a facility will likely be faced with similar costs. What follows are general guidelines; however, the actual costs will vary from facility to facility depending on its unique characteristics.

Labor

Each of the following factors tends to increase annual labor costs. This has proven to be a difficult factor to break out as a separate item.

Compared to previous decades of golf course operation, recent changes in regulatory oversight and compliance has led to greater levels of golf course superintendent concern. The educational process associated with understanding the nature of the new problems and learning new procedures to deal with high salinity water adds additional costs from a human resource perspective.

Monitoring and Testing

High salinity water supplies require a higher care in terms of awareness of the chemical constituents in the water supply. While most municipal water providers conduct regular tests, even golf course facilities on municipal supplies will do at least monthly monitoring. For facilities that do not have other agencies test their water supply, the testing of the water can generate regular water testing costs.

Chemicals

Wetting agents have typical annual costs for chemicals run around $15,000 per 18-hole facility.

Sulfur, gypsum, and other chemicals used to lower salt levels in irrigation water cost about $61,000 annually for an 18-hole facility. An unintended side effect of the sulfur usage is a shortened useful life of golf course bunker sand and irrigation infrastructure. These consequences are noted below.

General pesticides cost around $16,000 per year to deal with the variety of infestations and build-ups that occur in the poorer quality water. Protozoa infestations can cost around $4,000 per event in both materials and labor. The additional labor costs to manually water during a shut down due to the infestation can be very expensive.

Additional Agronomic Practices

Increasing the movement of water through the root zone to help flush out the salts requires additional treatments using heavy equipment. Aerification and verticutting can remove Thatch build-up. Under high salinity water conditions these agronomic practices have to be done on a more frequent basis.

For facilities that buy or lease their own aerification equipment, the capital costs can be in the range of $100,000 over 5 years. The costs related to aerification alleviation of high salinity problems include $5,000 to $10,000 each year for employee labor just to run the aerification equipment. Every 3 or 4 years the fairways require an additional deep aerification with an outside contractor costing about $8,000 per year (rotate around 4 fairways per year).

Additional Water

The cost of additional water to flushing salts from the turfgrass constitutes a considerable expense. Most facilities on effluent probably use as much of their 40% overage allowance as they can, or an additional 200 acre feet annually to flush the salts. At Tucson pricing this could add about $87,000 a year to operational costs and at RWDS pricing this would add about $50,000 in operational costs. Even those not on effluent but with high TDS content must flush as much as possible and may encounter similar expense.

Increased Operations and Maintenance Expenses

Sulfur burners to treat high TDS/sodium laden water cost about $25,000 to install and about $15,000 annually to run.

Top dressing the golf courses annually with sand to increase drainage characteristics of the soil costs about $12,000 per year for each 18-hole facility, with an additional labor component of approximately $3,000 per year.

Annual resodding to replace turfgrass that is irretrievably damaged by salts costs about $8,000/year.

Cleaning out wet wells and lakes costs about $10,000/year.

Capital Replacement

Replacing a bentgrass green can cost around $56,000.

Laying down 3 inches of bedding sand on a golf course to increase the percolation of water through the soil profile can cost from $150,000 to $300,000 per 18-hole facility.

Some facilities will have to redesign and reconstruct portions of their courses to increase drainage from areas that are tending to stay wet due to the salinity problems.

Premature wearing out of the irrigation infrastructure due to the use of sulfuric acid treatments costs about $5,000/year.

One fairly severe side affect of this is that in addition to the normal earlier replacement of sandtraps due to the TDS, the sulfur actually causes an even more severe clumping. Whereas typically the national standard useful life of sandtrap sand is near 5 years, with the addition of a sulfur treated water supply, the useful life of bunker sand is cut to 2 years, or by 50%.

Fish species costs run about $2,000.

Design

Facilities designed for high salinity water use can find additional design and construction costs running about $1,000,000 to provide sufficient additional drainage.

Lost Revenues/Downtime/Aesthetics

Modifying golfers choices due to operational practices to counter-act effects of high TDS water supply include keeping golf cars on cartpaths which results in lengthened rounds of golf and lower revenues as well as lowered golfer enjoyment.

Employee Safety and Health

Many of the chemicals used to treat high salinity water are regulated and can only be applied by a licensed operator. Nevertheless, there is a constant concern that given how labor intensive the operational side of the golf business is employees are constantly working in close proximity to harmful substances. Many employees may not be English language proficient, which also places a burden on golf course operators to make sure warnings are communicated effectively.

Suggestions for the Future

Among golf course superintendents there is some recognition that with current turfgrass species the industry is about at the limit of water conservation that can be accomplished. Any further tightening of conservation standards would drastically alter the product offered, e.g., it is likely that overseeding could not be done with less water. In addition, the primary remedy for the problems associated with high salinity water sources involves the application of greater amounts of water to flush the salts out of the root zone.

The reporting golf course superintendents would argue that any increase in salt content of golf course irrigation water would have a corresponding negative impact on this important component of the Arizona economy. At this point the full impact of the current problem and any future increase in salts is unknown. Further research will be needed to see the generalizability of the current findings across a broader cross-section of golf courses and to predict the generalized economic impact.

Some reporting golf course superintendents would argue for changing the wastewater reuse regulations in the state to be more conducive to the end user, i.e., lowering the permissible TDS and nitrate output from wastewater treatment plants. This debate would have to be joined by regulators and regulated entities.

An even tougher but perhaps better solution would be to find ways to reduce the sodium chloride use in homes.

CENTRAL ARIZONA SALINITY STUDY—PHASE I

Technical Appendix M

Impact of High and Variable TDS on Central Arizona Industry
Focus on Process and Cooling Water

January 2003

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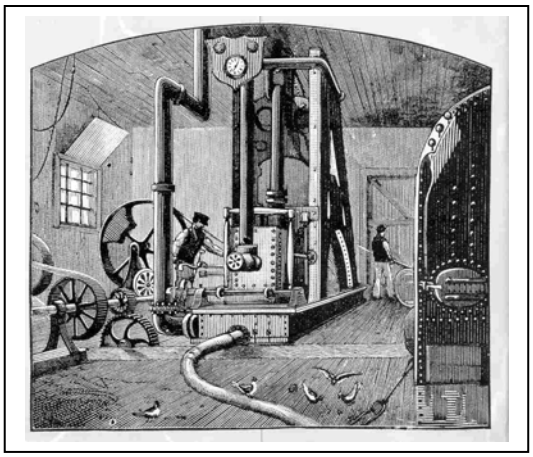
1.0 Introduction

Industry in the greater Phoenix area is dominated by electronics manufacturers, most visible being Motorola and Intel. Other manufacturing includes aerospace, automotive, food, and materials. In Arizona, the total 2001 manufacturing employment stood at 212,600, with approximately 147,000 in the Phoenix Valley. From golf clubs to semiconductor chips, any manufacturing that requires process and cooling water has to accommodate the salinity of the source water. During this extended period of drought, the objectives of water conservation as defined in the DWR are in direct conflict with operation methods that suit the high salinity of source water.

This white paper will define water use and the impact of rising salinity on process and cooling. Typical volumes, costs and issues caused by specific constituents in the water will be outlined with references to source documents of this data. Semiconductor, general manufacturing and power plant use of water for process and cooling will be examined as examples of moderate to high-volume users of water. Future trends and economic impacts are addressed as best known.

2.0 Historical Perspective and Background



The Industrial Revolution in the eastern and central United States was built using water to generate power and move machinery. The steam engine, patented by James Watt in 1769, supplied the power for mass production. Considered free, because it flowed in a river past the factory or near the power plant, water consumption was not deemed a cost of doing business. Contaminated wastewater was returned to the river without a second thought. This mentality migrated to the desert areas of the western US as the irrigated agricultural lands brought people and then industry. To compensate for the salt content of western water, companies just used more for production and cooling, diluting the effects of the salt. Water was then, and still is a cheap commodity. However, the cost of wastewater was finally recognized when EPA regulations gained enforcement clout in the mid 1980's. Today, environmental compliance can range from ½ to 8 percent of revenue, a significant part of total manufacturing and power costs. Reducing a portion of that cost by recycling wastewater within a factory has now become commonplace. Ironically, air quality compliance increases water use for washing out contaminates. Many western power plants now use lower cost treated municipal wastewater as a source of cooling and process water.

2.1 Overview of Economic Impact of Manufacturing

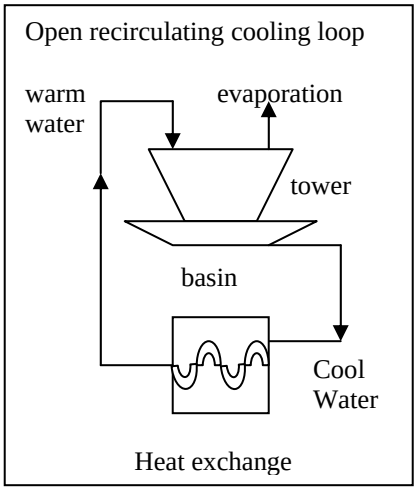
From the 1950's, manufacturers built factories in the Valley because land was cheap and available, labor costs were low and favorable taxes and regulations were common. In the last decade, despite competition from other states, Mexico and China

for those same employers, Arizona's manufacturing increased. From 1991 to 2001, employment increased 18% and Gross State product increased 246%. The largest manufacturing subsector is computer and electronic products. This subsector, in 2001, ranked 10th in total employment (57,378), 5th in earnings ($4.3 million) and contains the 2nd highest paying employers in the state. An abundant supply of water and power is required to keep this subsector paying taxes and salaries
.

2.2 Overview of Water for Cooling

Desert heat drives the need for cooling the air for human comfort. More than mere comfort, cooling is essential for manufacturing and power generation. Electronic manufacturers control air temperature and humidity in production areas to achieve the highest product quality. Efficient power plant operation requires turbines and power generating equipment be kept cool. And water is the least expensive way to cool air and equipment.

The desert dry air provides a perfect vehicle for evaporation of water. A cooling tower is a low cost method of evaporating water and reducing its temperature. The basic function of a cooling tower is to cool a circulating stream of water by evaporating a portion of it. The cool water is pumped from a tower to equipment that generates a heat load (such as an air conditioning system). There, a heat exchange occurs. The equipment is cooled and the water becomes warmer. The warmed water returns to the tower, is re-cooled and the cycle repeats. The picture to the right is a simplified drawing of that process. Figure 1 in the Appendix, shows a detailed flow diagram with water and salt balances.



The efficiency of a tower depends upon the amount of time the water is in contact with air and control of the water quality. *Fill* supports a thin film of falling water and provides a long contact time with air. Water flows slowly along the intricate surface of the *fill*, which is typically a plastic honeycomb. A large fan at the top of the tower pulls air through the louvers and the fill. A portion of the water evaporates, cooling the remaining water about 10 degrees F. The cooler water sinks to the lowest spot in the tower basin and is supplied to the copper tubes inside of a heat exchanger. Air is cooled as it passes over the copper tubes containing the cool water. This cool air is then used to cool the building. In exchange, the water inside the tubes is warmed and flows back to the tower to start the evaporation process again.

Control of water quality is essential because evaporation in the tower, leaves behind salts, impurities and solids in the recirculating water. In addition, airborne impurities are often introduced into the tower water, intensifying the problem. The purpose of a water quality control system is to suspend those impurities and prevent

them from precipitating as *scale* onto the copper tubes in the heat exchanger or the tower itself. In addition, effective control of these contaminants is needed to prevent corrosion of metal surfaces and biological growth in the cooling system, any one of which can reduce heat transfer efficiency and increase system operating costs. Variations in makeup water quality can require changes in the chemicals used for water quality control, especially when calcium, alkalinity, chloride or silica concentrations vary by more than 10%.

Cooling tower manufacturers offer general guidelines for chemical management but specifically recommend two things – a) do not use acid unless the metal parts of the system are compatible and b) unchecked growth of algae, slimes and other micro-organisms will reduce system efficiency and may contribute to growth of potentially harmful micro-organisms including *Legionella*. Acid is the cheapest way of reducing the pH of alkaline recirculating water and keeping the calcium in solution. Using acid alone, however has proven to be costly in the long run if the dosing meter sticks in the open position and the amount of acid is sufficient to "eat" the tower. This did occur at Bank One Ballpark shortly after it opened.

Cycles of Concentration(COC)is the term used to define the number of times water is used in the tower before it is discharged as *blowdown*. Bleed is the amount of water that must be removed from the tower in order to control the salt content of the recirculating water. COC is calculated as the conductivity of the blowdown divided by the conductivity of the makeup water. Typically a conductivity meter is set to automatically open a discharge valve on the tower basin when the salt content rises to a preset level. Although, conductivity can be related to total dissolved solids, it does not accurately reflect the total salt content of the water. Chemical suppliers such as GE-Betz/Dearborn, and Odeca/Nalco blend dispersant chemicals with acid so that the alkaline pH of western water can be modulated to maximize the cycles of concentration. They publish COC's up to 6 but in practice, cycles vary between 2.5 and 4.5.

Makeup water is typically fed to a tower using a float valve so that both the evaporation and blowdown losses can be automatically replaced. Makeup water volume can be reduced significantly up to a COC between 4 and 6. The ratio of water use and COC is shown in the Table 1. At higher COC, most of the water is lost to evaporation, so the total water savings for higher COC's diminishes to a limiting value. Salinity in the makeup water limits the practical operating COC for a given water quality management program.

Table 1 – Ratio of COC to Water Use

Cycles of Concentration	Gallons per Day per Ton of Cooling
1.5	10,200 gpd
2.0	7,000 gpd
4.0	4600 gpd
6.0	4200 gpd

Another water loss can come from the backwash of a tower filtration system. Many towers have side stream filtration units to prevent buildup of solids, which are the vehicle for growth of microorganisms including *Legionella*.

2.3 Overview of Water for Process

Process water is used for rinsing, cleaning, chemically treating and generally manufacturing a product. Circuit boards, semiconductor chips, aircraft parts, medical devices, golf clubs, LCD displays, machined parts, juices and soda are all made using water. Water becomes part of the product in the case of cosmetics, juices and soda. Purification of water for process is driven by the need for consistency of product quality. The more critical the product quality, the higher the degree of purity required. Semiconductor and most electronic manufacturing uses ultrapure water, which has all of the salts removed. Beverage manufacturers purify water to different standards, and actually cannot use ultrapure water for human consumption. Ultrapure water is a very aggressive solvent and extracts metals and salts from anything it touches.

Many manufacturing processes need cooling water to maintain a specific temperature. This water is cooled in the same manner as air is cooled for air conditioning. It flows in a closed loop and is designated non-contact cooling water. Due to local regulations, most factories have eliminated discharge of this cooling water. Another use for water is for cleaning of the factory, to maintain quality and safety standards.

3.0 Issues and Trends

3.1 Power Industry Water Consumption

Power and water are still linked today in manufacturing as they were in the beginning of the Industrial Revolution. This fact may not be obvious to the casual observer of a factory building, but the link is obvious when observing the steam rising from Valley power plants. Ninety million gallons per day of secondary treated water from 91st Avenue Wastewater Treatment Plant flows to the 3.8 Gigawatt Palo Verde Nuclear Power Plant. 70,000 acre-feet are used annually for cooling water to condense steam. This water is treated to tertiary standards with filtration, trickling filters to remove ammonia, cold lime softening and clarifiers to remove the hard water salts. Table 2 below shows the amount of scale-producing constituents in the 91st Avenue effluent that are removed at Palo Verde. Each of 4 cooling units demands 15,000 gpm water flow to compensate for the evaporation rate and bleed to the solar evaporation ponds, which averages 600 gpm

per unit. (An additional 1 MGD of well water provides drinking water for the site and feeds a process water purification system.)

Table 2 – Water Quality at Palo Verde NPP			
Constituent	91st Avenue 2° Treated Effluent (m/l)	Palo Verde 3° Treated Effluent (mg/l)	Palo Verde CT Bleed (mg/l)
Calcium	162	71	1916
Magnesium	120	14	395
Silica	20	4.6	113
Conductivity (MicroSiemens/cm)	1487	1496	32,142

Because of the high demand for water at each of APS's and SRP's power plants, use of reclaim water is highly desirable. It's cheaper and it's better public relations. All types of power plants require cooling water for the generators. The volume varies with the amount of power generated and seasonal demand. Palo Verde consumes more water during the summer than 91st Avenue can produce. It may become economically feasible to recover water from the cooling tower bleed for recycle back to the towers rather than lose the water to evaporation. A brine concentrator is in operation at one of APS's sites. This is one technology that offers a lower cost option for desalinization.

Arizona's power demand has grown with the population, which has lead to new power plant generation capacity and increased water demand. Energy conservation and water conservation have not been emphasized to the public that demands abundant and clean water and pollution-free power. Power use by the semiconductor industry is described below. As a rule of thumb, it takes 8-9 gallons of water for each Kilowatt of electricity produced. A single semiconductor manufacture using over 100 million KWh/year requires approximately 1 billion gallons of water per year for power alone.

3.2 Semiconductor/Electronic Manufacturing Water Consumption

As semiconductor "chips" became more complex, tiny amounts of salt in the water became sources of contamination that cause low yields. This drove the development of water purification technologies to remove all of the salt from the source water, and created ultrapure water. A typical high volume semiconductor manufacturer uses 3 to 6 million gallons per day of water – 70% for ultrapure process water, 20% for cooling and air pollution abatement and 10% for sanitary and landscape. Water is no longer free – it has to be treated before it can be used in production processes. Then is must be treated before disposal. Ultrapure water costs approximately $15.00/1000 gallons ($4887/acre-foot), including source water, treatment and disposal costs. Yet the mentality of "more is better" persisted through the early 1990's. Conservation of water became an economic goal as water use increased with wafer size and wastewater disposal costs increased with environmental regulations. Suddenly the cost to obtain, purify, use, treat and dispose of water showed an economic payback for reuse of the water on-site. The Semiconductor

Roadmap, an industry-generated document used to focus technology and cost issues shows goals of 65% reduction in ultrapure water use, 30% reduction in ultrapure water cost and 20% reduction in power consumption.

Public perception of water use by the large semiconductor companies and "green" investors has driven investigations and investments into water conservation and reuse. Intel spent over $15million in New Mexico to keep water use to a maximum of 3.9 MGD despite increased production needs. Today most of these manufacturers recycle between 21 to 40% of their total water use. Some have invested in equipment to demonstrate good corporation citizenship and do not worry about pure economic payback. Water is still cheap, but good PR is expensive. Up to 3 million gallons per day of Intel wastewater is recharged after treatment in the Chandler RO plant, a facility purchased by Intel and run by the city. Increasing density and size of wafers (200mm and 300 mm plate-sized disks from which hundreds of chips are cut) increases the cost and use of water and drives investment to reduce both. New technology for equipment and processes are well underway and adapted by all new and refurbished plants. The new equipment uses less water in each process, which is still the cheapest way of reducing water use and operation costs. All water reuse technologies create wastewater that is higher in salinity than normal wastewater. The constituents in that wastewater include salts from the manufacturing processes and the wastewater treatment chemicals.

Figure 3 shows a typical semiconductor water and approximate salt balance based on the Motorola site in Tempe. Other facility water use is noted. Cooling towers consume the second largest volume of water in the factory. Semiconductor products must be manufactured in cleanrooms that provide dust-free air and are precisely controlled for temperature and humidity. More than 50% of the power consumed by a factory is used for the pumps, fans, cooling and heating that provides that control. The Motorola Tempe site has approximately 12,000 Tons of HVAC. Those cooling towers bleed off 60,000 gallons per day. It is estimated that makeup for evaporation averages 100,000 gpd.

This site has two specific water conservation plans. The first will add a secondary RO system to squeeze more useable water out of the ultrapure water. The second will blend some of the high quality wastewater with source water for cooling tower makeup. This will allow higher COC's in the towers. Both efforts, however, will increase the salinity of the wastewater discharged to the sewer.

3.3 General Manufacturing Water Consumption

Water consumption by general manufacturers depends upon the type of product, the processes and the size of the operation. Many manufacturing operations do not have cooling towers, but rather have packaged air conditioning systems that do not require water. For example, a machine shop uses water for cleaning the floors, washing parts and for makeup for the machine tool coolant. They will often purify the water used for cleaning and rinsing parts, but will not invest in an elaborate ultrapure water system. More likely, they will rent water softening or deionizing canisters from a vendor that replaces them periodically. If the wastewater contains no

dissolved metals, then it only needs to have the pH adjusted to meet discharge standards before release to the sewer. For this type of factory, the increase in salinity in the water over the background in the source water is minimal. Figure 4 is a simple water flow diagram for a simple, general manufacturing plant.

4.0 Future Implications and Opinions on the Future

4.1 Salt Management Today

Large manufacturers and many smaller ones rely on chemical suppliers to manage cooling tower water quality. Variations in source water, especially during this drought period likely increased chemical costs, but not significantly. Palo Verde's tertiary water treatment for removal of salts has experienced an increase in chemical costs as salinity has risen in the effluent from 91st. Avenue. However, such chemicals are purchased in bulk and likely are not be tracked closely enough to attribute and increase to rising salinity.

Many of the large semiconductor companies contract their ultrapure water system operation and maintenance to Ionics. Antiscalants and other pretreatment chemicals used to protect those membrane systems likely increased, but not significantly. The gradual increase in salinity has been absorbed and has likely been masked by the dramatic slow down in the high technology sector of the economy. Small and general manufacturers that use rented ion exchange canisters would have seen an increase in costs if their production levels remained constant. Unregulated salts in wastewater discharges are not managed or tracked, so it is difficult to confirm the salt load that is discharged to the municipal wastewater treatment facilities.

4.2 Costs, intangible and tangible

Manufacturing and specifically semiconductor plants have chosen Arizona sites based upon a number of factors. Typically, they want the impact of their facility to be less than 10% of a municipal system's total capacity to supply and treat water. They also look for a skilled labor force, good infrastructure (i.e. nitrogen lines, fiber optic cable), availability and cost of land and power, and fast and favorable environmental permitting. Water quality, in and of itself, is not a determining factor and won't be until the treatment costs exceed the targeted product cost. Intel's investment in New Mexico proves this point. They located the plant in an area that would not have the volume of water needed for a large semiconductor manufacturing plant without extensive water reuse within the factory. Intel's investment in Chandler for water recharge also demonstrates their desire to be good corporate citizens and not base a decision solely on water and wastewater capacity. Downward price pressure on semiconductor chips does require manufacturers to constantly reduce operation costs. This is being addressed in the redesign of process equipment that coincides with new chip technology manufacturing. Therefore the additional cost for reducing water use is absorbed into the equipment cost for new technology.

The estimated costs for equipment and operation of reuse of water systems in semiconductor plants is shown in Table 3 below. The range is wide and varies with the particular source of water that will be treated and reused.

Table 3 – Water Reuse Costs	
Equipment Component	Cost per million gallons processed
Carbon filtration	$70 – 1000
Particle Filtration	$20 – 100
Ion Exchange	$250 – 1000
Reverse osmosis membrane	$30 – 2000
TOTAL	$370 – 4150

These costs are independent of the rise in salinity in the source water because the plant's main ultrapure water system will be the only system that experiences a rising cost associated with salinity. In a membrane system, the osmotic pressure increases 1 psi for each 100 mg/l of TDS. As salinity rises, a given membrane system will either require more energy to pump water across the membrane to maintain a constant volume or it will lose productivity. At the same time, more salt will permeate the membrane because a given membrane material has a fixed salt flux, i.e. the percent removal of a range of salts. The increased cost of a pump and the requirement for more membrane area will increase capital investment. As calcium, magnesium, carbonates, silicates, phosphates and sulfates rise in the source water, the membrane system will be more prone to scaling and will require more frequent cleaning. This will increase operating costs.

Process water that is purified to ultrapure standards typically costs $15 per 1000 gallons produced including equipment depreciation, operation and maintenance costs to obtain, treat and discharge wastewater. A rise in that cost may not be important when it coincides with reduced overall demand for water by the new production equipment. This will not be true for manufacturers that rent ion exchange canisters. Each canister has a fixed capacity for adsorbing the hard water constituents in source water. If salinity doubles, then the cost for changing out those canisters will increase 1.5 to 2.5 times, depending upon the concentration of the constituents in that water.

Cooling water chemical costs are not measured in terms of water use, but rather cooling load. For example, Motorola Tempe spends between $100,000 and 120,000 per year to manage approximately 18,000 tons of cooling capacity.

So far, industry is coping with the rate of salinity rise experienced to date. Their investment in reuse methods and technologies to reduce their cost of operation, however, will drive up salt levels at municipal treatment plants. The costs for dealing with rising salinity in wastewater discharge will be born by municipalities as they look for options for reclaim and recharge.

4.3 Future Impact of Salinity

The feature sizes on semiconductor chips are shrinking below 130 nanometers. This means that the surface tension of water will limit its use for chemical processes and rinsing because it will no longer be able to penetrate these smaller spaces. In addition the smaller chip features do not have the mechanical strength to withstand such processes. Supercritical carbon dioxide has been researched and tested for cleaning and rinsing applications. It is anticipated that it could replace water in the next 10 to 15 years. Even if it does not replace it entirely, the water demand and therefore the impact of salinity would be reduced. The timeframe for switching away from water will be determined by the economics of using supercritical carbon dioxide compared to the quality impact of continuing to use water.

Since semiconductor plants are very visible in their communities as "big water users" they have been implementing water conservation and reuse programs for many years. This investment results in higher salt loads in their wastewater discharges that increase the burden on municipalities seeking to reclaim or recharge secondary treated wastewater. (See Figure 3) Any discharge restriction based on salinity is a disincentive for water reuse within the factory. These disincentives include the cost and availability of the technology to further remove the TDS and the related issues of increased energy consumption and solid waste disposal.

General industrial users of water have learned that process water quality is tied to product quality. The degree to which the water must be purified depends upon the technical complexity and aesthetic appeal of the specific product. Variability of water salinity increases the time and labor associated with maintaining product quality. Increased salinity increases the capital investment and/or operating costs to produce sufficient amounts of purified water. It is interesting to note that this cost will not go away if the industrial plant is moved to a "low-cost" manufacturing location, such as a third world country. It might even increase due to the other constituents in the Third World's water supply.

The desert is not going to cool down in our lifetime. And water is still the cheapest ingredient for making cool air. As salinity rises in the source water used for cooling, more chemicals will be needed to mitigate the effects of scaling, corrosion and fouling on plant equipment. In addition, the number of cooling cycles will decrease and will not meet Arizona law for water conservation. Cooling tower bleed is set by the conductivity of the water in the tower basin. Both the salt ion content and the total salinity contribute to the conductivity. As the salinity rises and ion content varies, bleed will occur more often, increasing water use. Discharges to the municipal treatment works will remain fairly constant however.

Power use and therefore the water demand at Palo Verde will be directly affected by a rise in salinity. Population growth and increased manufacturing will both increase power demand. 91st Avenue effluent will be affected by source water salinity and therefore the tertiary treatment at Palo Verde will need more chemicals to remove the salts.

5.0 References:

"Conserving Natural resources in Wafer Fabs", R. Bonsisolli, C. Lynn, ADP Marshall; Semiconductor Fabtech 11th Edition.

"Fixing Leaky Fabs", Valerie Rice; Electronic Business, May 2002

"Energy Efficiency in Semiconductor Manufacturing: a Tool for Cost Savings and Pollution Prevention," M.C. Williamson, USEPA, Semiconductor Fabtech, 8th Edition

"Environmental, Health & Safety Considerations in Site Selection of High Technology Facilities," J. Sabin, Jacobs Engineering, Semiconductor Fabtech, 8th Edition

"FXT Cooling Towers, Operating and Maintenance Instructions," Baltimore Aircoil

"How to Determine & Justify Water Conservation for Cooling Towers," presentation by W. Midkiff, Los Alamos National Lab. May, 2000.

"Planning for Water Reclamation in a Semiconductor Fabrication Faciliy," A. Chasey and E. Striffler, American Water Works Journal, Vol. 94, No. 7, July 2002.

"Playing It Cool: A Guide to Achieving Cooling Tower Efficiency," Conservation Assistance program, City of Tucson Water Dept., Spring 1995.

"Profits and Cold Water," R., Burger, Engineered Systems, September, 2000.

"Microchips' Heavy Burden," S. K. Ritter, Chemical & Engineering News, Dec. 23, 2002.

"Microelectronics Water System Evolution Through 300 mm," J. Payne, K. Sommer and R. Williams, Ultrapure Water, may/June 1999.

"More data becoming available by the NAICS," Tom Rex, ASU College of Business Research Manager, Arizona Business, Vol. 49, No. 12, December 2002.

"Reducing water use in exhaust management systems," J. Van Compel, V. Chidgopkar, MICRO, july/August 1999.

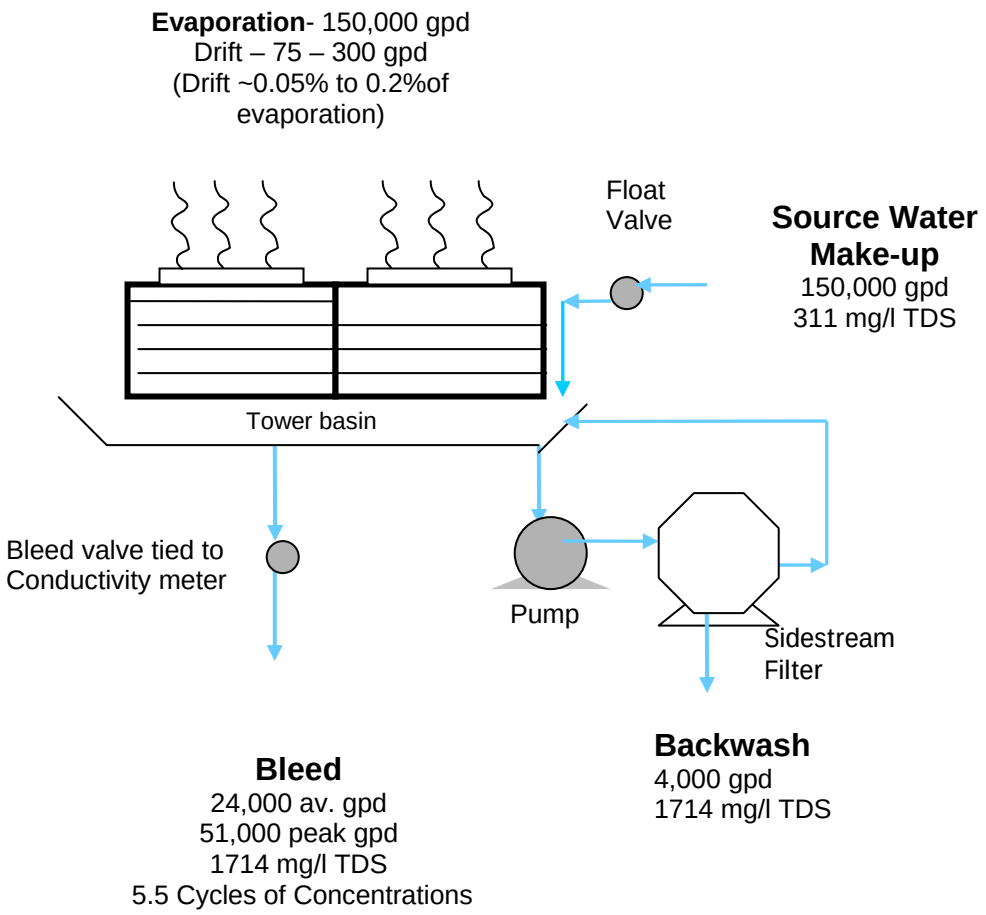
"Semiconductors / Microelectronics Water System evolution Through 300 MM, " by J. Payne, K. Sommer and R. Williams, Ultrapure Water, May/June 1999.

"Tweaking: The Art and Science of Successful Cooling Water Treatments," M.A. Ward, T. M. Laronge, CTI Journal, Vol.21, No.1, Winter 2000.

"Wastewater Reuse," T. Clark, Industrial Wastewater, May/June 1998

"Water Use," brochure published by Palo Verde Nuclear Generating Station.
"Water Reclamation Facility," brochure published by Palo Verde Nuclear Generating Station.

Figure 1
Typical Cooling Tower Water Flow and Salt Balance
Est. 3500 Tons of Cooling



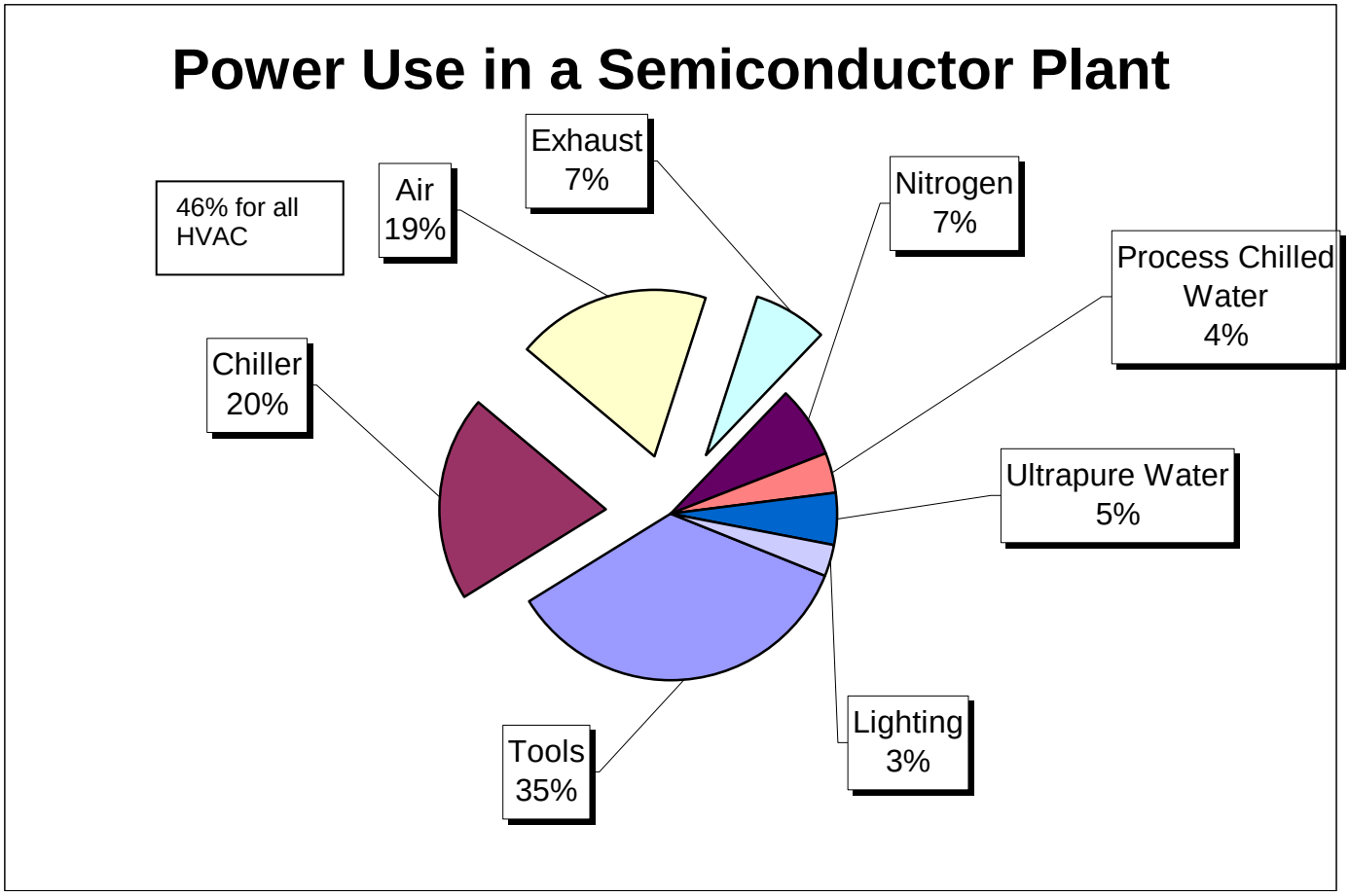
Daily Salt Balance

Makeup: 150,000 gpd x 3.85 liters/gal. = 577,500 liters/day
X 311 mg/l TDS = 180 Kg or **396 pounds of salt**

Bleed: 24,000 to 51,000 gpd (92,400 to 196,350 liters/day)
PLUS Backwash: 4,000 gpd 15,400 liters per day
X 1714 mg/l TDS = 184 to 363 Kg or **405 to 799 pounds of salt**

Each pound of salt input results in two pounds output to sewer

Figure 2


Power Use in a Semiconductor Plant
46% for all HVAC
Air 19%
Exhaust 7%
Nitrogen 7%
Process Chilled Water 4%
Chiller 20%
Ultrapure Water 5%
Lighting 3%
Tools 35%

CENTRAL ARIZONA SALINITY STUDY --- PHASE I

Technical Appendix N

ARTIFICIAL BRINE in the SALT RIVER VALLEY (SRV)

Executive Summary

While there is limited authoritative data documenting the impacts of brine streams, (regardless of their source), on the local environment, it is clear that managing these streams will represent a long-term issue in many areas of the country. In the Phoenix metropolitan area, this is particularly true in light of the latest Maricopa Association of Governments (MAG) build-out population projection of 12,000,000. Water supplies to serve this population have not been secured, and the impact of drought on current supplies has not been considered. The lack of reliable information represents the most significant issue that must be addressed if long-term, cost effective, solutions are desired for managing the actual impact of brine on the local environment.

Undoubtedly, poor quality waters, such as saline aquifers and reclaimed effluent, will play an increasingly significant role in meeting the needs of the growth expected within the Salt River Valley (SRV). To make these poor quality waters acceptable for public use, advanced technologies will play an important role in meeting the long-term water supply needs of this community. Most important among these technologies will be reverse osmosis (RO) and nanofiltration (NF) membranes because of their ability to reject not only salt, but also the vast majority of the compounds now being considered as emerging contaminants. Both produce brine as a by-product; therefore, brine management will be the core issue that must be addressed when considering the deployment of these technologies. While brine must be considered as part of a comprehensive salinity management strategy, the need to utilize poor quality waters as a

renewable potable source far outweighs this issue in this rapidly growing desert community.

To see the ramifications of applying the wrong solution to a salinity issue one needs to look no further than the Yuma Desalting Facility. This $250,000,000 facility has never been fully operated, and may never be operational again. It should serve as a valuable lesson to the SRV. That lesson should be that the valley's salinity issues should be addressed in a proactive manner, based on careful consideration of a wide range of scientifically valid data collected over a statistically relevant period of time.

Introduction

Brine enters water and wastewater systems by a variety of mechanisms. Natural introduction, such as saline springs can impact bulk raw water supplies; while a variety of treatment systems (RO, NF, water softeners and cooling towers) can either concentrate naturally occurring salts, or add new salt to wastewater streams. Irrespective of its source, concentrated salt, in sufficient quantities, can result in a variety of problems for downstream systems and users.

Other papers within this document will address naturally occurring brine, cooling towers, and the impact of salinity upon a variety of interests. While those issues may be touched on here, this paper will limit its focus to artificial brine sources. Scottsdale, Arizona, and its Water Campus Project (WCP), will serve as the primary example of the points addressed in this discussion.

The WCP is a state of the art water resources management facility internationally recognized as a leader in applying technology to meet the long-term water quality and supply issues faced by a growing number of communities worldwide. The facility consists of a 54 mgd conventional water treatment plant, a 12 mgd water reclamation plant, an advanced water treatment (AWT) facility (15 mgd microfiltration (MF), 12 mgd RO), a 20 mgd reclaimed water distribution system, and approximately 20 mgd of vadose-zone recharge capacity. This is an indirect potable reuse facility. Central Arizona Project (CAP) water is treated by MF, and effluent is treated by MF followed by RO, prior to vadose zone recharge. The recharged water percolates through several hundred feet of soil and will eventually be pumped from recovery wells as part the city's potable supply. Membrane systems, (in conjunction with vadose zone recharge) were selected for this project because they best met the water quality concerns associated with indirect potable reuse.

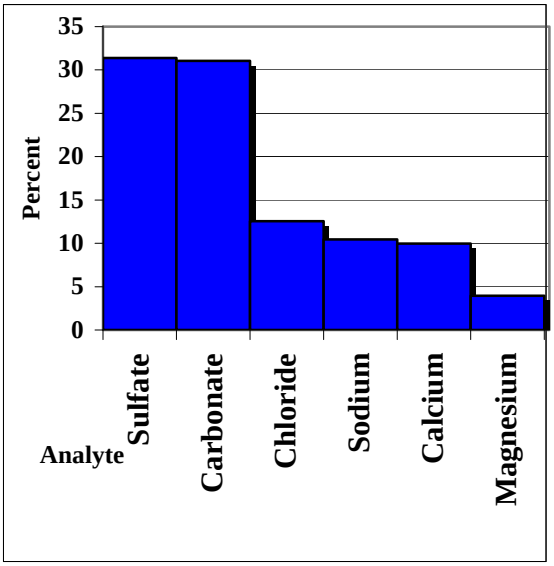
What is Brine?

Brine is often thought of as being concentrated sodium chloride (NaCl); however, this is not necessarily the case, particularly when considering brine streams in the SRV. In general, calcium and magnesium (hardness causing compounds) are very prevalent in the SRV's water supplies. Further, in many valley water sources, carbonate, (and in the case of Colorado River water, sulfate), are more common than chloride. The nature and variety of these salts influence the challenges associated with brine disposal issues. **Figure 1** illustrates this point by showing ion distribution, (as percent), of Central Arizona Project (CAP) water. This imported water source has become a significant component of the SRV's water supply. The ion distribution of CAP water has remained relatively stable since its introduction into the valley.

Sulfate, carbonate, calcium and magnesium comprise 77% of the six most predominant ions found in CAP water, while chloride and sodium constitutes only 23%. Conventional processes, such as lime softening, have historically been used to remove calcium and magnesium, while chloride removal requires membrane systems or evaporative processes. Fortunately, advances in membrane technology, (most notably the introduction of polyamide composites) have provided a common technological solution to both problems.

Figure 1.

CAP WATER ION DISTRIBUTION



Ion distribution in Salt River Project (SRP) water is highly variable due to the various feed sources delivered through the canal system. Further, groundwater quality in the SRV is also inconsistent. These two water sources represent the bulk of the SRV's supply, and

given the variability in their TDS, will present the biggest challenge when selecting the appropriate combinations of technology needed to meet desired water quality goals.

Sources of Brine

Key sources of artificial brine within the SRV include cooling towers, water softeners and RO/NF systems. Each process contributes salt by a different mechanism, and is discussed briefly in the following paragraphs.

Cooling towers concentrate salt as water evaporates, (typically by four or more times). As an example, Scottsdale Arizona's water conservation regulations require a minimum total dissolved solids (TDS) of 2000 mg/L be maintained in cooling tower blow down water. Valley-wide, the water lost through this evaporative process is not recovered, and in most cases the concentrate stream is discharged to the sanitary sewer system. Most commercial buildings utilize cooling towers as part of their HVAC systems, and these systems operate almost year-round; therefore, their impact on TDS is expected to be significant in this desert environment. Cooling towers, and their contribution to the valley's salinity issues, are discussed in a separate paper.

RO and NF systems concentrate salts to varying degrees, depending on membrane chemistry, the size of the unit and its application. NF is similar to RO in that both concentrate salts by physical rejection mechanisms, and both are pressure driven. The key difference is that NF systems typically reject all divalent ions (such as calcium and magnesium) while allowing partial permeation of monovalent ions such as sodium. Brine issues are similar for both.

Systems commonly found in residential use operate at low product recoveries (33% or less); while large commercial, industrial and municipal systems may operate with recoveries as high as 90%. The product from these systems may or may not be lost from a given system. For example, a home RO system will probably cause no great difference in

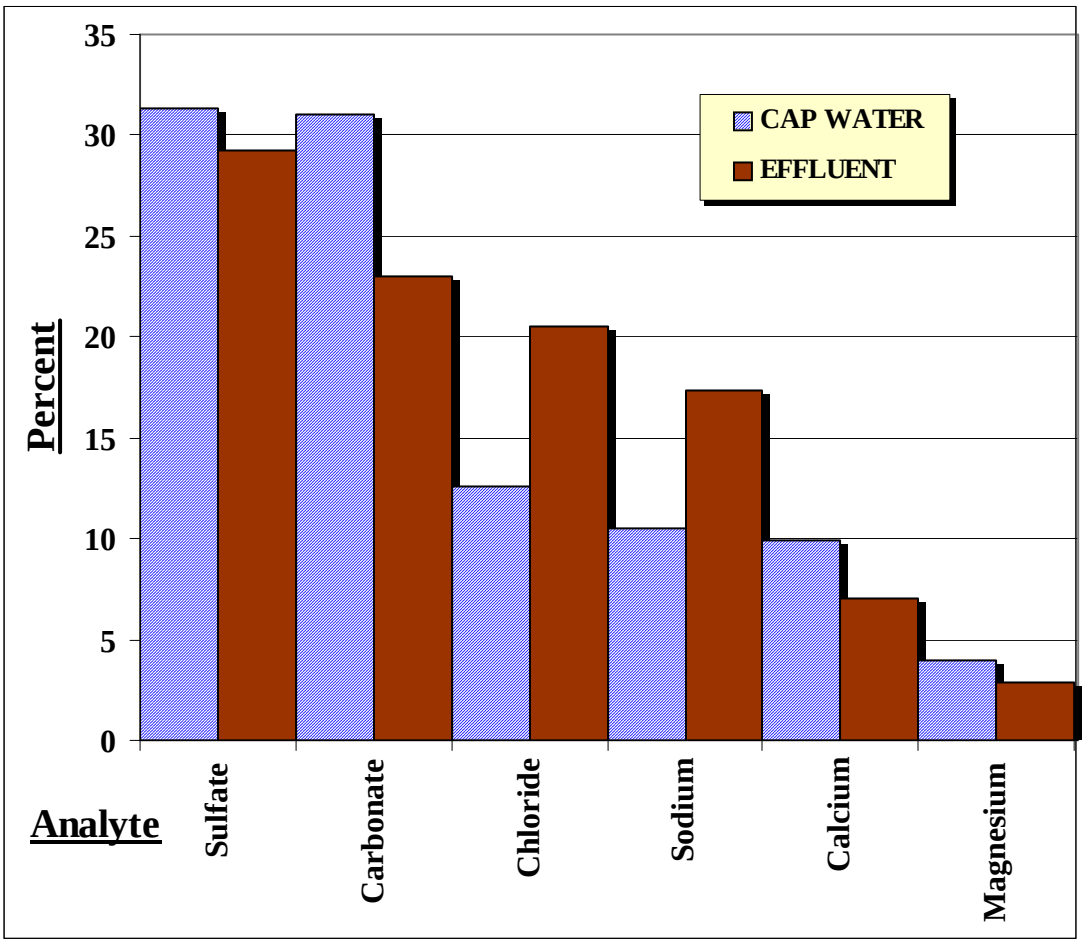
TDS levels discharged to the sewer system when compared to a home with no treatment device, since most of the product water is returned to the sewer system within the home, and no additional salt is added during the process. On the other hand, a large system, such as Scottsdale, Arizona's RO facility (11.9 MGD permeate, 2.1 MGD concentrate during peak production), sends product to one place (the aquifer beneath the facility), while sending brine to another (through the sewer system to the regional water reclamation plant (WRP), and eventually out of the system via stream bed discharge, irrigation, and delivery to a power generating facility). Others, such as the Chandler RO facility, discharge brine to evaporative ponds. This facility treats industrial wastewater for the adjacent Intel® microchip manufacturing facility.

Given an average reclaimed water TDS of 884 mg/l, and product recovery of 85%, a theoretical worst-case TDS of 5900 mg/L would be produced at the WCP.

Water softeners result in a net addition of salt into the SRV environment via the ion-exchange process. Basically, calcium and magnesium are replaced by sodium or potassium. These treatment devices use a saturated (~250,000 mg/L) NaCl or potassium chloride (KCl) solution to regenerate the ion exchange media, and all streams are usually discharged to the collection system. The TDS from these units far exceed that of seawater (~30,000 mg/L). Most water softeners are set up to remove all hardness when installed, and are never adjusted again. Unfortunately, there are no data detailing the amount of salt introduced into the SRV environment by these systems. Estimates are that approximately 110 mg/L of TDS (over background) are contributed by in-home water softeners (Salinity Management Study, Final Report; MWD, USBR; 1999). Because of significant differences in water quality between coastal California and central Arizona, this figure probably understates the impact of water softeners in the SRV. Arizona produces or imports 107,000 metric tons of salt annually (SALT, USGS, 1999) for a variety of uses. The amount of this salt actually used, and subsequently discharged to the sewer system, is not provided in that report.

Figure 2 compares CAP water (the predominant water source in north and central Scottsdale) ion data (shown in **Figure 1**), with reclaimed water treated at the WCP AWT facility, which serves the same area. These data indicate there is a significant increase in sodium and chloride (from 23% to 38%). Overall, TDS in this area increases from approximately 625 mg/L to 884 mg/L between distribution and collection.

Figure 2.



Regulations Governing Brine Disposal

Most brine is discharged to local water bodies, (including sewerage systems), when available. Thirty four percent of RO/NF plants discharged brine to a sewerage system in 2001, up from 23% prior to 1993 (Mickley & Associates; American Membrane

Technology Association; Technology Transfer Workshop; Mesa, Arizona; April 2003). Deep well injection increased from 12 to 15% over the same period, while all other disposal methods (surface water, evaporation ponds, etc.) decreased.

There are no federal regulations governing the discharge of brine streams to a publicly owned treatment works (POTW). Regulations do exist that limit the concentration of specific contaminants discharged to wastewater treatment plants (WWTPs) as part of the pretreatment program required under the National Pollution Discharge Elimination System (NPDES) program.

The Environmental Protection Agency (EPA) has established a secondary, (guidance-only), maximum contaminant limit (MCL) for TDS of 500 mg/L for potable water; however, few water sources within the SRV meet this limit. Additionally, the variability in Salt River TDS (roughly 300 – 1000 mg/L) would make the establishment of regional regulations difficult, and the loss of water required to meet these regulations would be prohibitive in this desert environment.

Federal Underground Injection Control (UIC) regulations provide some control over the sub-surface injection of brines (40 CFR 144); however, these are general in nature due to the variety of geologic conditions existing throughout the country. As a result, considerable flexibility is given to states maintaining primacy over UIC programs.

Local regulations governing brine discharges are limited and vary widely across the United States. One community has established rules banning chloride discharge based on site-specific environmental conditions, while others have actually reduced restrictions on brine discharges. Two examples are provided below which should serve to “book-end” the variability in which communities deal with this issue.

- **Santa Clarita, California** has placed a total ban on the use of all self-regenerating softening systems (Attachment 1) in order to limit the amount of chloride discharged from two reclamation facilities, (the Saugus and Valencia

WWTPs). These facilities discharge into an environmentally sensitive river (the Santa Clara), which is the last natural river in California, as well as home to several endangered species. A study, conducted as part of the regulatory process, attributes 42% of the chloride load to residential use, and of that, 69% from water softeners. These restrictions affect approximately 70,000 people. Other treatment plants in the area, not discharging to this river, have no restrictions on chloride discharge.

- **Tampa Bay Water** has built the largest potable water RO system in the U.S. (as of 2003). The project met the requirements of a significant environmental review, and began operation in 2003. Its feed water will be taken from the cooling tower feed of an adjacent power plant, and the concentrate will be discharged into the cooling tower's discharge line. The combined brine streams will then be returned to Tampa Bay. This approach (locating RO facilities at power plants) is referred to as co-siting, and some of its key advantages are:
    - The use of cooling tower discharge to dilute the concentrate from the RO system,
    - Pre-heated RO feed water significantly reduces the power required to force water through a membrane and,
    - "Inside the fence" power costs significantly reduce operating costs for RO systems.

Florida has a long history of utilizing RO to treat brackish ground water for potable use, and as a result, has significant experience when it comes to dealing with brine disposal. In the early 1990s, most RO and NF plants were failing Whole Effluent Toxicity (WET) tests that were required to be performed on their brine streams, endangering issuance or renewal of discharge permits for these facilities. The state legislature has recently amended state law 403.0882, F.S. (Attachment 2) precluding the use of WET tests as the sole basis for denying discharge permits for RO facilities if the failure is due to "constituents naturally occurring in the source water."

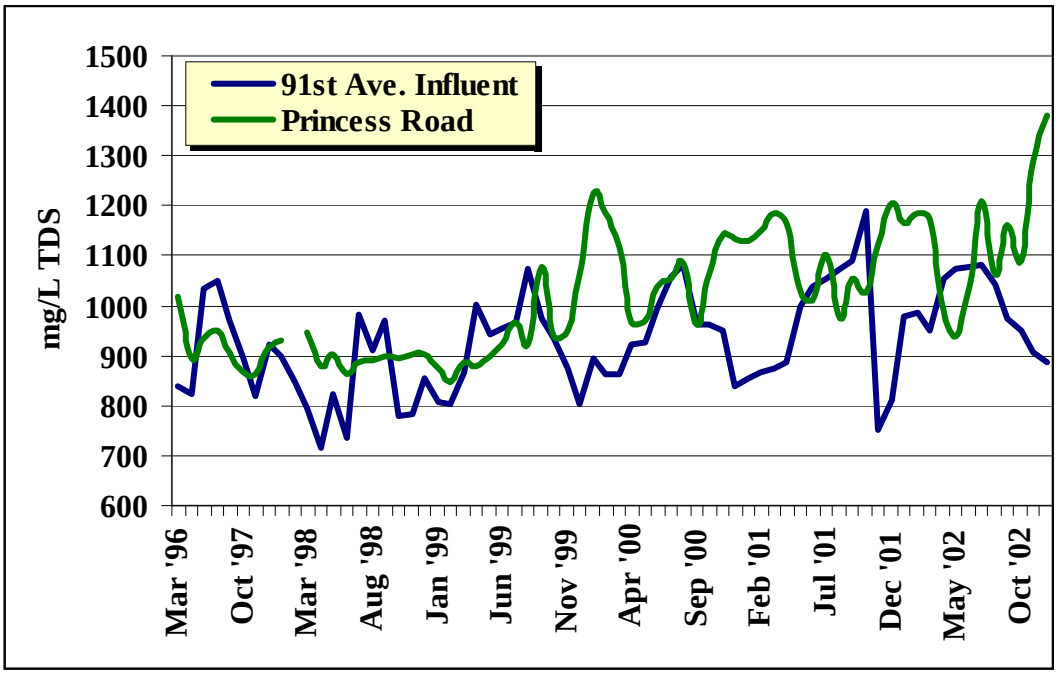
Interestingly, both Texas and California are investigating co-siting for converting brackish coastal waters into potable supplies.

Impact

Most brine streams in the SRV are discharged to a sewer system, and unfortunately, there are no data available documenting actual impacts attributable to these discharges. WWTPs typically rely on biological processes, and the hypothesis has been put forward that increasing salinity may adversely impact the treatment process. In low-lying coastal communities, wide swings in TDS are often experienced at treatment facilities (due to infiltration) as tides rise and fall. WWTPs treating these waters consistently meet compliance requirements. There are exceptions to this. Plants experiencing extreme infiltration episodes have reported problems with the settling characteristics of the biomass. It is safe to assume that given sufficient volumes and concentrations, brine discharges would adversely impact treatment facilities and other downstream users.

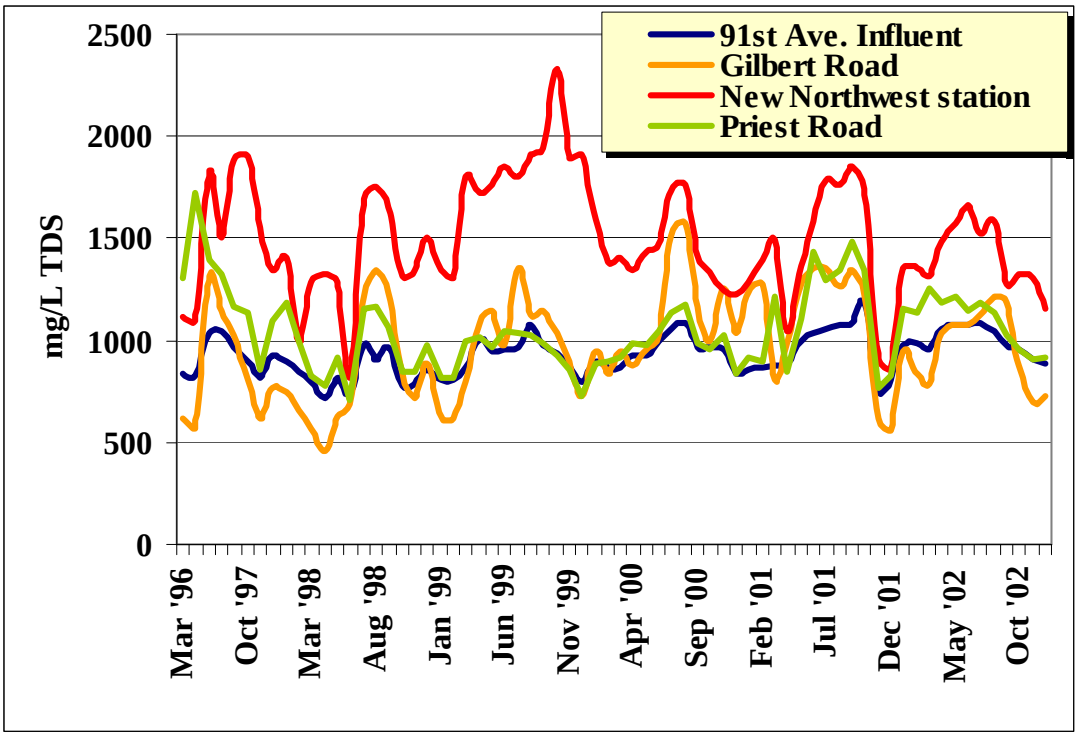
When evaluating the impact of brine streams on WWTPs in the SRV, a particularly difficult challenge comes into play due to the drought cycles routinely experienced in this area. Drought cycles cause wide background swings in TDS concentrations at local water and wastewater facilities. When rainfall is plentiful, TDS is diluted and it appears that there are no salinity issues in the SRV. When drought returns, TDS again increases. **Figure 3** compares the TDS at the Princess Road metering station (which includes WCP brine beginning in the fall of 1999) with the 91st Ave. WWTP influent. Wintertime TDS increases at Princess Road can be clearly seen once brine production begins at the WCP; however, there is no correlation between brine production at the WCP and TDS at the 91st Ave. WRP. Recognizing that the WCP sends most of its reclaimed water to irrigation during warmer months, and treats effluent through the AWT prior to recharge during colder months, this pattern of higher wintertime Princess Road TDS is to be expected.
A correlation with 91st Ave. WWTP TDS is seen at three other sampling sites (Gilbert Road, Priest Road, and New Northwest station), as shown in **Figure 4**.

Figure 3.



Source Data – SROG database

Figure 4.



Source Data – SROG database

Increasing TDS contributions, coupled with drought conditions, could eventually cause impacts to treatment facilities. These impacts could range from increased operations and maintenance costs, to non-compliance issues attributable to the presence of specific contaminants. Unfortunately, there is no real data available to make that determination at this time. The impact of TDS on wastewater treatment facilities is discussed further in a separate paper.

Treatment and Disposal

Treatment and disposal costs of brine streams are important considerations when evaluating the use of advanced technologies for large-scale water purification, as well as advanced water reclamation. The significance of these costs is primarily a function of the value of water in a particular region. Generally, brine disposal methods, and issues, tend to be geographically segregated, and are highlighted in the following paragraphs:

> In coastal areas, brine is usually discharged to local brackish waters or piped out into the ocean. Issues that arise when discharging brine streams to brackish waters center around the impact on young marine species, which use these protected areas as nurseries. With ocean discharges, there have been some concerns raised regarding the development of salt gradients along the ocean floor, and whether or not these gradients result in impacts upon bottom dwelling species. Regardless of these concerns, facilities disposing of brine via these methods routinely meet regulatory requirements and receive discharge permits.
>
> Inland brine disposal methods consist of deep well injection, evaporation in solar ponds, and crystallization using traditional brine concentrators. All are expensive, waste valuable water, and face significant regulatory restrictions.

Technologies for Brine Management

Many of today's technologies and management strategies are impediments to the widespread implementation of membrane technologies. Brine disposal methods, in the absence of direct discharge, are expensive. Fortunately, alternate technologies, and approaches, are being explored to address concentrate disposal issues. Among these are:

- Salt-gradient ponds,
- Newer generations of brine concentrators that are more energy efficient,
- Membrane processes which have improved significantly over the last several years,
- Irrigation practices that move high TDS waters through fields of multiple crops, with each subsequent crop species being more salt tolerant than its predecessor and,
- Co-siting membrane facilities with power plants to minimize power costs.

Selecting the appropriate combination of technologies and management practices will afford cost-effective solutions to the long-term salinity issues this region faces.

Future Brine Generation

Brine production will probably increase in the SRV; however, the rate at which this occurs is undefined at this time. Current estimates are that the use of RO and NF systems are increasing by 15-18% per year nationally, with many of these facilities treating brackish coastal waters. As population increases, the use of cooling towers and water softeners will also increase. Further, as finite water resources are spread across an ever-increasing demand base, and water quality regulations become more stringent; an increasing number of municipalities and private interests will turn to reliable, high-recovery treatment processes to meet their water resource needs. This is particularly true in the west valley, where ground water tends to be much higher in TDS than ground water in the east valley.

Summary

The generation of brine will, in all probability, increase in the SRV, particularly as population growth requires the utilization of poor quality waters in the southwest valley. More data is needed to determine the amount of brine that will be generated, the impact this will have upon the environment, and the best combination of technologies and management strategies that should be utilized to cost effectively address these issues. Fortunately, technological improvements and innovative planning strategies are providing a greater range of opportunities for managing this long-term SRV issue.

References and Relevant Literature

1999 Salinity Management Study, Final Report, Bookman-Edmonston Engineering, Inc., For the Municipal Water District of Southern California and the Bureau of Reclamation.

D. Kostik, Salt, U.S. Geological Survey Minerals Yearbook-1999

Technical Memorandum B.5, Applicable Rules and Regulations for Concentrate Management: Reiss Environmental, Inc., November 2001

State of Florida, Florida Statutes, Chapter 2001-188

H. Day, Phoenix Salinity Presentation, Presented at various forums

Desalination and Water Purification Research and Development Program Report No. 69, Membrane Concentrate Disposal: Practices and Regulation; Mickley and Associates, for the U.S. Department of Interior, Bureau of Reclamation, Technical Services Center, Water Treatment and Engineering Group.

Mickley & Associates; American Membrane Technology Association; Technology Transfer Workshop; Mesa, Arizona; April 2003

Wastewater Reuse for Golf Course Irrigation, The U.S. Golf Association

Reverse Osmosis and Nanofiltration, AWWA Manual of Water Supply Practices M46

Major Ion Toxicity in Membrane Concentrate; American Water Works Research Foundation

W. Vernon, The Application of Membrane Systems in Scottsdale Arizona, 2003 American Water Works Membrane Technology Conference, Atlanta, Georgia.

Current Management of Membrane Plant Concentrate; American Water Works Research Foundation

Sub Regional Operating Group (SROG) Database

ATTACHMENT 1

August 28, 2002

Notification of the Continued Prohibition on Brine Discharges from Self-Regenerating Water Softeners and the Imposition of New Chloride Discharge Requirements at Santa Clarita Valley Businesses

This letter is being sent to all businesses in the Santa Clarita Valley as a reminder that it is illegal to discharge salt waste from water softening or conditioning appliances, such as self-regenerating water softeners, to the sewer. If your business has a water softener or conditioning appliance that regenerates on-site, any discharge of concentrated salt waste, also called brine, must be discontinued immediately. As background, the Sanitation Districts of Los Angeles County (Districts) are a confederation of special districts serving the wastewater and solid waste management needs of over five million people in Los Angeles County. The Districts operate eleven wastewater treatment plants, including two water reclamation plants in the Santa Clarita Valley. The two water reclamation plants (the Saugus and Valencia Water Reclamation Plants) discharge tertiary-treated wastewater to the Santa Clara River. While the extensive treatment processes at the water reclamation plants provide a high-quality reclaimed water, they do not remove salt from wastewater. Salt passes through the plants into the river and, if present at high levels, could harm wildlife and interfere with downstream beneficial uses such as agriculture. In the Santa Clarita Valley, the component of salt that is of most concern is chloride. Chloride is best known as one of the two main parts of table and rock salt (sodium chloride).

The Los Angeles Regional Water Quality Control Board (Regional Board), a state regulatory agency, has proposed to further restrict the amount of chloride that can safely be discharged to the Santa Clara River. The Regional Board has announced that it will soon be adopting a water quality plan for the river that will result in the imposition of very stringent chloride limits on discharges from the Saugus and Valencia Water Reclamation Plants. To date the Districts are not in agreement with the Regional Board's proposed permit requirements, but have been actively participating in the process for adopting the water quality plan and providing information to the Regional Board to hopefully ensure that the final chloride limits are reasonable and based on sound science. Because the Saugus and Valencia Water Reclamation Plants do not remove chloride, it will be necessary for all Santa Clarita-area businesses to do their part to reduce the amount of chloride entering sewers, in addition to complying with the prohibition on the discharge of brine wastes. To this end, the Districts are actively investigating potential sources of chloride discharged into the sewerage system and regulating them to the extent feasible. **If source reduction is not successful, the alternative in light of the Regional Board's proposed action is to install very costly treatment processes at the Saugus and Valencia Water Reclamation Plants, which unfortunately would mean that sewer bills for Santa Clarita Valley businesses and residences would increase by four to five times over the current rate.** One significant source of chloride in sewers is self-regenerating water softeners, to which rock salt is added at the point of use on a regular basis for the purpose of resin regeneration. When water softeners regenerate, they produce a waste stream that contains significant amounts of chloride. In Santa Clarita, virtually all of the chloride that is added to a self-regenerating water softener as salt eventually ends up in the Santa Clara River. To protect the quality of the Santa Clara River, the discharge of brine to the sewer from softeners at businesses has been prohibited in Santa Clarita since 1961. Through on-site inspections, the Districts have found that self-regenerating water softeners have been illegally installed at several commercial businesses in the Santa Clarita Valley, and, due to the impending regulations of chloride discharges, we are taking actions to ensure that the prohibition is being strictly observed by all businesses. If your business is currently operating a self-regenerating water softener or other water conditioning system that generates a brine waste, you must immediately stop discharging brines from the unit and adopt an alternative brine disposal method. This prohibition applies regardless of whether you add the salt to a water-softening unit yourself or if you employ water conditioning service provider to add salt to a softener. The prohibition also applies to any business that uses a point-of-use treatment system, such as a reverse osmosis system, that generates a brine waste. Note that it is also

illegal to discharge brines into gutters or storm drains, as these structures flow directly to the Santa Clara River without treatment. If soft water is necessary for your business, you may use water softening exchange tanks that are regenerated off-site at a facility that is permitted to accept salt discharges. There are local businesses that offer exchange tank services. Another option is to collect the brine waste and arrange for a service to properly dispose of it. Please be advised that representatives of the Districts' Industrial Waste Section are visiting businesses in the Santa Clarita Valley to make sure the prohibition on the discharge of brine wastes is being followed. In addition to water softener brines, your business may generate other types of chloride waste that is sewered. The Districts are currently conducting a study to identify practices that can reduce sources of chloride-containing wastewater at commercial businesses in Santa Clarita to the extent that is economically and technically feasible. The Districts, along with their representatives, will be performing inspections of local businesses over the next several months as part of this study. Based on the study results, the Districts will be developing a set of available best management practices and requiring Santa Clarita-area businesses to adopt those that are economically and technologically feasible to reduce the discharge of chlorides. You will be notified by mail of any new requirements imposed on your business.

The Districts are firmly committed to continuing to provide an environmentally sound and low cost sewerage service to the residents and businesses in the Santa Clarita Valley. However, as set forth above, this goal is threatened by the action proposed by the Regional Board to unreasonably limit the discharge of chloride to the Santa Clara River. The Districts believe that the environmental integrity of the river and its beneficial uses can be protected without resorting to the extremely restrictive discharge limitations being proposed by the Regional Board.

The Districts appreciate your cooperation in minimizing your company's chloride discharges to the sewer and thus helping to significantly reduce chloride discharges to the Santa Clara River without the addition of extraordinarily expensive treatment processes at the Districts' facilities. For more information on chloride and water quality, please visit the following web-site: www.santaclarita.com/cityhall/pbs/environment/chlorides.htm. If you have any questions about the requirements outlined in this letter, contact Dave Whipple of the Districts' Industrial Waste Section at 562/699-7411, extension 2909.

Very truly yours,
James F. Stahl

Paul C. Martyn
Head, Industrial Waste Section

PCM:dfd
PC Docs: 147048

ATTACHMENT 2

CHAPTER 2001-188
Senate Bill No. 536
An act relating to demineralization concentrate; amending s. 403.0882, F.S.; reorganizing and clarifying the section; directing the Department of Environmental Protection to enter into rulemaking; creating a technical advisory committee to assist in rule development; providing permitting requirements relating to failure of toxicity tests due to naturally occurring constituents; amending s. 403.061, F.S.; providing an exemption allowing demineralization concentrate mixing zones in Outstanding Florida Waters with specific requirements; providing an effective date.
Be It Enacted by the Legislature of the State of Florida:
Section 1. Section 403.0882, Florida Statutes, is amended to read:
(Substantial rewording of section. See s. 403.0882, F.S., for present text.)
403.0882 Discharge of demineralization concentrate.—
(1) The Legislature finds and declares that it is in the public interest to conserve and protect water resources, provide adequate water supplies and provide for natural systems, and promote brackish water demineralization as an alternative to withdrawals of freshwater ground water and surface water by removing institutional barriers to demineralization and through research, including demonstration projects, to advance water and water byproduct treatment technology, sound waste byproduct disposal methods, and regional solutions to water resources issues. In order to promote the state objective of alternative water supply development, including the use of demineralization technologies, and to encourage the conservation and protection of the state's natural resources, the concentrate resulting from demineralization must be classified as potable water byproduct regardless of flow quantity and must be appropriately treated and discharged or reused.
(2) For the purposes of this section, the term:
(a) "Demineralization concentrate" means the concentrated byproduct water, brine, or reject water produced by ion exchange or membrane separation technologies such as reverse osmosis, membrane softening, ultrafiltration, membrane filtration, electrodialysis, and electrodialysis reversal used for desalination, softening, or reducing total dissolved solids during water treatment for public water supply purposes.
(b) "Small water utility business" means any facility that distributes potable water to two or more customers with a concentrate discharge of less than 50,000 gallons per day.
(3) The department shall initiate rulemaking no later than October 1, 2001, to address facilities that discharge demineralization concen-
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CODING: Words stricken are deletions; words underlined are additions.
trate. The department shall convene a technical advisory committee to assist in the development of the rules, which committee shall include one representative each from the demineralization industry, local government, water and wastewater utilities, the engineering profession, business, and environmental organizations. The technical advisory committee shall also include one member representing the five water management districts and one representative from the Florida Marine Research Institute. In convening the technical advisory committee, consideration must be given to geographical balance. The rules must address, at a minimum:

(a) Permit application forms for concentrate disposal;
(b) Specific options and requirements for demineralization concentrate disposal, including a standardized list of effluent and monitoring parameters, which may be adjusted or expanded by the department as necessary to protect water quality;
(c) Specific requirements and accepted methods for evaluating mixing of effluent in receiving waters; and
(d) Specific toxicity provisions.
(4)(a) For facilities that discharge demineralization concentrate, the failure of whole effluent toxicity tests predominantly due to the presence of constituents naturally occurring in the source water, limited to calcium, potassium, sodium, magnesium, chloride, bromide, and other constituents designated by the department, may not be the basis for denial of a permit, denial of a permit renewal, revocation of a permit, or other enforcement action by the department as long as the volume of water necessary to achieve water quality standards is available within a distance not in excess of two times the natural water depth at the point of discharge under all flow conditions.
(b) If failure of whole effluent toxicity tests is due predominately to the presence of the naturally occurring constituents identified in paragraph (a), the department shall issue a permit for the demineralization concentrate discharge if:
1. The volume of water necessary to achieve water quality standards is available within a distance not in excess of two times the natural water depth at the point of discharge under all flow conditions; and
2. All other permitting requirements are met.
A variance for toxicity under the circumstance described in this paragraph is not required.
(c) Facilities that fail to meet the requirements of this subsection may be permitted in accordance with department rule, including all applicable moderating provisions such as variances, exemptions, and mixing zones.
(5) Blending of demineralization concentrate with reclaimed water shall be allowed in accordance with the department's reuse rules.

(6) This subsection applies only to small water utility businesses.
(a) The discharge of demineralization concentrate from small water utility businesses is presumed to be allowable and permittable in all waters in the state if:
1. The discharge meets the effluent limitations in s. 403.086(4), except that high level disinfection is not required unless the presence of fecal coliforms in the source water will result in the discharge not meeting applicable water quality standards;
2. The discharge of demineralization concentrate achieves a minimum of 4-to-1 dilution within a distance not in excess of two times the natural water depth at the point of discharge under all flow conditions; and
3. The point of discharge is located at a reasonably accessible point that minimizes water quality impacts to the greatest extent possible.
(b) The presumption in paragraph (a) may be overcome only by a demonstration that one or more of the following conditions is present:
1. The discharge will be made directly into an Outstanding Florida Water, except as provided in chapter 90-262, Laws of Florida;
2. The discharge will be made directly to Class I or Class II waters;
3. The discharge will be made to a water body having a total maximum daily load established by the department and the discharge will cause or

contribute to a violation of the established load;
4. The discharge fails to meet the requirements of the antidegradation policy contained in the department rules;
5. The discharge will be made to a sole-source aquifer;
6. The discharge fails to meet applicable surface water and groundwater quality standards; or
7. The results of any toxicity test performed by the applicant under paragraph (d) or by the department indicate that the discharge does not meet toxicity requirements at the boundary of the mixing zone under subparagraph (a)2.
(c) If one or more of the conditions in paragraph (b) has been demonstrated, the department may:
1. Require more stringent effluent limitations;
2. Require relocation of the discharge point or a change in the method of discharge;
3. Limit the duration or volume of the discharge; or
4. Prohibit the discharge if there is no alternative that meets the conditions of subparagraphs 1.-3.

(d) For facilities owned by small water utility businesses, the department may not:
1. Require those businesses to perform toxicity testing at other than the time of permit application, permit renewal, or any requested permit modification, unless the initial toxicity test or any subsequent toxicity test performed by the department does not meet toxicity requirements.
2. Require those businesses to obtain a water-quality-based effluent limitation determination.
(7) The department may adopt additional rules for the regulation of demineralization and to administer this section and s. 403.061(11)(b).
Section 2. Paragraph (b) of subsection (11) of section 403.061, Florida Statutes, is amended to read:
403.061 Department; powers and duties.—The department shall have the power and the duty to control and prohibit pollution of air and water in accordance with the law and rules adopted and promulgated by it and, for this purpose, to:
(11) Establish ambient air quality and water quality standards for the state as a whole or for any part thereof, and also standards for the abatement of excessive and unnecessary noise. The department is authorized to establish reasonable zones of mixing for discharges into waters.
(b) No mixing zone for point source discharges shall be permitted in Outstanding Florida Waters except for:
1. Sources that which have received permits from the department prior to April 1, 1982, or the date of designation, whichever is later;
2. Blowdown from new power plants certified pursuant to the Florida Electrical Power Plant Siting Act; and
3. Discharges of water necessary for water management purposes which have been approved by the governing board of a water management district and, if required by law, by the secretary; and.
4. The discharge of demineralization concentrate which has been determined permittable under 403.0882 and which meets the specific provisions of s. 403.0882(4)(a) and (b), if the proposed discharge is clearly in the public interest.
Nothing in this act shall be construed to invalidate any existing department rule relating to mixing zones. The department shall cooperate with the

Department of Highway Safety and Motor Vehicles in the development of regulations required by s. 316.272(1).
Section 3. This act shall take effect upon becoming a law.
Approved by the Governor June 8, 2001.
Filed in Office Secretary of State June 8, 2001.
Ch. 2001-188 LAWS OF FLORIDA Ch. 2001-188
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CENTRAL ARIZONA SALINITY STUDY ---- Phase I

Technical Appendix O

Municipal TDS Research

Introduction

Water availability and quality are among the world's most important environmental issues. Demand for water is increasing at an alarming rate and so are people's water quality expectations. High quality, readily available, and safe water, is essential to our quality of life. One aspect of water quality is salinity. Arizona municipalities are actively participating in studies and research to evaluate salinity in the water and wastewater. This paper will discuss the projects related to salinity or total dissolved solids (TDS) that are currently being examined by the City of Phoenix and others.

Total Dissolved Solids

TDS is considered an emerging contaminant. Although salinity has been a problem in agriculture for years, within the past 5-10 years municipalities have begun the address this issue. Municipalities across the country, particularly in the southwest, are actively researching salinity issues. Salinity or TDS is defined as the sum of dissolved solids in the water. The main constituents that make up dissolved solids include: calcium, sodium, sulfate, magnesium, chloride, and potassium.

Source Water

The City of Phoenix source water supply consists of water from the Salt River, Colorado River, Verde River, and groundwater wells. Each of these sources has a different water quality, including TDS concentrations. Colorado River water is diverted to central Arizona through a 336-mile long system of aqueducts, tunnels, pumping plants and pipelines known as the Central Arizona Project (CAP). **Figure 1** shows the TDS concentrations in the Salt River, CAP, and Verde River from January 2000 to January 2003. The TDS concentration in the water supply varies with the weather. During drought years, the levels of lakes and rivers decline due to evaporation. As the water is evaporated away, salts and impurities are left behind. This results in a direct relationship between low flow years and high salinity. **Figure 2** is a graph of the Lake Roosevelt water storage in acre-feet from 1990 through 2003. The Salt River TDS concentration is plotted along the right side of the graph. As the water storage in the reservoir decreases, the TDS in the Salt River increases. There is also a direct relationship between TDS levels in source water and drinking water because there is no reduction of TDS in a conventional water treatment plant using coagulation, sedimentation, and filtration processes. Therefore, the TDS in the source water is approximately equal to the TDS in the water distribution system.

Wastewater

Source water, irrigation runoff, residential and commercial sources, and industrial discharges all contribute to the TDS concentration entering the wastewater treatment plants. The concentration of TDS entering the wastewater treatment plant is somewhat

proportional to the concentration of TDS in the water treatment plant. **Figure 3** shows the breakdown of the 1.83 Million pounds of TDS per day that are entering the 91st Avenue Wastewater Treatment Plant (WWTP). The source water is the largest contributor of TDS to the wastewater plants. Approximately 73 percent of the TDS entering the wastewater plant is a result of source water. The correlation can be seen on the graph in **Figure 4** where the Arizona Canal Water Treatment Plants (WTPs) are plotted against the 91st Avenue WWTP. The increase in TDS between the two lines is due to the salt load added from industrial, residential, commercial, and irrigation sources. The addition is also due to water conservation and concentration of salts in the system.

Residential/Commercial

Residential and commercial sources include water softeners, sanitary waste, food waste, and cooling towers. Water softeners in homes use an ion exchange system to reduce the hardness of water. Hard water, like the water supply in the southwest, contains a high concentration of calcium and magnesium. Water softening systems replace the calcium and magnesium ions with sodium ions. Water softening units require salt addition for the ion exchange to take place. The salts from the ion exchange process are normally discharged to the sewer system, thus increasing the concentration of TDS in the wastewater. Food waste also increases the TDS load in the system. Garbage disposals and discarding of liquid waste down the drain elevate concentrations. Many commercial facilities use cooling towers as an effective method to cool air in the hot months in Phoenix. A study performed by the Phoenix water conservation department concluded that 15 percent of all water produced goes to cooling towers. These units use water cycled through the system to cool the air through the process of evaporation. The water is discharged to the sewer system when the salt concentration gets too high and starts impacting the cooling process. Standard practice calls for concentrating brine 3 to 5 times before discharging to the sewer. Currently there are no regulations on brine discharge from cooling towers into the sewer system.

Industrial

Industries also have an impact on the concentration of TDS in the wastewater. Many industries require highly purified water, and must provide expensive pretreatment to remove dissolved solids before they can use the water. The concentrated brine that results from this pretreatment is frequently discharged back into the sanitary sewer system. This increases the salt load to the wastewater treatment or water reclamation plants. Membrane usage for industry needs is expected to increase as technology improves and the cost of the membrane technology decreases. This increase in membrane usage is going to result in an additional TDS load to the sanitary sewer system.

Membrane Technology

As communities are searching for additional water sources, many coastal cities are turning to the ocean to supplement their water supply. Membrane technologies have made it possible to transform ocean water into drinking water. The concern is “What to do with the brine?” In 1992 there were 133 desalting plants in the United States. This number has increased to 203 in 1999 and many more plants are in the development stages. Brine disposal is one of the critical issues that must be solved before a desalting

plant can be put into operation. The US Bureau of Reclamation conducted a survey of brine disposal practices and reported that 45 percent of brine waste is discharged to surface water or the ocean. Because many cities are landlocked, like Phoenix, discharge to sewer accounts for 42 percent of all disposal methods. Deep well injection, evaporation ponds, and spray irrigation are 9 percent, 2 percent, and 2 percent, respectively.

Impacts

There are many impacts to society associated with the increase of TDS in the water system. The EPA has established "secondary maximum contaminant levels" or "SMCLs" as guidelines to assist public water systems in managing their drinking water for aesthetic considerations, such as taste, color, and odor. The SMCL for TDS is 500 mg/l. Dissolved solids are not considered a risk to human health at the SMCL. The EPA believes that the presence of these contaminants above the SMCL may cause the water to appear cloudy or colored, or to taste or smell bad. This may cause people to stop using water from their public water system even though the water is actually safe to drink. Drinking water high in TDS has a salty and unpleasant taste. The EPA has identified a concentration of 250 mg/l, above which sodium can be expected to impart a "salt" taste to drinking water. In addition to the objectionable taste, there are also possible adverse health effects associated with high TDS drinking water. Individuals on restricted or low sodium diets or pregnant women suffering from toxemia may be affected by high sodium concentrations in the drinking water system.

The impact of elevated salinity on irrigated agriculture land is profound. In the U.S., 14 million acres of land (25% of the total) have been adversely impacted by the build up of salinity in soils and underlying groundwater. Worldwide, 190 million acres have been either taken out of production or have reduced crop yields associated with excess salinity. There is an annual worldwide increase in impacted irrigated land of 2.5 to 5 million acres.

Some plants and crops are very sensitive to high concentrations of salt. Research conducted on fruit crops, such as grapefruit, orange, and lemon reveals that these crops show signs of lower yields when irrigated with water that has TDS values above 1,000 mg/l. Strawberries are among the most sensitive crop with salinity tolerance levels of 650 mg/l. Source water supplies above these concentrations will impact agricultural crops. Additionally, reclaimed water is often used to irrigate crops. Reclaimed water typically has a higher TDS than source water, many times as much as 300 to 400 mg/l greater than source water. This high TDS water could negatively impact the growth and yield of certain crops.

Groundwater is also impacted by high salinity in surface water and reuse water. Farming practices such as fertilizing and irrigation impact the groundwater. Irrigation runoff consists mainly of fertilizers and pesticides. Most fertilizers are forms of salts. Therefore, crops fertilized and irrigated produce a runoff that is high in TDS. This is due in part to the fertilizer used and partly due to the evaporation of the water. Transpiration from plants and evaporation from soils return essentially distilled water to the

atmosphere, leaving the salts behind in the root zone. Over time, these salts accumulate in the root zone and could cause the plant to become yellow and stunted or even die. To keep this from happening, additional water is applied to flush the salts out of the root zone. Typically, an additional 5 to 20 percent above the requirement for plant growth is applied. Once this water has percolated through the root zone, it goes on to the underlying groundwater. This deep percolation water also carries all the salts that were in the root zone, the salt in the irrigation water, and the residues of fertilizers and pesticides. This practice of "over watering" to remove salts from the root zone is common among farmers, but not so common with groundskeepers, homeowners, parks departments, etc. Areas with heavy agriculture have higher concentrations due to the practice of deep percolation or flushing salts through the root zone into the groundwater. Since some of the drinking water source water comes from groundwater, the concentrating cycle of salts continues.

Industrial facilities are also impacted by high TDS water. If the potable water they receive is high in TDS, they must spend additional money and resources to "condition" the water prior to use. Many times this conditioning requires membranes such as reverse osmosis units. In the future, wastewater regulations for industries may be in place. These regulations could limit the amount of TDS they can dispose to the sewer. The industry will have to pay for pretreatment devices to treat the water prior to discharge. In addition, surcharges could be imposed for those industries that exceed the limits.

Economics

The economic impacts of increased salinity include corrosion of infrastructure and fixtures, increased treatment costs, on-site pretreatment for industrial use, reduction of reuse alternatives, and an increase by a concerned public in point-of-use devices such as home water treatment systems. In Southern California urban areas, the USBR/MWD salinity management study estimated $100 million dollars per year in damages, and concluded than an additional $100 million in damages per year will occur with each 100 mg/l increase in TDS. In the Colorado River Basin estimated damages per year exceed $330 million dollars.

Research

Research is currently taking place to address regional salinity issues. Watershed studies and source water management plans are underway to monitor TDS in the system. Source control efforts to use water supplies that are low in TDS may be one way to lower the TDS in both the drinking water and wastewater systems. The removal of TDS at water treatment or wastewater treatment plants using reverse osmosis (RO) or membrane filtration technology is another option. Research to increase concentration of brine from RO or membrane facilities will result in higher water recovery. However, this will also produce higher concentrated reject brine that must be disposed. Brine disposal options such as solar ponds, brine pipelines to the ocean, and evaporation ponds are currently being evaluated.

The City of Phoenix has many projects underway to study salinity and brine disposal. In 2002 a study was initiated with Arizona State University to study the Palo Verde Nuclear

Generating Station (NGS) evaporation ponds. For the past 20 years, the Palo Verde generating station has purchased effluent from the 91st Avenue WWTP to use for cooling water. Approximately 64,000 acre/ft a year is delivered to the Palo Verde NGS via a 35-mile pipeline. The wastewater is treated further on-site for use in the cooling towers adjacent to the nuclear generators. Continuous blowout and replacement of solution is required to properly maintain total TDS concentration at approximately 30 times the initial concentration. The blowout from the cooling towers is discharged into two, 250-acre storage ponds located on-site where evaporation is the main mechanism for disposal. Unless the structural integrity of the lining underlying the ponds has been compromised, the entire mass of solutes should remain within the confines of the ponds. The ponds have been in continuous use for over 15 years. The study will characterize the water in the ponds. The concentration of brine in the ponds will be evaluated. If there is a high concentration of brine in the pond, it is possible that natural density stratification has occurred. This would create a solar pond condition in which energy could be recovered from the lower level of the pond. The residuals in the bottom of the pond will be studied. As the residuals become more concentrated due to evaporation of the water from the pond, there could be a potential for a concentration of contaminants. The use of solar ponds as a viable method for brine disposal will be evaluated.

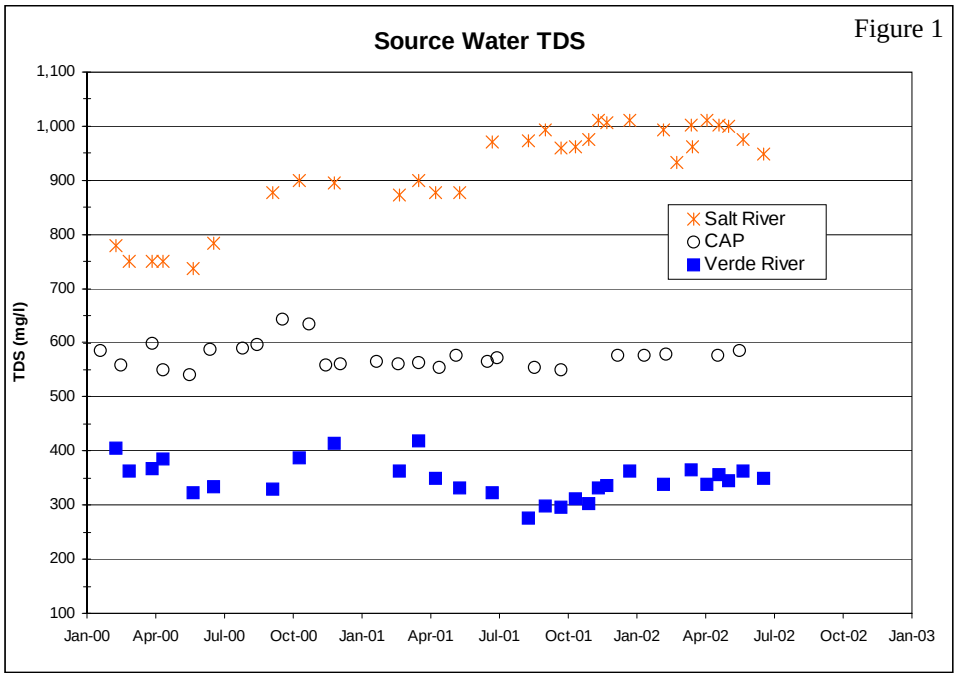
The City of Phoenix is taking part in an AWWARF multi-city study. Five cities were selected to participate in case studies to evaluate TDS contributions from urban residential sources. Phoenix, El Paso, Irvine Ranch, Monterey, and Santa Clara will use water flow meters and in line devices to evaluate common household products and practices, and their impact on the sewer system.

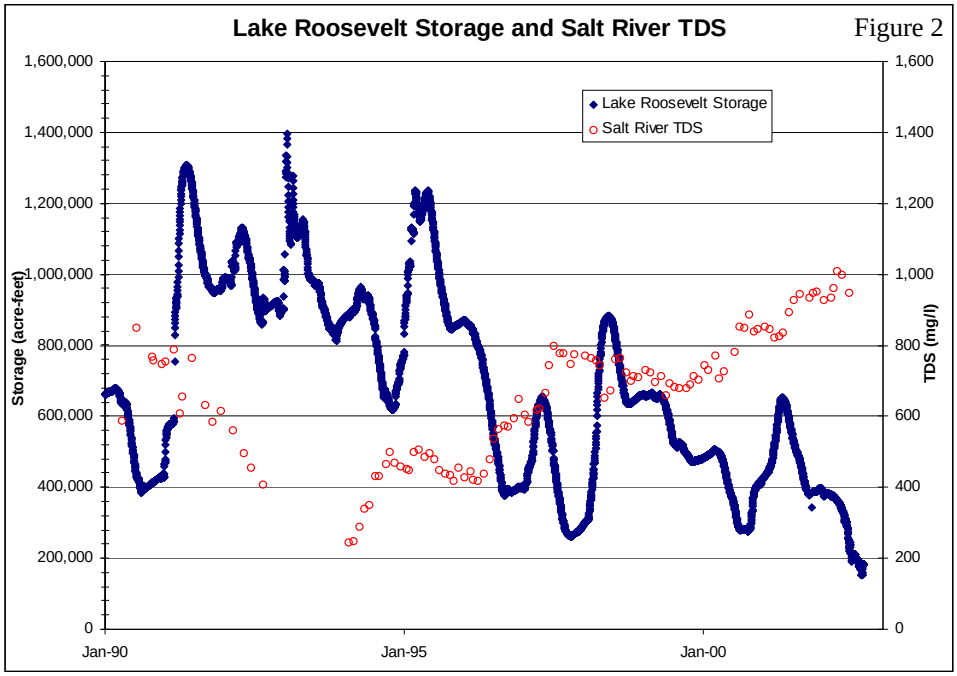
The 23rd Avenue WWTP was selected as a test site for an enhanced water recovery membrane pilot project. The project will evaluate a reverse osmosis (RO) treatment facility as a method to improve the quality of treated effluent for reuse. The membrane effluent will be blended with effluent from the plant. Quantities and concentrations will be studied to determine the most cost effective mix for reuse. Another potential goal of the study will be to evaluate enhanced water recovery systems. RO systems recover approximately 80 to 85 percent of the effluent resulting in a brine reject of 15 to 20 percent. The dewvaporation system was developed at Arizona State University as a low cost method of further concentrating brine. The dewvaporation system will further concentrate the 15 to 20 percent of brine reject from the RO system by utilizing a continuous contact tower that uses evaporation and dew formation to separate water from brine. The dewvaporation system will be operated in series with the membrane system to increase water recovery. Of the liquids entering the dewvaporation system, 99 percent will result in effluent and 1 percent will be brine reject. The potential for industrial and/or commercial applications for the dewvaporation system will be evaluated.

In February 2003, the City of Phoenix initiated a contract with a consulting company to inventory cooling towers in the valley. Cooling towers concentrate salinity in the feed water and discharge it when the salinity reaches a specified level. It is estimated that industries use upward of 30% of their water for cooling. The purpose of the study is to take an inventory of cooling towers and assess the volume and salt content of discharges

sent to the City of Phoenix wastewater treatment plants. The study will focus on all cooling towers greater than 250 tons and then use this data to estimate the impact from the smaller tonnage towers. The quantity and concentration of TDS discharged from cooling towers is unknown. This project will quantify both the number of cooling towers as well as the amount of TDS discharged to the sewer from this source.

Salinity build-up and assured water supplies are readily becoming an issue of concern. Consumers, industries, and the environment are adversely impacted by higher salinity concentrations. Treatment alternatives to reduce salinity focus on source waters, industries, and domestic inputs, such as softeners and treatment systems. Although progress has been made to identify the problem, the solution is still unknown. There are many research opportunities available in the areas of source water management, membrane filtration technologies, and brine disposal options. Overall, salinity will continue to be a growing issue that impacts sustainable water supply sources. There are many organizations that have been formed to research and evaluate the impacts of salinity on our water resources. The Central Arizona Salinity Study (CASS) is a project funded by municipalities in Arizona to evaluate the impacts of salinity on the watershed. The multi-state salinity coalition consists of 4 states that have joined together to evaluate desalinization and membrane options for the removal and disposal of TDS from water supplies. The USBR and Sandia Laboratories have teamed up to develop a salinity research roadmap. This research and resulting advancements will minimize the impact of TDS on water supplies in the future.


Source Water TDS
Figure 1
TDS (mg/l)
1,100
1,000
900
800
700
600
500
400
300
200
100
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Salt River
CAP
Verde River


Lake Roosevelt Storage and Salt River TDS
Figure 2
Storage (acre-feet)
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
TDS (mg/l)
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan-90
Jan-95
Jan-00
Lake Roosevelt Storage
Salt River TDS

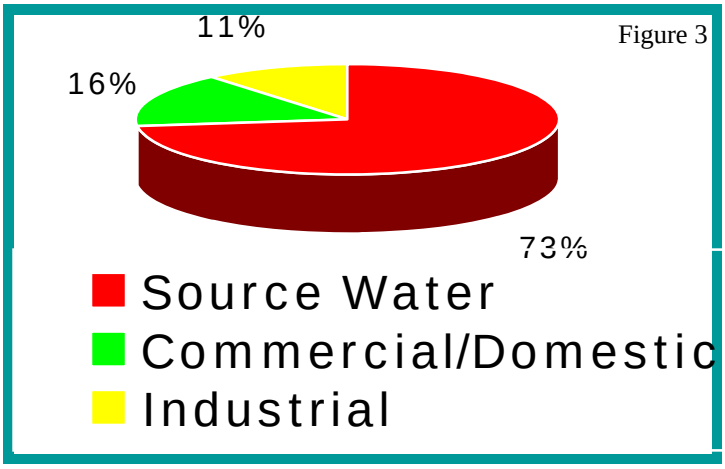


Figure 3
11%
16%
73%
Source Water
Commercial/Domestic
Industrial

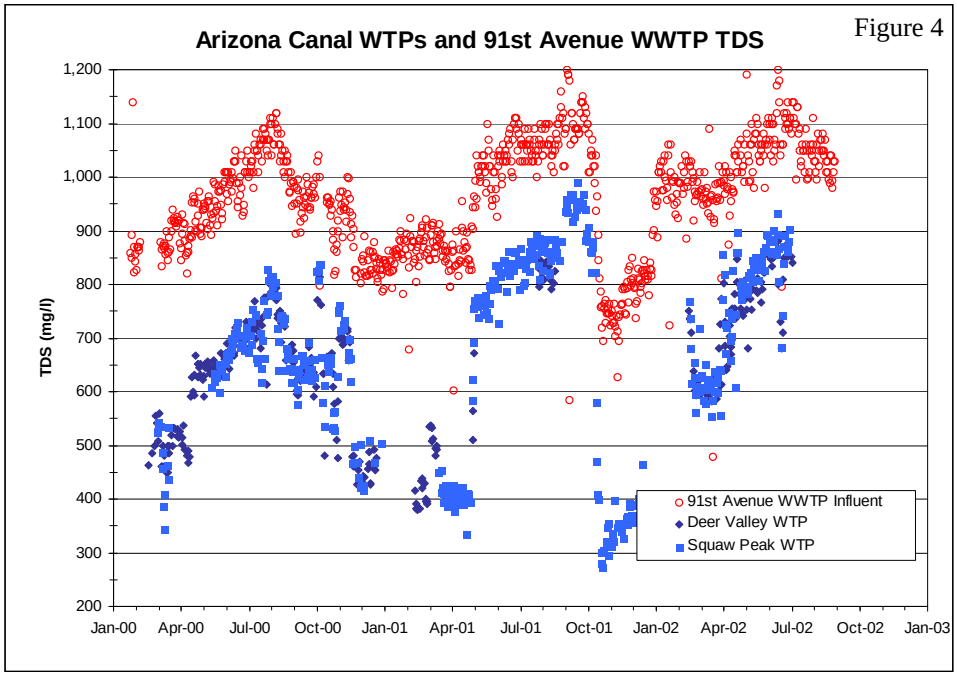


Figure 4
Arizona Canal WTPs and 91st Avenue WWTP TDS
TDS (mg/l)
1,200
1,100
1,000
900
800
700
600
500
400
300
200
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
91st Avenue WWTP Influent
Deer Valley WTP
Squaw Peak WTP

CENTRAL ARIZONA SALINITY STUDY – PHASE I

Technical Appendix P

ACCUMULATION AND MANAGEMENT OF SALT IN SOUTH CENTRAL ARIZONA

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Introduction

The only source of fresh water on this planet is atmospheric precipitation. Some of this precipitation evaporates and returns to the atmosphere. Some of it runs off the land and forms surface water in lakes and streams, and some of it infiltrates deeper into the soil and moves downward to form groundwater. Some of this groundwater may drain into streams to provide base flow so that the streams keep flowing when it does not rain. Eventually, most of the water not evaporated from the land areas ends up in the oceans from where it evaporates again to form clouds that produce precipitation on the land to close the hydrologic cycle.

All natural waters contain some salt, which is expressed as total dissolved solids or TDS. Rainfall and other atmospheric precipitation have the lowest TDS content, averaging about 10 mg/P (Bouwer, 1978). Surface water in streams and lakes have higher TDS contents because the water has been in contact with soil and rocks from which it picks up dissolved minerals and other constituents and pure water has evaporated from the watershed. TDS contents of surface water typically are on the order of a few tens to a few hundred mg/P. For the Colorado River, a main source of salts is the Mancos Shale in Colorado which is a marine deposit that adds predominantly sodium chloride to the water. For the Salt River, salt springs in the watershed contribute to the TDS of the water. Sometimes toxic chemicals are leached from the soil like the selenium in drainage water from irrigated land in California•s Central Valley that was discharged into Lake Kesterson where it caused serious environmental problems (Lemly, 1993). The desirable maximum value of TDS for drinking water is 500 mg/P, but a lot of people drink water with higher TDS contents.

While water itself is indestructible, its use often causes deterioration of its quality. Municipal use typically adds about 200 to 300 mg/P TDS to the water. This is due to the addition of salts and other chemicals in homes and industries, and by removal of distilled or very pure water by evaporation (evaporative coolers or cooling towers) or membrane filtration (reverse osmosis) by industries needing ultra pure water, and putting the reject brine into the sewers. Reverse osmosis also is important in potable reuse of water, because it not only removes salts but also organic compounds. If all the reject brines are returned to the sewer but all the ■good• water is not

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because of, for example, outdoor use of the water, sewage effluent has a higher salt content than the input water. A lot of water also evaporates in agricultural and urban irrigation of crops, plants, and turf, leaving salts behind in the soil which must be leached out of the root zone by applying more irrigation water than needed to meet the evaporative needs of the plants. The salty ■deep-percolation• water created by this leaching moves down to underlying groundwater where it increases the salt content of the groundwater and causes groundwater levels to rise where there is not much groundwater pumping. Of course, the biggest evaporators are the oceans themselves, where the salt content of the water now is about 35,000 mg/P. Oceans contain about 97% of the global water (Bouwer, 1978). Of the remaining 3%, about 2% is in the form of snow and ice in our polar regions and mountain ranges. This leaves only about 1% as liquid fresh water, almost all of which occurs as groundwater and very little as surface water which often is fed by groundwater. This shows the importance of groundwater and the need for proper management of that resource to prevent depletion and quality degradation.

Salt loadings

The main renewable water resources, i.e., surface water, for South Central Arizona are the Salt River system (about 0.8 million af/yr with a TDS of about 500 mg/P), and the Central Arizona Project Aqueduct (about 1.2 million af/yr of Colorado River water with a TDS of about 650 mg/P). Groundwater in this area is essentially a non-renewable resource, because natural recharge in a dry climate is very small (on the order of a few mm per year; Bouwer, 1989 and 2002) and there is essentially no ■new• groundwater being formed. Almost all of the recharge in the Phoenix-Tucson area is deep percolation water from irrigated areas, which is a return flow and does not represent ■new• water. Groundwater pumping for irrigation in the Phoenix, Tucson, and Pinal Active Management Area is about 0.9 million af/yr (Drew Swieczkowski, Arizona Department of Water Resources, personal communication 12/18/01) with an estimated average TDS of about 1000 mg/P. This represents a total salt load in surface water and groundwater of about 2.8 million tons per year. For the present population of about 4 million people in the area, this amounts to 3/4 ton or 1500 lbs per person per year or about 4 lbs per person per day. This is much more than the amount of salt ingested with food and drink and excreted again into the sewers or, for that matter, the salt added by other sources like water softeners.

Since there is little export of water and salt away from the Phoenix-Tucson area, the salts accumulate in the area itself, and mostly in the groundwater below irrigated areas where most of the water evaporates back into the atmosphere and salts accumulate in the root zone. These salts must be leached out with excess irrigation water to create drainage or deep percolation water that moves down to underlying groundwater. Hydrologically, irrigated areas basically are large evaporators like oceans where distilled water is returned to the atmosphere and salts remain behind.

Movement of irrigation water, salts, and nitrate to groundwater

Irrigated agriculture and urban irrigation of residential yards, parks, golf courses, playgrounds, landscaping, etc. are sustainable only if the salts and other chemicals that are in the irrigation

water are leached out of the root zone to avoid accumulation of plant damaging salt levels in the root zone itself. In dry climates this is achieved by applying more irrigation water than needed for evaporation. This extra water can be applied with each irrigation, or it can be applied seasonally with special ■deep• irrigations. Usually, the normal ■inefficiency• of irrigation and resulting over-irrigation are sufficient to create enough deep percolation water to maintain a salt balance in the root zone. In addition to salts, the deep-percolation water moving down through the vadose zone and to the groundwater contains all the other chemicals in the irrigation water that are not absorbed by the plants or bio-degraded in the root zone. In Mediterranean climates with winter rains or in other areas with significant periodic rainfalls, the leaching can be achieved naturally with excess rainfall. The vadose zone is the mostly unsaturated zone between the groundwater and land surface. Some salts like calcium carbonate or sulfate may precipitate in the vadose zone. This reduces the salt load on the underlying groundwater but may create undesirable caliche like deposits that could hamper drainage. More research is needed to see how significant this precipitation can be.

Leaching of salts and other chemicals out of the root zone must be managed in an environmentally responsible way to avoid undue rises of groundwater levels and contamination of underlying groundwater, and to protect the surface water into which the drainage water eventually is discharged after it leaves the aquifer through natural drainage into surface water, through tile or ditch drainage systems, or through vertical drainage with pumped wells. Chemicals that are naturally present in soils and deeper geologic formations of vadose zones and aquifers also can be leached by the deep percolation water, like, for example, salts and selenium in marine shales (Lemly, 1993). This can add to the contamination of groundwater and of surface water into which the groundwater is ultimately discharged. For relatively unpolluted irrigation water, the main chemicals of concern are dissolved salts naturally occurring in the water, and the agricultural chemicals like fertilizers and pesticides that are added to the water, plants, or soils (Bouwer 1990). Where sewage effluent or sewage contaminated water is used for irrigation, other compounds like pharmaceuticals, disinfection byproducts, THM precursors, and other synthetic organic compounds may also be of concern (Bouwer 2000; Daughton and Jones-Lepp, 2001; Drewes and Shore, 2001).

To illustrate the concepts of leaching and groundwater contamination, an irrigated area will be taken in a dry, warm climate with negligible rainfall that is continuously cropped and requires about 5 ft of water per year for evapotranspiration (evaporation from the soil plus transpiration by the plants), like in south-central Arizona. Defining the irrigation efficiency as evapotranspiration divided by water applied and assuming an irrigation efficiency of about 80%, the required irrigation application would then be about 6 ft of water per year of which about 1 ft per year will move through the root zone and downward as drainage or deep percolation water to the underlying groundwater. If the salt concentration of the irrigation water is 700 mg/P, the salt content of the deep percolation water will then be 6 x 700 = 4200 mg/P, well above the desired upper limit of 500 mg/P for drinking, and also well above the value of 2000 mg/l where use of that water for irrigation becomes severely restricted (Ayers and Westcott, 1985). This means that it can then only be used for very salt tolerant crops, preferably after mixing with lower TDS water, if normal crop yields are desirable. Yields of less salt tolerant crops would be greatly

reduced (Ayers and Westcott, 1985; Tanji, 1990). Concentrations of other chemicals in the irrigation water not absorbed by the plants or attenuated in the root zone also will be six times higher in the deep percolation water than in the irrigation water.

Nitrogen fertilizer requirements are about 240 lbs/acre per crop (Baier and Fryer, 1973; Bouwer and Idelovitch, 1987). As a rule-of-thumb, half of this nitrogen is absorbed by the crop, one-fourth is lost by denitrification and returns to the atmosphere as nitrogen gas and oxides of nitrogen, and one-fourth or 60 lbs/acre in this case is leached out of the root zone as nitrate in the deep percolation water (Bouwer, 1990). For the above example of 1 ft/yr deep percolation water, this would give a nitrate nitrogen concentration in the deep percolation water of 60 lbs per acrefoot or 22 mg/P. This is well above the maximum limit of 10 mg/l for drinking water.

Conventionally treated secondary sewage effluent (activated sludge) may contain about 30 mg/l total N, mostly as ammonium (Bouwer et al., 1974). If this effluent were used for irrigation with a total application of 6 ft per year or growing season, the amount of nitrogen applied with the water would be about 490 lbs/acre per year or growing season, more than twice the normal requirements. Assuming no luxury uptake of nitrogen by the crop so that again one-fourth of this nitrogen is leached out as nitrate with the deep percolation water, and assuming also that the irrigation efficiency again is about 80%, would then give a nitrate nitrogen concentration in the drainage water of about 45 mg/P. Thus, irrigation with sewage effluent and no additional application of nitrogen fertilizer already can cause more nitrate contamination of underlying groundwater than irrigation with normal water and the nitrogen applied as fertilizer. Nitrate contamination of groundwater due to irrigation with reclaimed municipal wastewater can be reduced by removing nitrogen in the sewage treatment plant with nitrification-denitrification or other processes. Also, nitrogen can be removed naturally from water in the underground environment by denitrification, ammonium adsorption, and possibly by the recently discovered anammox process (Van de Graaf et al., 1995) if both ammonium and nitrate occur in the groundwater under anaerobic conditions.

If sewage effluent is used for irrigation, the nitrogen in the effluent often is more than enough to satisfy the nitrogen requirements of the crops and fertilizer nitrogen should not be given. As a matter of fact, the effluent may already contain too much nitrogen which can not only adversely affect underlying groundwater but also the crop itself. Adverse crop effects due to excess nitrogen include delay of harvest, too much vegetative growth and not enough reproductive growth (seeds), impaired quality of crop (reduced sugar contents in beets and cane, reduced starch content in potatoes), reduced yield of marketable fruit, and nitrate toxicity in people and animals consuming the crop (Baier and Fryer, 1973). Contamination of groundwater with other sewage chemicals like synthetic organics and pharmaceuticals is also possible (Lim et al, 2000). Not much is known about the underground fate of these chemicals. Some pharmaceuticals have been detected in groundwater below losing streams that carried effluent-contaminated water, and in systems of artificial recharge of groundwater with sewage effluent (Drewes and Shore, 2001). Thus contamination of groundwater with pharmaceuticals and other organic compounds below sewage irrigated areas may be possible. Since irrigation with sewage effluent can be expected to drastically increase in the future as populations increase and water reuse will become

increasingly necessary, more research on adverse effects of effluent irrigation on plants and groundwater will be needed.

The minimum leaching requirement for salt balance in the root zone depends on crop salinity tolerance and salt content of irrigation water (Tanji; 1990; Ayers and Westcott, 1985). Typically, a leaching ratio of 10% is suitable for most cases, giving a maximum irrigation efficiency of 90%. Most farm irrigation systems have efficiencies well below 90%. Well designed and well managed irrigation systems may have an efficiency of about 80%. Many surface irrigation systems have much lower efficiencies, for example 60% or less. The higher the TDS of the irrigation water, the larger the amounts and frequencies of leaching need to be. Thus, normal inefficiencies of irrigation systems often are more than sufficient for adequate leaching of salts and other chemicals out of the root zone. This leaching avoids buildup of salts and other chemicals in the soil and maintains a salt or chemical balance for the root zone. Eventually, however, these chemicals will show up in underlying groundwater and from there in surface water via natural drainage of groundwater into surface water, via discharge from ditch or tile drains or from pumped drainage wells, or via sewage effluent discharges in areas where the affected groundwater is first used for municipal water supply. A sustained irrigation efficiency of 100%, as advocated by some, is only possible if distilled water or other water with a TDS content of zero is used for irrigation,

While downward flow of deep percolation water below the root zone is unsteady and occurs in pulses after each irrigation, the pulses flatten out with depth so that actual downward water velocities or pore velocities deeper in the vadose zone can be estimated as the average deep percolation Darcy flux divided by the volumetric water content of the vadose zone. Thus, for the previous example with a deep percolation rate of 1 ft/yr and assuming a water content of 15% in the vadose zone, the pore velocity of the deep percolation water would be 1/0.15 = 6.75 ft/yr. Where groundwater is deep, for example at about 300 ft as in south central Arizona, it would thus take the deep percolation water about 45 yrs to reach the groundwater. In many areas irrigation has been going on much longer so that significant amounts of deep percolation water already have joined the groundwater. This can also cause groundwater levels to rise. For example, if the aquifer is unconfined and the fillable porosity in the vadose zone is 20%, the arrival of 1 ft of water per year would cause the water table to rise 1/0.2 = 5 ft/yr, assuming no other recharges or discharges of groundwater or pumping from wells that affect groundwater levels or produce lateral flow in the aquifer away from the irrigated area. The fillable porosity is the difference between the water content in the vadose zone and that below the rising water table.

Where an irrigation project has just been started and deep percolation water begins to move downward for the first time, the time for the first deep percolation water to arrive at underlying groundwater can be estimated from the difference between the original water content of the vadose zone and the water content in the zone wetted by the deep percolation water. This flow is like that in an infiltration system where dry soil is flooded, water infiltrates into the soil and moves downward to create a wetted zone as the wetting front continues to advance downward. The rate of downward movement of the wetting front can be estimated from the infiltration rate

and the difference between the water content of the wetted zone and that of the drier vadose sone below it. For example, if the water content is 15% in the wetted zone and 5% in the relatively dry vadose zone below it, and the deep percolation rate is 1 ft per year, the wetting front will move downward at the rate of 1/(0.15-0.05) = 10 ft per year. Thus, where the groundwater is at a depth of 400 ft and a new irrigation project is started, it would take 400/10 = 40 years for the deep percolation water to reach the groundwater and to start causing TDS increases in the well water, especially if the well is perforated or screened to the top of the aquifer or even higher.

The pore velocity in the vadose zone of 6.7 ft/yr and the water table rise of 5 ft/yr in the previous example are based on year-round irrigation. For more seasonal irrigation, with only one crop per year and fallowing between crops, these values will be less and closer to about 3 ft/yr for the pore velocity in the vadose zone and about 2 ft/yr for the rise of the groundwater table. For mixed irrigated agriculture with a combination of seasonal and year-round irrigation, downward pore velocities in the vadose zone thus may range between 2 and 5 ft/yr, and groundwater rises may be between 3 and 6 ft/yr. Thus, the long-term effects of irrigation on underlying groundwater are water quality degradation and rising groundwater levels. On the other hand, where overpumping occurs and groundwater levels are dropping, arrival rates of deep-percolation water at the groundwater are reduced and can even reach zero if groundwater levels are dropping faster than the pore velocity of the deep-percolation water in the vadose zone. If groundwater pumping and groundwater level declines then are reduced to where the deep-percolation water can ■catch up• with the water table, rising groundwater levels and significant groundwater quality reductions can be expected.

The calculated increases in groundwater TDS, nitrate levels, and groundwater levels themselves agree with observed values in a study conducted by the Salt River Project in the southeastern part of the Salt River Valley where groundwater pumping was greatly reduced and irrigation was mostly done with surface water starting in the late 1970s and continuing throughout the 1980s (Karol O. Wolf, Salt River Project, personal communication, 2002). For example, nitrate levels in groundwater pumped from the aquifer below the affected area increased from a range of 2 to 7 mg/P as nitrogen to a range of 10 to 20 mg/P. TDS increased from about 500 mg/P to about 1000 mg/P for some wells, and from 500 to 1800 and from 700 to 1500 mg/P for others, while groundwater levels rose about 2 ft/yr. The TDS values are significantly lower than expected from the TDS contents of the deep percolation water, which for efficient irrigation systems would be about 2500 mg/P. Nitrate levels were lower than expected in the deep percolation water. This is because the wells are perforated or screened for a significant depth interval, whereas the deep percolation water accumulates at the top of the aquifer. Thus, the well water consists of a mixture of salty deep percolation water from the upper part of the aquifer and much less salty natural groundwater from deeper in the aquifer. Simple calculations can be made to predict the TDS increase of the well water as a function of time after the arrival of deep percolation water. If the situation is more complicated, like well screens only in the deeper portion of the aquifer and/or presence of a middle fine-grained unit or other layers of low permeability, modeling techniques can be used to predict TDS increases in well water as a function of time of pumping. Since the contaminated water will remain mostly in the upper part of the aquifer according to the vertical stacking principle, wells with their screen or perforated

section near the water table will show the quality degradation first. Wells in unconfined aquifers with deeper screens will be affected later, as pumping produces vertical flow components in the aquifer and upper groundwater is drawn deeper into the aquifer and into the well, even if the deeper aquifers are semi-confined. Eventually, wells may produce mostly deep percolation water from the irrigation practices. Such water will not meet drinking water standards and also may be too salty for general agricultural use. Options then include blending the well water with better quality water, drilling the wells deeper or sealing off upper portions of screens to buy more time before the well water gets saltier, and treatment of the well water with, for example, reverse osmosis which, of course, produces a reject brine that may give disposal problems.

Urban irrigation can also cause groundwater levels to rise. For example, groundwater levels rose from a depth of about 120 ft to a depth of about 50 ft in a few decades below an old residential area with flood irrigated yards in north central Phoenix. This rise was mainly in response to the shutting down of several large capacity irrigation and water supply wells in the area. The rate of rise of the groundwater level in the affected area was about 1 to 2 ft per year. At one area (Camelback and Central), rising groundwater levels flooded the lowest level (level No. 5) of an underground parking garage below an office building. Initially, groundwater levels were adequately controlled by draining the ABC layer below the concrete floor slab. Eventually, however, wells had to be installed around the building to lower groundwater levels. The discharge water from the wells was contaminated by local leaking underground storage tanks. This required expensive treatment of the water before it could be discharged into a storm drain.

Evaporation from vadose zone

Where deep percolation rates are very small, as with very efficient irrigation systems, deficit irrigation, or low water use landscaping (xeriscapes), evaporation of water deeper in the vadose zone may become significant and deep percolation rates will then decrease with depth to the point where TDS concentrations become so high that salts precipitate in the vadose zone and maybe even in the root zone itself which would have adverse effects on the plants. Low deep percolation rates would cause low water contents in the soil of the vadose zone which would increase the permeability of the soil to air. Evaporation of water in the vadose zone could then be caused by diurnal barometric pressure variations that typically occur in a desert environment in the absence of major weather systems moving through. Barometric pressures then increase during the night when the air cools down and becomes heavier, and decrease during the day as the air warms up again and becomes lighter. This could cause the vadose zone to ■breathe,• ■inhaling• dry atmospheric air during the night that causes vadose zone water to evaporate into the soil air and ■exhaling• damp vadose zone air into the atmosphere during the day. This ■deep• evaporation could cause significant amounts of salt to be stored in the vadose zone which reduces the salt load on the underlying groundwater. More research on this phenomenon is necessary, especially on long-term effects to determine if salts could build up to the point where they form caliche-like layers that impede downward movement of water and could cause water logging of the upper soil, evaporation from the soil surface, and formation of salt flats where nothing will grow.

Salt tolerance of plants

Increasing TDS contents of well water or, for that matter, any water, are undesirable because for health and aesthetic reasons they should be below 500 mg/P for potable water. TDS increases are also undesirable because they shorten the useful life of pipes, water heaters, etc., and make water treatment more expensive for industrial uses where high water qualities, including ultra pure water, are needed. TDS increases are also undesirable for urban and agricultural irrigation of plants and crops. As a rule, water with a TDS content of less than 500 mg/P can be used to irrigate any plants, including salt sensitive plants. Between 500 and 2000 mg/P TDS, there can be slight to moderate restrictions on its uses, and above 2000 mg/P there can be severe restrictions like growing salt tolerant crops only and adequate leaching of salts out of the root zone (Ayers and Westcott, 1985; Tanji, 1990). For agricultural purposes, salt contents of irrigation water and water in soils and aquifers are often measured as electrical conductivity, EC, expressed in deciSiemens/meter or dS/m. For most natural waters 1 dS/m is equivalent to a TDS content of about 640 mg./P. Basic relationships between the EC of irrigation water and relative crop yields are shown in Figure 1 taken from Ayers and Westcott (1985). Typically, such relations show no decrease in crop yield with increases in the salt content of the irrigation water, as expressed by ECw, as long as ECw is small. Then, as ECw of the irrigation water is increased, a threshold value is reached where crop yields start to decrease linearly with further increases in ECw. This threshold value is about 0.7 dS/m (450 mg/P) for salt sensitive crops, 1.8 dS/m (1150 mg/P) for moderately salt sensitive crops, 4.0 dS/m (2600 mg/P) for moderately salt tolerant crops, and 6.5 dS/m (4200 mg/P) for salt tolerant crops. Examples of crops in these categories are shown in Table 1. The lines in Figure 1 show that if the ECw of the irrigation water increases beyond the threshold value, farmers have to accept a reduction in crop yield, or switch to a more salt tolerant crop. There is considerable research being done to increase the salt tolerance of crops (Apse et al., 1999; Ayers and Westcott, 1985).

Management of salty water

The first reaction to a decreasing quality of well water often is to shut the well down and use other sources of water. However, where groundwater is not pumped at adequate rates, water tables will then continue to rise due to continued arrival of deep percolation water until they become so high that they flood basements, damage underground pipelines, come too close to landfills or cemeteries, kill trees, reduce crop yields, and eventually water-log the surface soil so that water can evaporate directly from the soil, leaving the salts behind and creating salt flats. Failure to control groundwater levels in irrigated areas and resulting salinization of the soil has been the demise of old civilizations and is still causing irrigated land to go out of production at alarming rates (Postel, 1999). In addition to developed and developing countries, there now are also deteriorating countries. Where there are rises of salty groundwater, groundwater must eventually be pumped again to keep groundwater levels at a safe depth. For agricultural areas where higher groundwater levels can be tolerated than in urban areas, water tables can be controlled by tile or ditch drainage.

Great care must be taken that the poor quality salty water that comes out of out of these wells

and drainage systems is discharged into the surface environment in an ecologically responsible manner. Options include discharge into oceans or big rivers where dilution is the solution to pollution, or into dedicated ■salt• lakes for accumulation and storage of salts in perpetuity. Where the salty water needs to be transported over long distances to proper disposal areas, concentrating the salts into smaller volumes of water may be needed to reduce the cost of pipelines, aqueducts or other conveyance systems, and to reduce the volume of water that leaves the area. One way to concentrate the salts into smaller water volumes while making economic use of the desalted water is membrane filtration. The desalted water could then be used for potable or industrial purposes. As a matter of fact, mildly brackish groundwater could be an important reserve water resource in periods of drought since desalting this water is relatively inexpensive compared to desalting much saltier water like seawater.

Concentration of salts into smaller water volumes can also be achieved with sequential irrigation of increasingly salt-tolerant crops where the deep-percolation water from one crop is used to irrigate a more salt-tolerant crop, etc., starting with salt-sensitive crops and ending with halophytes (Shannon et al., 1997). This can increase the salt concentrations of the drainage water to sea water levels (about 30,000 mg/l) and in volumes that are a small fraction of the original irrigation water volume, as illustrated in Table 2. Depending on local conditions, sequential irrigation to halophytes may not be needed and the sequence may be stopped if the salt content of the deep percolation water has become high enough to achieve sustainable disposal at acceptable costs. The wells for pumping salty deep percolation from the aquifer in sequential irrigation projects should be rather shallow so that they pump primarily deep percolation water from the top of the aquifer and a minimum of deeper native and less salty groundwater. Also, sequential irrigation is best carried out by growing increasingly salt tolerant crops in relatively large blocs so that there is not much lateral flow in the aquifer that could interfere with proper control of the deep-percolation water from the different crops.

A third option for concentrating salts into smaller volumes is via evaporation ponds. For the Salt River Valley, evaporation rates of free water surfaces are about 6 ft/yr. Thus, if flows of drainage water are significant, large land areas will be required for such ponds. The ponds may also become environmental hazards. For example, if the irrigation amount is 5 ft/year, and the irrigation efficiency is 75%, evaporation ponds with a surface area of about 20% of the irrigated area would be required if all the deep percolation water must be evaporated. This will eventually increase salt concentrations in the ponds to values well in excess of those for sea water as happened in the Salton Sea in California with about 40,000 mg/L and the Dead Sea between Jordan and Israel with about 340,000 mg/L. However, complete evaporation may not be necessary if the main purpose of the pond is to concentrate the salts into manageable smaller volumes of water that can then be more economically exported to an ocean or designated inland salt lake. In that case pond areas will be less. Another possibility for concentrating the salts into smaller volumes of water by evaporation is to use the salty well water for power plant cooling. For example, the 3810 megawatt nuclear power plant west of Phoenix is cooled with about 65,000 acrefeet per year of treated sewage effluent. The effluent is recycled 15 to 20 times through the plant and is then discharged into 500 acres of evaporation ponds where it completely evaporates. At an annual evaporation of about 6 feet, the evaporation from the ponds is about

3,000 acrefeet per year. Thus, the salts in 65,000 acrefeet of effluent are concentrated into 3,000 acrefeet of cooling tower outflow, giving a volume reduction of about 95% and a 20 fold increase in salt concentration.

Perhaps the evaporation ponds can be constructed as solar ponds which can be used to generate hot water and/or electricity. For example, in an experimental solar pond project in El Paso, Texas, the pond was 9 ft deep with a 3 ft layer of low salinity water on top, a 3 ft layer of medium salinity water in the middle, and a 3 ft layer of high salinity (brine) at the bottom (Xu, 1993). This created a density gradient so that sun energy was trapped as heat in the bottom layer while the lighter top layers prevented thermal convection currents and acted as insulators. The hot brine from the bottom layer was pumped to a heat exchanger where a working fluid like iso-butane or freon was vaporized which then went through a turbine to generate power. The working fluid was condensed in another heat exchanger that was cooled with normal water which was recirculated through a cooling tower. The working fluid then returned to the brine heat exchanger where it was preheated by the brine return flow from the heat exchanger to the pond before it was vaporized again. The El Paso pond had a surface area of 0.8 acres and generated 60 to 70 KW. At this rate, a solar pond system of about 12,500 acres or an area of about 5 x 5 miles could generate about 1000 megawatts of electricity, which is typical of a good sized power plant. There was enough heat stored in the hot brine layer to also generate power at night. The El Paso studies have demonstrated the principles of solar power generation. Considerable research is still necessary to see how a large scale system should be designed and managed.

Concentrating the salts into smaller and smaller volumes with revenue producing techniques will be of special benefit to inland or other areas where salts need to be transported over long distances to reach suitable (or least objectionable!) places for final disposal like, for example, an ocean or a dedicated lake. Concentrating the salts into small volumes of water will then minimize the cost of pipelines and other conveyance structures. The ultimate concentration of salt is, of course, achieved by complete evaporation of the water, so that the salts crystallize and can be stored in perpetuity in landfills, or used commercially if beneficial uses can be developed.

PROGNOSIS

As the population in south-central Arizona continues to increase and the Phoenix-Tucson corridor expands into a Prescott-Nogales corridor, more and more water will be needed for municipal water supply and more and more sewage effluent will be produced. If all the main renewable water resources, i.e., the Salt river and Colorado river, were solely used for municipal water supply, the 2 million acre feet per year brought in by these rivers could support a population of about 9 million, assuming a gallons per capita per day use of 200, which is between the present gpcd of 250 for Phoenix and 150 for Tucson. At a sewage flow of 100 gallons per person per day, the 9 million people would produce 1 million acre feet of effluent per year. At an application rate of 5 ft per year, this could irrigate almost 200,000 acres, urban as well as agricultural. The salt content of the effluent would be below the 1000 mg/P which is the center of the range where moderately salt sensitive plants or crops can be grown (Fig. 1). The

effluent could also be used for potable water reuse via artificial recharge of groundwater (Crook et al., 1999), for cooling water for power plants, and for environmental purposes like restoration of stream flow and riparian habitats. Potable reuse of the effluent could add another 2 or 3 million people to the sustainable population. Such reuse would require more membrane filtration, which produces a reject brine that adds to the salt burden. Groundwater will be used where still available and of good quality. However, without incidental recharge from irrigation or without artificial recharge in engineered projects, natural recharge rates in dry climates are so low that groundwater basically is a non-renewable resource (Bouwer, 2002).

As described earlier, the salts in the water used for irrigation are concentrated in the deep percolation water that moves from the root zone to underlying groundwater where it will increase the salt content of the groundwater. It will also cause groundwater to rise where there is no serious over pumping of groundwater. Eventually, groundwater must then be pumped to prevent groundwater levels from rising too high. The salty water from the pumped wells then should be reduced in volume so that the salt in this water can be exported in relatively small amounts of water. Such concentration of salt into smaller volumes can be achieved with revenue producing processes, including membrane filtration that also produces drinking water, sequential irrigation of increasingly salt tolerant crops, and evaporation ponds that may be used as solar ponds for power generation. Final disposal of salt to obtain regional salt balances may then be via export to an ocean, or storage in perpetuity in inland salt lakes or land fills.

REFERENCES

Apse, M.P., Akaron, G.S., Sneeden, W.A., and Blumwald, E. (1999). ■Salt tolerance conferred by overexpression of a vacuolar Na^+/H^+ antiport in Aribidopsis.• *Science*, 285(31), 1256-1258.

Ayers, R.S. and D.W. Westcott, (1985) Water quality for agriculture FAO Irrigation and Drainage Paper 29, Food and Agriculture Organization of the United Nations, Rome.

Baier, D.C. and W.B. Fryer, (1973) Undesirable plant responses with sewage irrigation. *J. Irr. and Drain. Div.*, Proc. Am. Soc. Civil Engrs. 99-IR2:133-141.

Bouwer, H. (1978). Groundwater Hydrology, McGraw-Hill, New York, NY.

Bouwer, H. (1989) Estimating and enhancing groundwater recharge. In *Groundwater Recharge*, M.L. Sharma, ed, Balkema Publishers, Rotterdam, The Netherlands, p. 1-10.

Bouwer, H. (1990) Agricultural chemicals and groundwater quality. *J. Soil and Water Conservation* 45:184-189.

Bouwer, H. (2000) Groundwater problems caused by irrigation with sewage effluent. *Env. Health*, Oct. 2000, p. 17-20.

Bouwer, H. (2002). Artificial recharge of groundwater: Hydrogeology and engineering. *Hydrogeology Journal* 10:121-142.

Bouwer, H. and E. Idelovitch, (1987) Quality requirements for irrigation with sewage effluent. *J. Irrig. and Drain. Div.* Am. Soc. Civil Engrs. 113(4):516-535.

Bouwer, H., J.C. Lance, and M.S. Riggs. 1974. High-rate land treatment. II. Water quality and economic aspects of the Flushing Meadows project. *J. Water Polut. Contr. Fed.* 46(5)844-859.

Crook, J., J.A. MacDonald and R.R. Trussel, (1999). Potable use of reclaimed water. J. Am. Water Works Assoc. August 1999:40-49.

Daughton, C.G. and T. Jones-Lepp. (eds.) (2001) Pharmaceuticals and Personal Care Products in the Environment: Scientific and Regulatory Issues. Symposium Series 791, American Chemical Society, Washington D.C.

Drewes, J.E., and L.S. Shore, (2001) Concerns about pharmaceuticals in water reuse, groundwater recharge, and animal waste. In Pharmaceuticals and Personal Care Products in the Environment, C.G. Daughton and T. Jones-Lepp, eds. Symposium, Series 791; American Chemical Society; Washington, D.C.)

Lemly, A.D. (1993) Subsurface agricultural irrigation drainage: the need for regulation. *Regulatory Toxicology and Pharmacology* 17:157-180.

Lim, R., S. Gale and C. Doyle. (2000) Endocrine disrupting compounds in sewage treatment plant (STP) effluent reuse in agriculture - is there a concern? Proc. First Symp. Water Recycling Australia 2000, Adelaide, p. 23-28.

Postel, S. (1999) Pillar of Sand. Worldwatch Institute, Washington, D.C.

Shannon, M., Cervinka, V., Daniel, D.A. (1997) Drainage water reuse. In: Madromootoo, C.A., Johnston, W.R., Wallardson, L.S. (Eds.), Management of Agricultural Drainage Water Quality. Water Reports No. 13, Food and Agricultural Organization of the United Nations, Rome, Italy, pp. 29-40 (Chapter 4).

Tanji, K.K., ed. (1990) Agricultural Salinity Assessment and Management. Manual of Engineering Practice No. 71, Am. Soc. Civil Engrs., Reston, Virginia.

Van de Graaf, A., A. Mulder, P. de Bruijn, M. Jetten, L. Robertson, and G. Kuenen (1995) Anaerobic oxidation of ammonium is a biologically mediated process. *Applied and Envir. Microbiology* 61(4):1256-1251.

Xu, H., ed. (1993) Salinity Gradient Solar Ponds - a Practical Manual, Vol, 1 (Solar Pond Design & Construction) and Vol. 2 (Solar Pond Operation and Maintenance). Dept of Industrial and Mechanical Engineering, Univ. of Texas, El Paso, Texas.

Table 1. Relative salt tolerance of agricultural crops (Ayers and Westcot, 1985).

TOLERANT

Fibre, Seed and Sugar Crops

Barley	*Hordeum vulgare*
Cotton	*Gossypium hirsutum*
Jojoba	*Simmondsia chinensis*
Sugarbeet	*Beta vulgaris*

Grasses and Forage Crops

Alkali grass, Nuttall	*Puccinellia airoides*
Alkali sacaton	*Sporobolus airoides*
Bermuda grass	*Cynodon dactylon*
Kallar grass	*Diplachne fusca*
Saltgrass, desert	*Distichlis stricta*
fairway crested	
Wheatgrass, tall	*Agropyron elongatum*
Wildrye, Altai	*Elymus angustus*
Wildrye, Russian	*Elymus junceus*

Vegetable Crops

Asparagus	*Asparagus officinalis*

Fruit and Nut Crops

Date palm	*Phoenix dactylifera*

MODERATELY TOLERANT

Fibre, Seed and Sugar Crops

Cowpea	*Vigna unguiculata*
Oats	*Avena sativa*
Rye	*Secale cereale*
Safflower	*Carthamus tinctorius*
Sorghum	*Sorghum bicolor*
Soybean	*Glycine max*
Triticale	*X Triticosecale*
Wheat	*Triticum aestivum*
Wheat, Durum	*Triticum turgidum*

Grasses and Forage Crops

Barley (forage)	*Hordeum vulgare*
Brome, mountain	*Bromus marginatus*
Canary grass, reed	*Phalaris, arundinacea*
Clover, Hubam	*Melilotus alba*
Clover, sweet	*Melilotus*
Fescue, meadow	*Festuca pratensis*
Fescue, tall	*Festuca elatior*
Harding grass	*Phalaris tuberosa*
Panic grass, blue	*Panicum antidotale*
Rape	*Brassica napus*
Rescue grass	*Bromus unioloides*
Rhodes grass	*Chloris gayana*
Ryegrass, Italian	*Lolium italicum multiflorum*
Ryegrass, perennial	*Lolium perenne*
Sudan grass	*Sorghum sudanense*
Trefoil, narrowleaf birdsfoot	*Lotus corniculatus tenuifolium*
Trefoil, broadleaf birdsfoot	*Lotus corniculatus arvenis*
Wheat (forage)	*Triticum aestivum*
Wheatgrass, standard crested	*Agropyron sibiricum*
Wheatgrass, intermediate	*Agropyron intermedium*
Wheatgrass, slender	*Agropyron trachycaulum*
Wheatgrass, western	*Agropyron trachycaulum*
Wildrye, beardless	*Elymus triticoides*

Grasses and Forage Crops

Wildrye, Canadian	*Elymus canadensis*

Vegetable Crops

Artichoke	*Helianthus tuberosus*
Beet, red	*Beta vulgaris*
Squash, zucchini	*Cucurbita pepo melopepo*

Fruit and Nut crops

Fig	*Ficus carica*
Jujube	*Ziziphus jujuba*
Olive	*Olea europaea*
Papaya	*Carica papaya*
Pineapple	*Ananas comosus*
Pomegranate	*Punica granatum*

MODERATELY SENSITIVE

Fibre, seed and Sugar Crops

Broadbean	*Vicia faba*
Castorbean	*Ricinus communis*
Maize	*Zea Mays*
Flax	*Linum usitatissimum*
Millet, foxtail	*Setaria italica*
Groundnut/peanut	*Arachis hypogaea*
Rice, paddy	*Oryza sativa*
Sugarcane	*Saccarum officinarum*
Sunflower	*Helianthus annuus*

Grasses and Forage crops

Alfalfa	*medicago sativa*
Bentgrass	*Agrostis stolonifera palustris*
Bluestem, Angleton	*Dichanthium aristatum*
Brome, smooth	*Bromus inermis*
Buffelgrass	*Cenchrus ciliaris*
Burnet	*Poterium sanquisorba*
Clover	*Trifolium hydridum*
Clover, Berseem	*Trifolium alexandrinum*
Clover, ladino	*Trifolium repens*
Clover, red	*Trifolium pratense*
Clover, strawberry	*Trifolium fragiferum*
Clover, white Dutch	*Trifolium repens*
Corn (forage)(maize)	*Zea mays*
Cowpea (forage)	*Vigna unguiculata*
Dallis grass	*Paspalum dilatatum*
Foxtail, meadow	*Alopecurus pratensis*
Grama, blue	*Bouteloua gracilis*
Lovegrass	*Eragrostis sp.*
Milkvetch, Cicer	*Astragalus cicer*
Oatgrass, tall	*Arrhenatherum, Danthonia*
Oats (forage)	*Avena sativa*
Orchard grass	*Dactylis glomerata*
Rye (forage)	*Secale cereale*
Sesbania	*Sesbania exaltata*
Siratro	*Macroptilium atropurpureum*
Sphaerophysa	*Sphaerophysa salsula*
Timothy	*Phleum pratense*
Trefoil, big	*Lotus uliginosus*
Vetch, common	*Vicia angustifolia*

Vegetable Crops

Broccoli	*Brassica oleracea botrytis*
Brussels sprouts	*B. oleracea gemmifera*

Table 1. (Continued)

MODERATELY SENSITIVE

Vegetable Crops

Cabbage	*B. oleracea capitata*
Cauliflower	*B. oleracea botrytis*
Celery	*Apium graveolens*
Corn, sweet	*Zea mays*
Cucumber	*Cucumis sativus*
Eggplant	*Solanum melongena esculentum*
Kale	*Brassica oleracea acephala*
Kohlrabi	*B. oleracea gongylode*
Lettuce	*Latuca sativa*
Muskmelon	*Cucumis melo*
Pepper	*Capsicum annuum*
Potato	*Solanum tuberosum*
Pumpkin	*Cucurbita peop pepo*
Radish	*Raphanus sativus*
Spinach	*Spinacia oleracea*
Squash, scallop	*Cucurbita pepo melopepo*
Sweet potato	*Ipomoea batatas*
Tomato	*Lycopersicon lycopersicum*
Turnip	*Brassica rapa*
Watermelon	*Citrullus lanatus*

Fruit and Nut Crops

Grape	*Vitis sp.*

SENSITIVE

Fibre, Seed and Sugar Crops

Bean	*Phaseolus vulgaris*
Guayule	*Parthenium argentatum*
Sesame	*Sesamum indicum*

Vegetable Crops

Bean	*Phaseolus vulgaris*
Carrot	*Daucus carota*
Okra	*Abelmoschus esculentus*
Onion	*Allium cepa*
Parsnip	*Pastinaca sativa*

Fruit and Nut Crops

Almond	*Prunus dulois*
Apple	*Malus sylvestris*
Apricot	*Prunus armeniaca*
Avocado	*Persea americana*
Blackberry	*Rubus sp.*
Boysenberry	*Rubus ursinus*
Cherimoya	*Annona cherimola*
Cherry, sweet	*Prunus avium*
Cherry, sand	*Prunus besseyi*
Currant	*Ribes sp.*
Gooseberry	*Ribes sp.*
Grapefruit	*Citrus paradisi*
Lemon	*Citrus limon*
Lime	*Citrus aurantiifolia*
Loquat	*Eriobotrya japonica*
Mango	*Mangifera indica*
Orange	*Citrus sinensis*
Passion Fruit	*Passiflora edulis*
Peach	*Prunus persica*
Pear	*Pyrus communis*
Persimmon	*Diospyros virginiana*
Plum: Prume	*Prunus domestica*
Pummelo	*Citrus maxima*
Raspberry	*Rubus idaeus*
Rose apple	*Syzgium jambos*
Sapote, white	*Casimiroa edulis*
Strawberry	*Fragaria sp.*
Tangerine	*Citrus reticulata*

Table 2: **Sequential irrigation of increasingly salt tolerant crops with drainage water from less tolerant crops. Volumes are expressed in arbitrary units.**

Crop	**Sensitive**	**Moderately Sensitive**	**Tolerant**	**Very Tolerant**	**Halophyte**
Examples (Ayers and Westcot, 1985)	**peas, beans, strawberries, stone, pome, and citrus fruits**	**lettuce, kale, broccoli, celery, potato**	**wheat, sorghum, rye, beet**	**barley, cotton, sugar beet, bermuda grass, salt cedar, eucalyptus, poplar**	**salicornia**
Irrigation volume	100	25	10	5	2
Salt conc. mg/l	200	800	2,000	4,000	10,000
Efficiency %	75	60	50	60	67
Drainage volume	25	10	5	2	0.67
Salt conc. mg/l	800	2,000	4,000	10,000	30,000

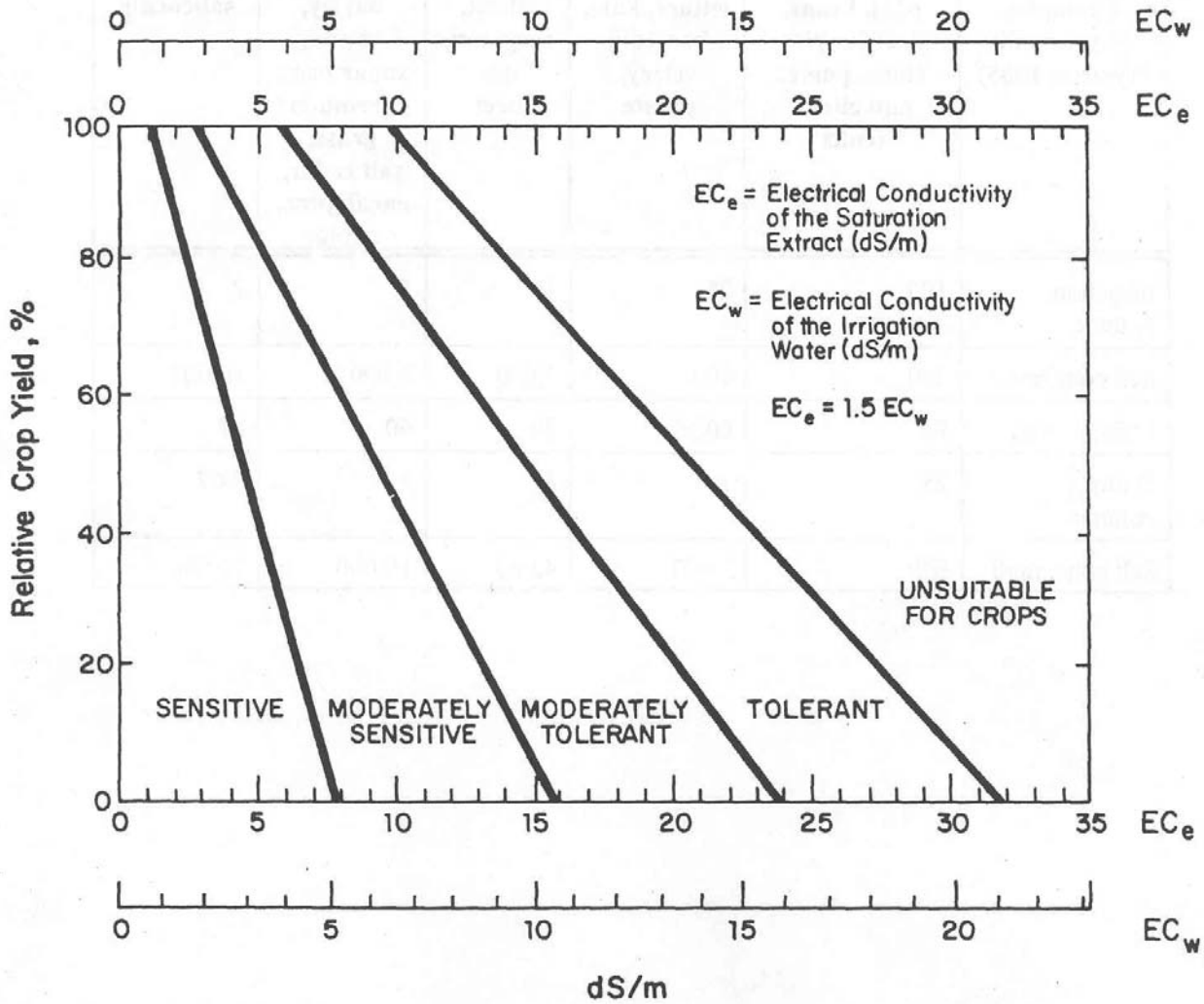


Figure 1. Relative salt tolerance ratings of agricultural crops (E.V. Maas, 1984, as shown by Ayers and Westcott, 1995).

CENTRAL ARIZONA SALINITY STUDY --- PHASE I

Technical Appendix Chapter Q

Soil Salinity Levels of Gila River Indian Community soils

Background: Irrigation development on about 53,000 acres of new lands on the Gila River Indian Community (GRIC) could result in leaching of salts into the regional aquifer. The total irrigation project was planned for 146,000 acres originally but is currently sized at about 130,000 acres based on water supply limitations[(1)] . A total of 77,000 acres have an irrigation history and have probably been leached of native salts[(2)]. The difference between the historically irrigated acreage and the total acreage is 53,000 acres.

In order to better understand and predict the magnitude of this possible occurrence a review of existing soil and vadose zone (refer to definitions section) data was conducted. This data was used to prepare a salinity curve for non-irrigated land that will be developed for irrigation. One curve was developed for upper alluvial fans sites dominated by creosote bush while a separate curve was prepared for relict basin and basin rim soils dominated by desert saltbush vegetation. While extensive soil, and soil substrata data was available from US Bureau of Reclamation (USBR) Land Classification and drainage logs, the Natural Resources Conservation Service (NRCS) soil survey[(3)], and other sources, only limited data was available for vadose zone salinity below a depth of about 30 feet below grade.

The salinity of the vadose zone was estimated to be in balance with the groundwater that once occupied these substrata. Under historic conditions the vadose zones were very thin. As the water table receded deep aggressive root systems of desert scrubs such as mesquite, wolfberry, and saltbush followed the water table down to depths of 30 feet or more. Evidence of this thick root zone includes highly saline soils to depths of 20-30 feet. Evapotranspiration of these deep-rooted plants tended to concentrate salts in the remaining soil water. This soil water was finally consumed as the water table receded even lower beyond the reach of all roots. Eight deep soil borings evaluated by Reclamation commonly found dry soil conditions to depths over 30 feet below grade. Dry soil conditions extended to depths of about 34-37 feet below grade in four of the deeper borings, however some soil moisture was encountered below this depth.

The thick dry soil layers have implications for calculating the time it will take deep percolation waters and salts to reach the water table. The deep percolation will have to fill almost all the micropore space in the soil above a soil depth of 35 feet below grade as well as the macropores that commonly transmit water downward. The total porosity of the aquifer materials probably ranges from about 40-50 percent, while the specific yield probably ranges between 10 and 20 percent. Deep percolation will only need to fill the macropores below a depth of 35-40 feet. The vadose zone anticipated under irrigated conditions extends from a depth of approximately 6 feet or so to the static water table

level, which ranges from about 50 –100 feet in much of the reservation. As the water table continues to be drawn down by pumping the thickness of the vadose zone will increase. For the purpose of this report, the vadose zone at equilibrium conditions, under irrigation, is expected to extend between 6 to 200 feet below grade.

A separate salinity curve was developed for the post irrigation development on previously irrigated lands. This curve assumed irrigation with a combination of Central Arizona Project (CAP) water, Gila river water, other surface waters and groundwater. A leaching fraction of 25 percent on irrigated lands was assumed based on data in reference[(1)]. This leaching fraction is somewhat higher than the current leaching fractions on nearby irrigated lands but is lower than State of Arizona goals. Because the future project will use groundwater as a source of irrigation, the 25 percent leaching fraction is realistic since this level is needed to maintain groundwater quality suitable for irrigation. This level of leaching is judged to be readily attainable on properly designed and managed flood irrigation systems.

The two current dryland salinity curves were compared to the projected irrigated curve to determine the net loss or gain of salts to the aquifers following irrigation development. (Attachment 1). Generally these curves indicate dissolution and removal of salts to a depth of about 17 feet below grade, then extensive salt storage capacity to a depth of about 200 feet below grade. The salt storage capacity of the 17-200 foot substrata zone should minimize any leaching of native salts to the aquifers under irrigated lands.

Based on current development maps it appears that conversion of dryland to irrigated lands will occur on two primary landforms. These landforms are described below.

GRIC Land Characteristics

<u>Basin rims and relict basins</u>

These lands constituent about 90 percent of future project development or about 48,000 acres. The average rainfall in the area typically leaches salts from the top 2 feet of soil but salinity rises sharply below this depth. Salinity in the intermittent slick spot areas is elevated to the soil surface. Soil amendments and leaching operations are needed on most of these lands to reduce soil salt and sodium content prior to successful irrigation. Salt tolerant shrubs such as desert saltbush, wolfberry, and mesquite dominate these lands. Scattered slick spot areas are barren and have iodine bush around the perimeter. These soils are highly saline down to a depth of about 17 feet below grade. Electrical conductivities (ECe) of the soil saturation extracts are in the 10 to 100 decisiemens per meter (ds/m) range and average about 25 ds/m, which indicates soil water salinities of about 50 ds/m. The depth of these saline deposits vary, however, at depths below 30 feet, the salinities must be lower since existing groundwater which has receded from the deeper vadose zones in recent years has an ECe in the 2.0 ds/ m range. This value is roughly equivalent to a soil saturation extract value of about 1.0 ds/m. The average value of 17 soil samples collected below the zone of salt accumulation was 1.02 ds/m. Many of the deeper drainage logs do show indications of a soil salinity decrease from 12-30 feet

below grade. Depth to groundwater maps presented in recent reports[1] suggests the current depth to groundwater ranges from 50-100 feet below grade. Historic groundwater records[3] indicate pre development groundwater depths were about 10- 50 feet below grade. Based on the recent decline in groundwater levels, it is assumed that soil salinity in the 25-200 foot depth zone should be at levels in equilibrium with the groundwater.

The source of the elevated salinity to depths of 12-30 feet is uncertain, however it is postulated that the very deep root zones of the desert shrubs must have pulled water from the water table. The plants used the water for evapotranspiration but the salts were left behind in the soil. As the water table was drawn down by groundwater pumping out of the reach of the deep rooted plants some of the plants died and the other plants are now severely stressed by a combination of excess salts and lack of water.

Alluvial fans and Fan Terraces

Alluvial fans and fan terraces will constitute about 10 percent of the planned irrigated lands. Approximately, 50 percent of the currently developed lands in the Sacaton ranch area are of this type. The soils are coarse textured and generally non-saline. Native vegetation is dominated by Creosote bush. Some of these lands will probably be developed for drip irrigated orchards. Large, deep cut and fills would be needed to develop gravity irrigation on these sloping lands into field size level basins. The average ECe of these lands is about 5 ds/m to a depth of 20 feet. Based on analysis of existing soil boring logs it appears the salinity of the upper vadose zone above 50 feet is about 1ds/m. The salinity of the lower vadose zone is also estimated at 1ds/m based on soil materials being in balance with current ground water salinities.

The NRCS soil survey lists the Denure soil series as representative of this land type. These soils are not listed as saline. They are characterized as non-saline, coarse textured soils. According to the NRCS soil survey [3], these soils cover over 30,000 acres of land on the reservation.

USBR Data Summaries

A summary of USBR data collected on GRIC is presented below: Weighted average soil salinity values, as well as the observed depth of the salinity drop off were evaluated. Many of the logs extending to a depth of 20 feet below grade or less did not exhibit any salinity drop off to the observed depth. The soil data was sorted by vegetation type. Of the 43 logs examined, the estimated breakdown by vegetation type is listed on the next page:

Table 1 - Vegetation type

Vegetation type	Landform	Relative Extent of newly developed acres
Saltbush, wolfberry scrub, mesquite	Relict basins, 0-3 percent slopes, uneven	90 %
Creosote bush	Alluvial fans and fan terraces, 2-6 percent slopes	10%

Table 2 – Reclamation Data summary

Parameter	Number of observations	Average	95% range low	95% range high
Weighted Average Ece to salinity reduction point. Basin lands	30	25.1 ds/m	20.8 ds/m	29.4 ds/m
Ece below 17.2 feet. Basin lands.	17	1.02 ds/m	0.79 ds/m	1.25 ds/m
Depth to Salinity reduction point. Basin lands.	11	17.2 feet	12.7 feet	21.7 feet
Fan Terrace lands, weighted average Ece to salt reduction point.	3	5.1ds/m	ID	ID

Ece = electrical conductivity of the saturation extract.
ID = insufficient data

NRCS Soil Survey Data Summary

The following table presents soil data from the NRCS soil survey. This data is commonly for a soil depth of 0- 5 feet below grade.

Table 3 - Soil Series Salinity Summary

Soil unit principal soil	Average Ece at 5 feet ds/m	Landform (NRCS)	Extent acres (x 1000)
Shontic	17	Relict basins	40
Casa Grande	25	Relict basins	53
Redun	31	Relict basins	21
Denure-Pahaka	2-5	Fan terraces	33
Yamato	42	Higher floodplain	18
Indio	22	Higher floodplain	19

The soils listed in Table 3 make up the bulk of the current and future irrigated acreage. The NRCS data generally supports and is very similar to data collected by the USBR. The NRCS soil survey narrative indicates that groundwater was much shallower in the survey area prior to about 1870. Evidence in soil profiles indicate shallow groundwater was present in vast areas of the floodplain, and in relict basin lands surrounding the floodplain. Water tables were probably shallower than 10 feet over much of the survey area prior 1900. Since the advent of upstream irrigation diversion, dams controlling floodwater, and the extensive groundwater pumping in the reservation, the groundwater table has been lowered to depths ranging from about 50 feet to over 100 feet below grade in the interior of the reservation[(1)]. One deep boring drilled in 1996 by Reclamation drainage crew's encountered groundwater at about 29 feet below ground surface. None of the other 7 borings drilled encountered any evidence of groundwater or capillary fringe conditions above a depth of 40 feet. The GRIC water use plans call for continued use of ground water and a gradual draw down of the static water table. Stabilization of groundwater levels at roughly 200 feet may occur as gradients to off reservation aquifers are reduced, and project pumping comes into balance with recharge and off reservation subsurface flows.

The NRCS soil survey of the area indicates the most common soil series on the relict basins is the Casa Grande soil. This soil comprises over 50,000 acres of land in the irrigation areas. The typical soil profile of this soil indicates that salts have been leached to an ECe level of less than 4 ds/m near the soil surface to about 16 ds/m at a soil depth of 11-18 inches however below this depth the profile has a salinity of about 25-29 ds/ meter to a depth of 60 inches. These values agree very well with the values found at the 43 USBR deep boring sites.

Project Water Management Planning Data Summary.

Current groundwater quality and depth conditions as well as future water management plans, were estimated from data contained in the Draft Gila River Indian community water management plan[(1)]. A summary of data presented in the draft water management plan, and considered in this paper, is as follows:

1. Depth to groundwater 50-100 feet below ground surface
2. Average groundwater salinity 1200 mg/l range 500- over 2500 mg/liter
3. Average surface water salinity all sources 860 mg/l
4. CAP water salinity 550 mg/liter, expected to increase by 15 percent.
5. Groundwater pumping will increase to about 260000 acre-feet per year, which will draw the water table down over time.
6. The average recharge of the Gila river to GRIC aquifers is estimated at 44000 af/year
7. Conveyance efficiency 90 percent
8. On farm efficiency 70 percent
9. Leaching Fraction 25 percent

10. Safe yield of aquifers 157000 af/year.
11. Full water allocation 653,492 af/year
12. Water applied per acre is about 5-acre feet/year on irrigated land.
13. Total project development limited to 130000 acres due to water supply issues.
14. Irrigation application uniformity goal is 80 % plus.
15. Deep percolation from irrigation will reach the water table within 3-6 years.
16. Salt movement to the water table will be somewhat slower about 6-12 years.

Anticipated Post Irrigation Soil and Vadose Zone Salinity curve

The calculations presented below were used to determine the average salinity of water infiltrating the soils. Infiltrated Water ECe determination assumptions:

3 feet of surface water at Eciw 1.34 ds/m
2 feet of groundwater at ECiw 1.88 ds/m
0.5 feet of rainwater at ECe 0.0 ds/m
Weighted average water quality 1.41 ds/m

The post irrigation development salinity curves are based on the following assumptions:

The leaching fraction will be about 25 percent of applied water
The salinity of CAP water will be about 0.85 ds/m.
The survey areas rainfall is about 8 inches per year of which 6 inches infiltrates the soil and is available for crop use and leaching.
Lands are irrigated with 60 percent CAP water and 40 percent groundwater.
Salts in soil water will be at equilibrium with drainage waters.
No dissolution or precipitation of gypsum or carbonate salts in soil or vadose zone.
Deep percolation from irrigation and rain is equal to 25% of applied water or roughly 163,000 acre feet / year. A portion of this deep percolation will flow beyond the reservation boundaries since current groundwater gradients are generally indicate subsurface flows to the northwest and north. As the reservations groundwater levels are drawn down these gradients should decrease which would in turn reduce the volume of these flows.

The time for the vadose zone to come to equilibrium with the new project irrigation development is estimated at 5-20 years; however the project soils to a depth of 6 feet below grade should be near dynamic equilibrium within five years of initial irrigation development. Based on a leaching fraction of 25 percent, the ECe of the vadose zone water below a depth of about 6 feet should be equal to the weighted average ECe of the infiltrated irrigation plus the rainwater divided by the leaching fraction. (1.41/ 0.25 or about 5.6 ds/m) This ECsw should extend down the water table at an estimated depth of 200 feet. The equivalent ECe would be roughly half of the ECdw or about 2.8 ds/m.

Since plants extract nearly pure water from root zone soils and leave behind most of the soluble salts, soil salinity should increase successively from a depth of 1-6 feet as plants use less water from the soil. The most commonly assumed plant water use pattern

assumes plants extract 40 percent of their water from the top foot of soil, 30 percent from the second foot of soil, 20 percent from the third foot of soil, and about 10 percent from the fourth foot of soil. Soil waters moving up from the 5th and 6 th foots also are used by plants, however under irrigated conditions very little water is used below the 6th foot. This analysis also assumes some water use in the 4-6 foot zone based on measured ECe and chloride levels at the 4-6 foot depth on the Maricopa field station and other local irrigated fields. Once the percolating waters and salts reach a depth of 6 feet they enter what is commonly referred to as the vadose zone. This zone extends to the water table.

Based on the water extraction pattern presented above and a leaching fraction below the root zone of 25 percent, the equivalent leaching fractions for the root zone and vadose zones, and the estimated soil salinity levels following irrigation development are listed below.

Table 4 Salinity conditions – post irrigation development

Soil depth	percent LF	Soil Salinity (Ecsw ds/m)	Soil Ece ds/m
1 foot	65	1.66	0.83
2 foot	55	2.56	1.28
3 foot	45	3.13	1.57
4 foot	30	4.70	2.35
5 foot	27	5.22	2.61
6 foot	25	5.64	2.82
vadose	25	5.64	2.82
wt depth	25	5.64	2.82

LF = leaching fraction
CAP water /Groundwater, blended at 60-40. Adjusted for 6 inches of rainfall infiltrating soil. Ec 1.41 ds/m

<u>Pounds of salt subject to leaching</u>

An estimate of the weight of salts in the top 17.1 feet of soil can be calculated for both the basin rim lands and the fan- terrace lands. The following assumptions were used for this estimate:

One acre foot of soil weighs 4 million pounds. (bulk density 1.47 grams/cc)
The average saturation percentage in substrata materials is 30 percent. (Sandy loam)

Relict basins Calculation:

Average Ece 25.1 * .64 = 16064 parts per million saturation extract
Parts per million soil Dry weight basis = 16064 * .30 = 4819 ppm soil
Salts per acre foot of soil = 4 * 4819 = 19276 pounds per acre foot
Salts per acre = 17.1 * 19276 = 329620 or about 165 tons per acre

Using the same calculations the salts contained in the top 17.1 feet of fan terrace lands is estimated at 66,963 pounds per acre or about 33 tons per acre. Based on an estimated

acreage split of 48,000 relict basin lands and 5,000 acres of fan terrace lands the total tonnage of soluble salts available for leaching from newly developed irrigated lands would be about 8.1 million tons.

Salinity interactions in the Vadose zone

Below a depth of about 17 feet the salinity of the substrata drops off dramatically. The salinity of the substrata below this depth should be related to the salinity content of the groundwater that was withdrawn from the aquifer materials. Based on limited upper vadose zone data the salinity level of the aquifer materials between 17.2 feet and 200 feet are estimated at 1ds/m. The low salinity associated with this thick vadose zone interval creates a large salt storage zone. The difference in the anticipated Ece under irrigation (2.82 ds/m) and the current ECe (1.0 ds/m) will permit the storage of a large mass of salts. These salts will be leached from the upper saline soil zones above 17.2 feet as well as from salts in the irrigation waters. The total estimated salt storage capacity in this zone is equivalent to an ECe of about 1.8 ds/m or a percent soluble salt content of about .035 percent or 1400 pounds per acre-foot. The total salt storage anticipated in the 17-200 foot zone is estimated at 183 feet * 1400 pounds/ foot = 256,200 pounds or about 128 tons per acre. Since the top 17 feet of soil and substrata will also contain some residual stored salts, about 10 tons. The total anticipated salt storage in the soil and vadose zone under the newly developed 53,000 acres would be about 7.3 million tons. This leaves a net salt outflow to groundwater prior to dynamic equilibrium conditions of about 8.1 million tons – 7.3 million tons = .8 million tons of salt. The six attached graphs depict the general soil and substrata salinity conditions before irrigation development and after dynamic equilibrium conditions are reached.

Definitions

Vadose Zone- The substrata zone between the root zone and the saturated zone (water table). Water in this zone is not concentrated due to the evapotranspiration process.
ECe- electrical conductivity of the soil saturation extract.
ECsw- electrical conductivity of the soil water.
ECdw- electrical conductivity of the drainage water.
ECiw- electrical conductivity of the irrigation water.
TDS mg/liter = total dissolved solids = Approximately equal to the ECe in ds/m times 640.

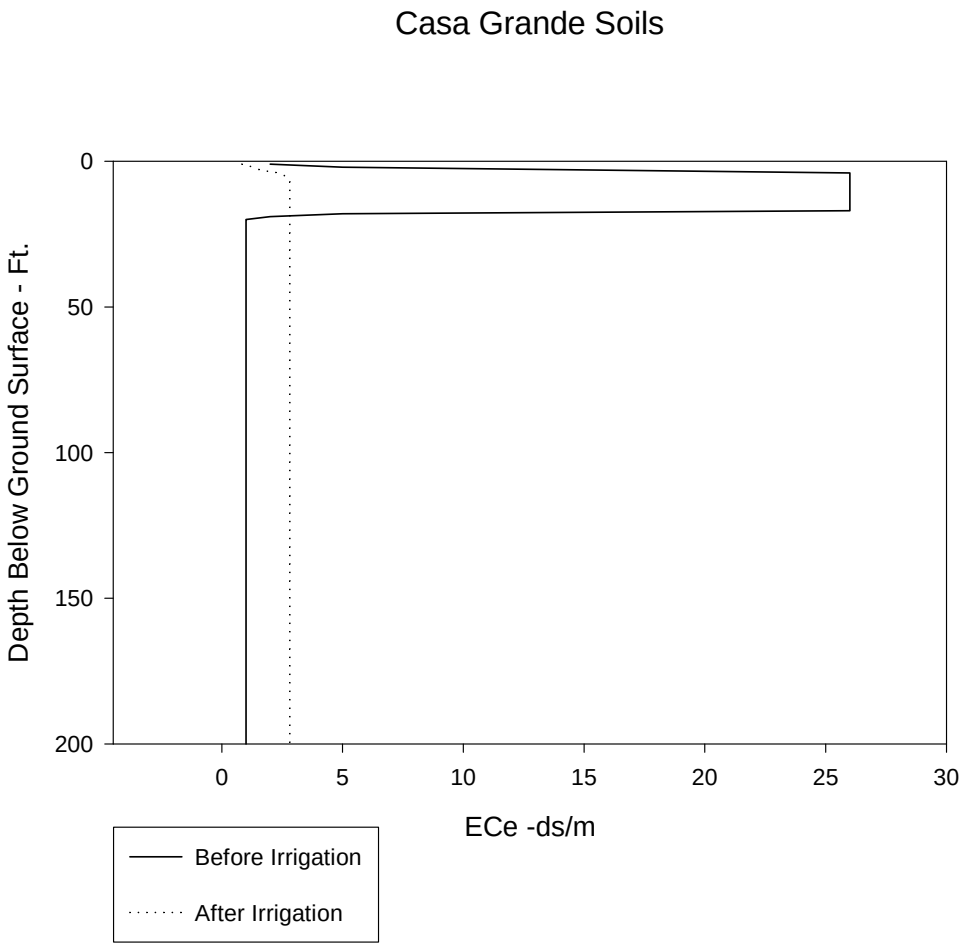
References

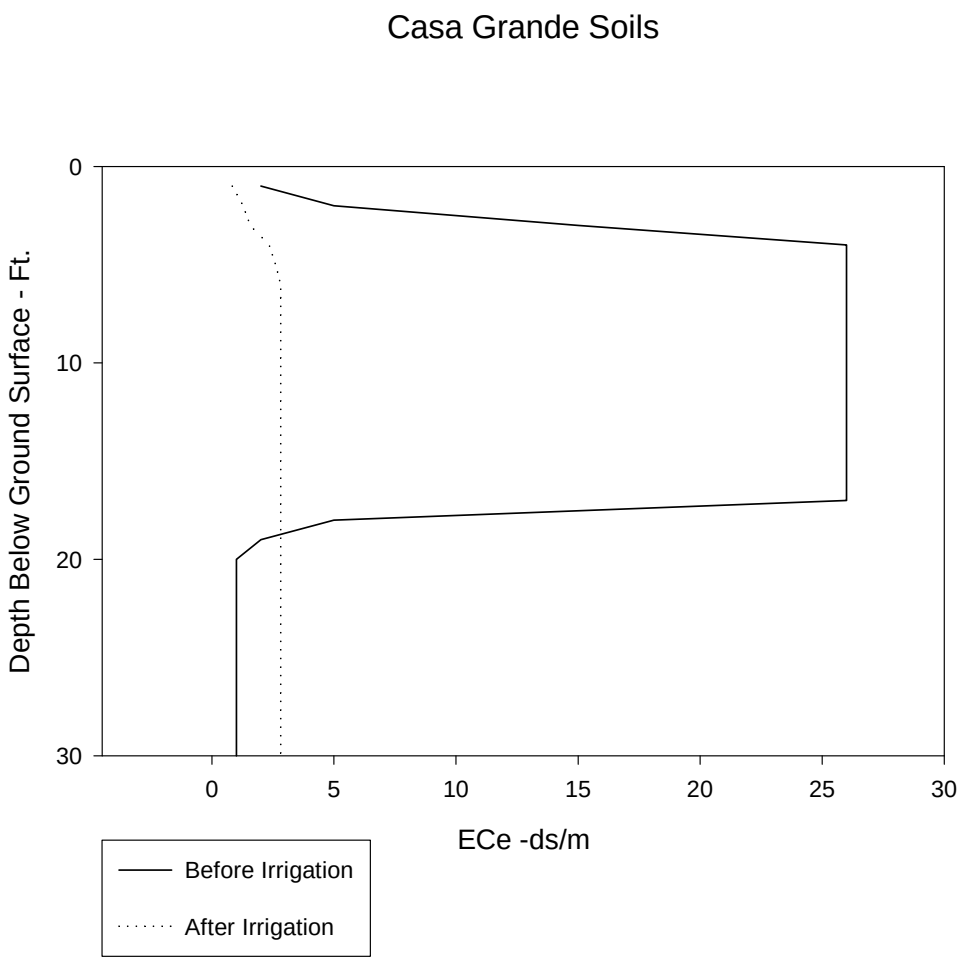
(1) Gila River Indian Community Draft comprehensive Water Management Plan, Keller- Bliesner Engineering, LLC, Associated Earth Sciences, INC, Northwest Economic Associates, August 10, 2001.

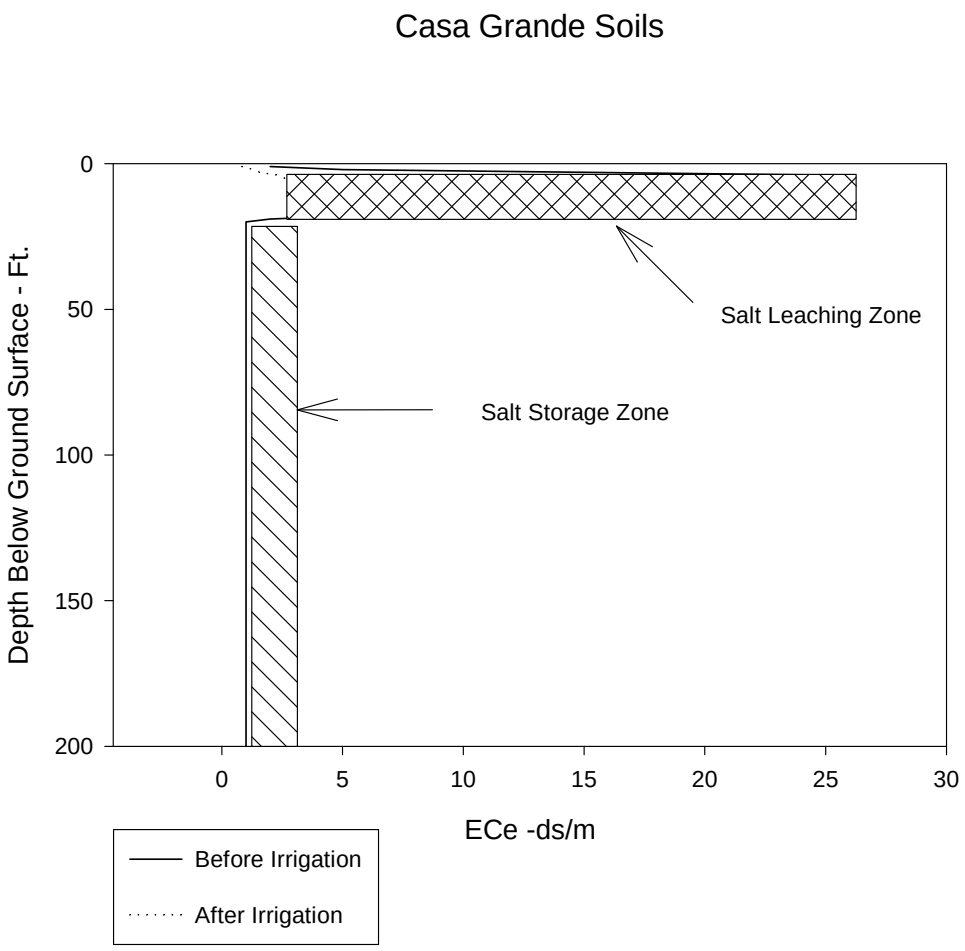
(2) Land Class Parameters, Gila River Indian Community, Pima Maricopa Irrigation Project, Ecoplan Associates, October, 1998.

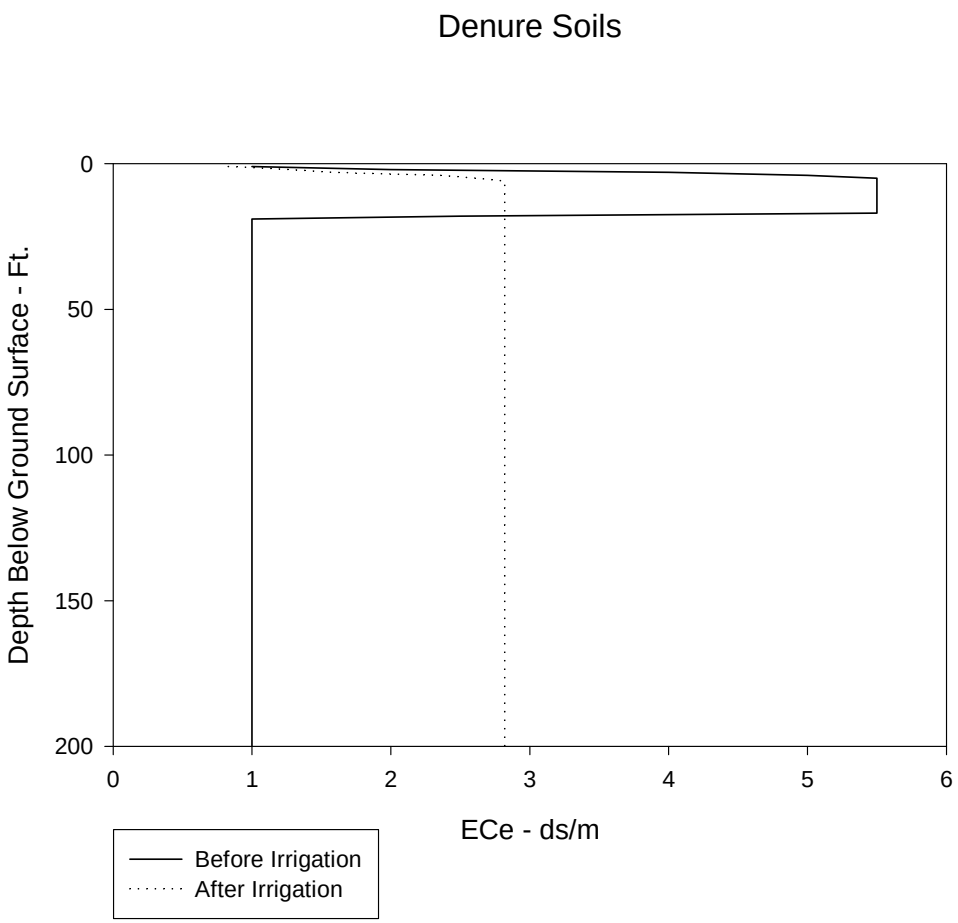
(3) Soil survey of Gila River Indian Community, Arizona, Parts of Maricopa and Pinal Counties, USDA, NRCS, no date. Fieldwork in 1986.

Attachment 1 - Representative soil salinity curves for before and after irrigation conditions.




Casa Grande Soils
Depth Below Ground Surface - Ft.
0
10
20
30
0
5
10
15
20
25
30
ECe -ds/m
Before Irrigation
After Irrigation


Casa Grande Soils
Depth Below Ground Surface - Ft.
0
50
100
150
200
0
5
10
15
20
25
30
ECe -ds/m
Salt Leaching Zone
Salt Storage Zone
Before Irrigation
After Irrigation


Denure Soils
Depth Below Ground Surface - Ft.
0
50
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150
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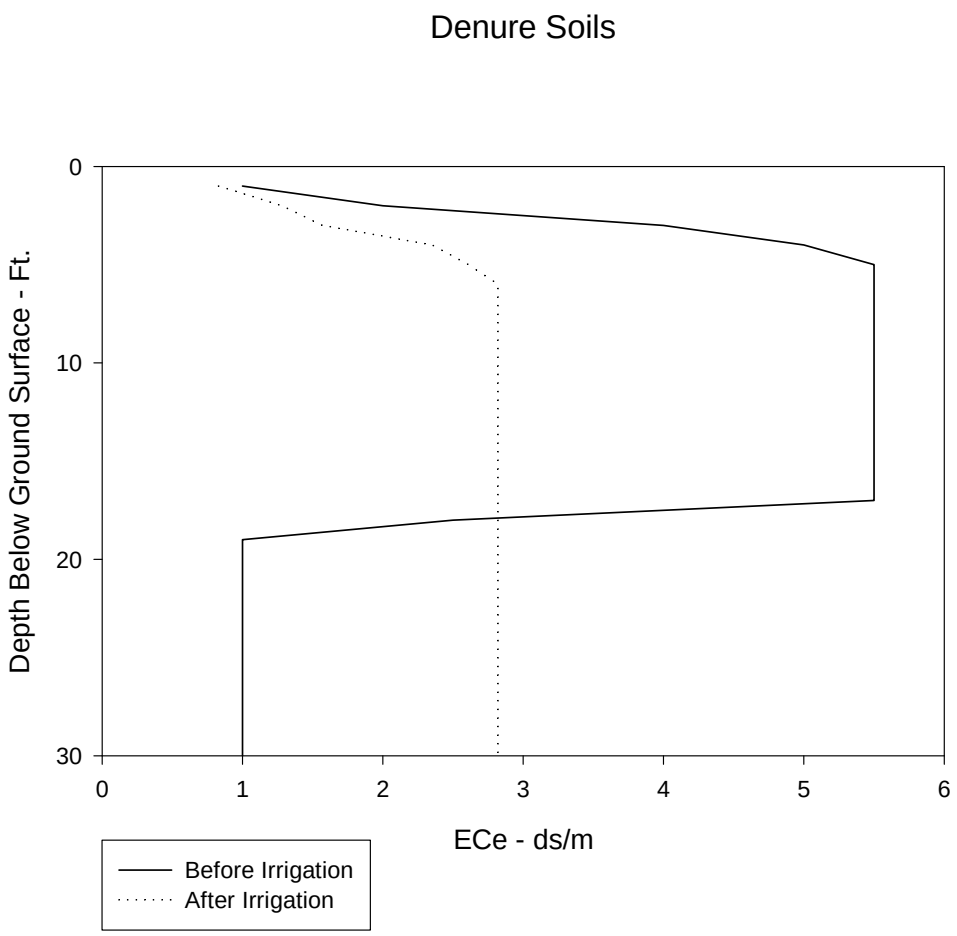
3
4
5
6
ECe - ds/m
Before Irrigation
After Irrigation


Denure Soils
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ECe - ds/m
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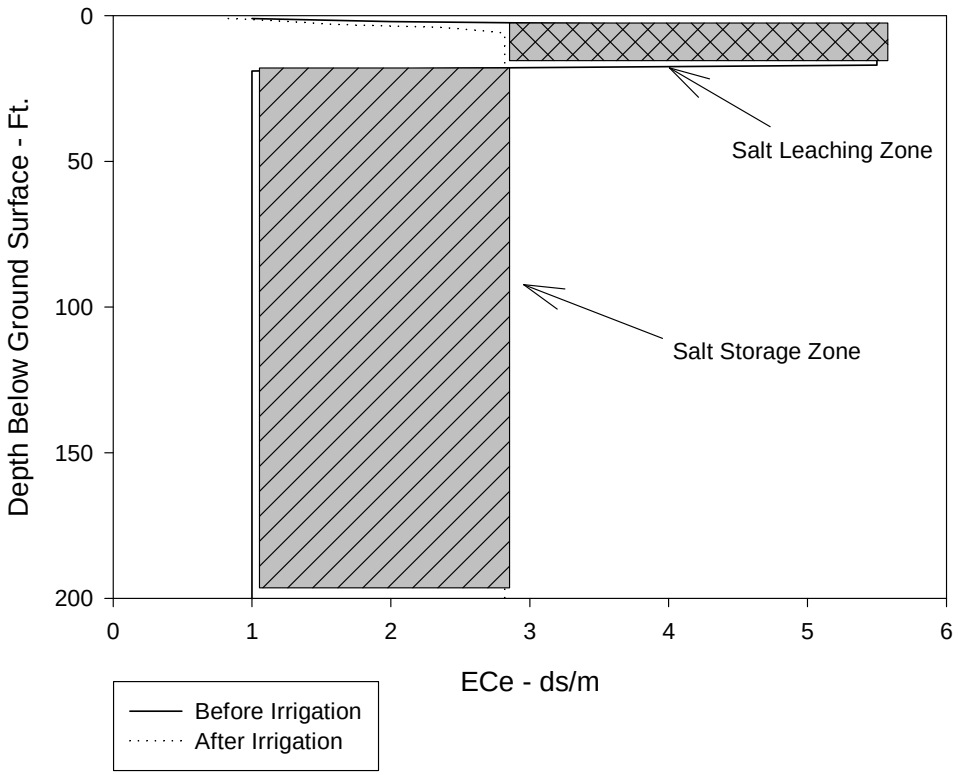
Denure Soils



CENTRAL ARIZONA SALINITY STUDY --- PHASE I

Technical Appendix R

Evaluation of fertilizer use and associated salt contributions to Central Arizona Project Area

The following paper was prepared to provide rough estimates of fertilizer use in the Phoenix Metro area as well as to narratively discuss other possible salinity inputs to the Central Arizona area that should be considered in long-term salt balance projections.

Cropping Pattern

Table 1 lists the cropping pattern for the Phoenix Metro area.

Crop Type	Phoenix Agriculture	GRIC Agriculture
Cotton	69,900	3,443
Barley	11,200	406
Alfalfa (Hay)	55,280	2,975
Wheat	8,420	1,703
Corn	600	
Broccoli	4,000	
Cantaloupe	9,600	
Watermelon	3,900	408
Potatoes	6,500	
Head Lettuce		
Grapefruit	2,400	250
Oranges	4,600	700
Lemons	1,400	
Tangerine	3,200	
Onions	900	233
Olives		600
Cauliflower	300	
Carrots	1,800	
Honeydews	2,700	
Grapes	2,000	
Totals (acres)	**188,700**	**10,718**

Table 1. Phoenix Area cropping pattern

Fertilizer characteristics and properties

Although technically most fertilizers are nearly 100 percent salts, plants use most of the applied nutrient salts. These nutrient salts are removed by the crop or recycled in the soil. The salt index values of fertilizers are an effort by the fertilizer industry to rate the different fertilizers in relation

to one another based on the amount of residual soluble salts contributed to the soils in addition to the primary nutrient salt used by plants. The salt index is based on the osmotic potential relative to Sodium Nitrate (salt index of 100). This data was developed by measuring the osmotic potential of the added fertilizer in planting beds. The main salinity hazard of the high salinity fertilizers is their use in bands near the seed row. Once the plants emerge and begin extending roots into the soil the salinity hazard from fertilizer is greatly reduced. From Table 3 it appears that a 500-pound application of ammonium sulfate (100 pounds of actual N) would contribute about 290 pounds of salt to the soil, while an application of anhydrous ammonia of about 123 pounds (also equal to 100 pounds of N) would only contribute about 48 pounds of soluble salt to the soil. These values are insignificant when compared to the salts applied in irrigation water. For example a four-foot annual application of 1000 mg/L salinity irrigation water would contain 10,880 pounds of salt. Eg: (1000ppm) (2.72 million pds/AF) (4AF) = 10,880 pds. Based on nutrient removal rates of crops listed in Table 4 compared to the fertilizer application rates listed in Table 4, it would appear that nutrient removal by crops would generally exceed and offset any salts applied in fertilizers. Removal of salts by crop plants probably ranges from about 200 - 600 pounds per acre, or about 3 percent of the harvested dry crop weight[3] removed from the field. Large portions of these salts are macronutrients that are added in fertilizers. Aside from the direct salinity inputs of fertilizer materials, there is a secondary influence on soil salinity, especially in soils containing residual carbonates such as the soils in the CAP area. Most fertilizer materials are acid forming. These acid forming constituents dissolve and combine with the residual calcium carbonate in the soil to form soluble salts. This is generally beneficial for exchangeable sodium reduction and the improvement of soil physical properties. However the soluble calcium salts do add to the salinity of the soil and groundwater. The acid forming potential of some common fertilizer materials is listed in Table 2.

Fertilizer	**Pds of CaCo3 dissolved in Neutralization process (100 pds bulk)**
Ammonium sulfate	110
Ammonium nitrate	62
Anhydrous ammonia	147
Uran	57
Super phosphate	0
Ammonium phosphate sulfate	88
Mono ammonium phosphate	58

Table 2 Acid forming potential of fertilizer components

The most common fertilizers used in the western states and their respective salt index values are presented on Table 3. Mixed fertilizers were evaluated based on the salt index of ammonium phosphate and of potassium chloride. A salt content value of 2.1 pounds of salt per pound of nitrogen and 0.1 pd per pound of phosphorous (P_20_5) and 0.77 pounds per pound of K_20 was used for mixed fertilizers.

		Pounds of salt per	
Fertilizer	**Salt Index**	**100 pds bulk fertilizer**	**pd of Nutrient**
Anhydrous ammonia 82-0-0	47.1	39.6	0.48
Ammonium nitrate 34-0-0	104.7	87.9	2.59
Ammonium phosphate 11-48-0	26.9	22.6	0.38
Ammonium sulfate 21-0-0	69.0	58.0	2.76
Calcium Nitrate 15.5-0-0	52.5	44.1	2.85
Ammonium, phos. Sulfate 16-20-0	48.0	30.7	0.85
Diammonium phosphate 16-48-0	29.9	25.1	0.39
Super phosphate 0–16-0	7.8	6.5	0.41
Super phosphate 0-48-0	10.1	8.5	0.18
Manure salts 20%	112.7	94.1	4.70
Sodium nitrate 16-0-0	100.0	84	5.25
Urea 46-0-0	75.4	63.3	1.38
Urea- am. nitrate sol. 32-0-0 (1)	66.4	42.4	1.32
Potassium chloride 0-0-60	116.3	46.5	0.77

(1) Liquid solution 11.2 pounds per gallon 1.33 sp gravity

Table 3 Fertilizer salt index values

Salts in soil amendments

Large applications of gypsum, sewage sludge, and manure and other materials are sometimes applied to agricultural lands. Gypsum applications on newly irrigated sodic soils can sometimes exceed 10 tons per acre. Gypsum application rates on most newly developed lands using CAP water can be reduced because Colorado River water contains significant soluble calcium. Sulfuric acid is the current soil amendment of choice in CAP irrigated lands. Chemical reactions and cation exchange processes that occur following application of these amendments generally liberates large quantities of calcium and sodium salts. Calcium and sodium salts are probably imported with the water into the area. Each amendment listed below would result in ten tons of soluble salts. Probably less than 10 percent of the land in the basin will require these amendments, including some lands planned for development on the Gila River Reservation.

Soil amendments	**Typical application rates required on newly developed lands**
Gypsum	10 tons per acre
Sulfuric acid	6 tons acre
Sulfur	2 tons acre

Table 4 Application rates of Soil Amendments

Manure applications of 10 tons per acre are generally considered an agronomic rate that would supply a crop with most of its nutrient needs. Sewage sludge application rates vary depending on heavy metal and nutrient content, but probably average about 5 tons per acre. Although these materials contain significant salts, the salts probably originate and are recycled in the survey area and thus should not be considered in the long-term salt balance.

Amendment	Typical application rate/ acre
Steer manure	10 tons
Dairy manure	10 tons
Sewage sludge	5 tons

Table 5 Manure Application rates

Plant food utilization

Plant food utilization is typically higher than fertilizer applications since soils typically contain a reserve of nutrient elements. For example desert soils such as those in the survey area are sometimes well supplied with native phosphorous and potassium but are typically low in nitrogen. These soil reserves may become depleted after many years of continuous cropping and additional fertilizers will need to be added. For example, a crop of alfalfa uses over 1000 pounds of nutrient elements, nearly all of which is removed from the field in the crop. Because the alfalfa is able to fix nitrogen from the atmosphere, little nitrogen is needed for this crop. Data from the University of Arizona Extension Service indicates that typical soils irrigated with CAP water are well supplied with potassium (K) and phosphorous (P). Alfalfa does respond to phosphorous fertilization in many areas of the west and also requires a great deal of potassium. It is predicted that in future years additional P and K will be added in fertilizers as native reserves of these elements are depleted.

Crop	Yield	Pounds per Acre			
		N	P_2O_5	K_2O	Source
Barley	2.5 tons	175	65	175	1
Cotton	1500 pounds	210	90	150	1
Wheat	3.0 Tons	175	80	140	1
Alfalfa	8.0 tons	450	80	480	1
Corn	5 tons	240	100	230	1
Cantaloupes	30 tons	190	60	340	1
Potatoes	500 cwt	250	115	355	1
Broccoli	18000 lbs	80	30	75	1
Oranges	30 tons	120	40	175	1
Grapes	15 tons	105	45	125	1
Carrots	20 tons	92	28	84	2
Lettuce	21 tons	95	28	208	2
Cantaloupe	7.25 tons	30	12	62	2
Onions	12.5 tons	53	26	64	2
Potatoes	18 tons	120	30	200	2
Tomatoes	15 tons	93	24	130	2
Cauliflower	13 tons	72	24	50	2
Broccoli	6 tons	60	20	50	2
Cabbage	15 tons	100	25	100	2

1 Western Fertilizer handbook (1), total crop use.
2 Vegetables growers' handbook (2), Nutrients removed in harvested portion of crop.

Table 6 Plant food utilization by crop

The data listed in Table 7 are based on crop budgets from the University of Arizona Extension Service. Data for citrus is based mostly on oranges since that is the dominant citrus crop in the area.

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Crop	Yield Per Acre	Nitrogen pds/acre	P_20_5 pds/acre	K_2O pds/acre	Net Salt pds/ acre	Bulk Fert.
Cotton	1227 pounds	150	0	0	206	326
Barley	4600 pounds	167	50	0	291	653
Alfalfa	8 tons	0	0	0	0	0
Wheat	5600 pds/ acre	182	50	0	230	628
Corn	8400 pds/ acre	341	90	0	223	660
Broccoli	597 cwt	151	158	23	238	786
Cantaloupe	260 cwt	371	126	15	546	1500
Watermelon	16.3 tons	189	115	0	225	608
Potatoes	291 cwt	150	184	0	346	824
Head lettuce	212 cartons	192	156	0	281	804
Citrus	30 tons	160	40	0	231	600
Olives	10 tons	160	40	0	231	600
Onions	928 sacks	252	212	0	375	1072
Cauliflower	816 cwt	197	208	0	524	894
Carrots	1046 car	154	60	0	235	636
Honeydews	638 cart	158	126	15	265	854
Grapes	15 tons	140	40	0	204	557
Lawns	na	100	40	40	245	543

Data from the University of Arizona Extension Service

Table 7 Fertilizer application rates

Lawn fertilization

Lawn areas do not require much fertilizer if the grass clippings are returned to the soil. However, since homeowner lawn management varies greatly, the fertilizer requirements for lawn areas presented below are based on good management practices. The following fertilizer application is assumed based on recommended values from various sources.

Spring	Weed and feed	26-3-3
Summer	ammonium sulfate	21-0-0
Fall	balanced fertilizer	12-12-12
Winter	winterizer	16-4-8

Lawn areas per acre 100pds N 40 pds P_20_5 40 pds K_20

Salt values:
Non nutrient salinity 245 pounds/ acre
Total Weight of fertilizer 543 pounds/ acre

Other sources of salts

Irrigated agriculture can lead to three primary avenues of salt pick up from the calcareous arid soils in the survey area.

1. Native, nonirrigated soils such as those on the Gila River Indian Community farms sometimes contain a large quantity of residual salt. During the first few years of irrigation a large portion of this salt will be dissolved and leached into the substrata and vadose zone. Eventually these salts will reach the groundwater. The top 10 feet of soil in some of the more saline arable lands contain about 1 percent soluble salts, or about half a million pounds of salt per acre. Although these soils are reclaimable, at least 50 percent of these salts will be leached from the soil during the agricultural development period.

2. Many fertilizer materials are acid forming. In the arid climate of the study area nearly all soils are calcareous and contain large quantities of residual carbonates (lime). The addition of acid forming fertilizers can solublize these salts. While this may be beneficial for short-term sodic soil remediation, it does tend to add to the long-term salt problem in the basin. For example: A grower decides to use ammonium sulfate to supply his nitrogen needs, which are 100 pounds of actual nitrogen per acre. This would require 476 pounds of bulk fertilizer. Based on Table 3, he is adding about 276 pounds of salt directly. However, the acid forming component of the fertilizer will also dissolve the equivalent of about 524 pounds of calcium carbonate from the soil. Generally the reaction by-products would be carbon dioxide, and soluble calcium sulfate. Calcium sulfate is only sparingly soluble, but the dissolved calcium will exchange with other cations on the exchange complex and liberate other soluble cations into the soil solution.

3. Chemical weathering of soil minerals generally accelerates following irrigation. Carbonates and gypsum are the primary minerals, but weathering of silicates and other minerals can also occur. Generally, the greater the deep percolation volume the greater the weathering. When a leaching fraction of over 25 percent is considered there is a net increase of drainage water salts at the bottom of the soil root zone[(3)]. At leaching fractions of less than 25 percent there is generally a net loss of salts in the drainage water at the bottom of the root zone due to precipitation of salts from the soil solution[(3)].

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Summary Crop	Fertilizer net salt inputs million pounds	Total weight of fertilizer million pounds
Cotton	14.4	22.8
Barley	3.3	7.3
Alfalfa	0.0	0.0
Wheat	1.94	5.3
Corn	0.13	0.4
Broccoli	0.95	3.14
Cantaloupe	5.24	14.40
Watermelon	0.88	2.37
Potatoes	2.25	5.36
Citrus	2.70	6.96
Onions	0.34	0.96
Cauliflower	0.16	0.27
Carrots	0.42	1.14
Honeydews	0.72	2.31
Grapes	0.41	1.11
Totals	**33.84**	**73.82**

Gila River Indian Community (GRIC) Crop		
Cotton	0.71	1.12
Barley	0.12	0.27
Alfalfa	0	0
Wheat	0.39	1.07
Watermelon	0.09	0.25
Citrus	0.22	0.57
Onions	0.09	0.25
Olives	0.14	0.36
Total	**1.76**	**3.89**

Table 8 Salts added to crops via fertilizers in Phoenix Metro area and GRIC

Results

Based on data presented in this paper, my estimate of salt inputs into the Phoenix area is presented below:

Salts imported in fertilizers non-nutrients to crops	35.60 million pounds/ year
Lawns	245-pounds/acre/ year

References

(1) Western Fertilizer Handbook, California Fertilizer Association, 1973, copyright 1975.
(2) Handbook for Vegetable Growers, J. E. Knott, 1957, University of California, Davis.
(3) Agricultural Salinity Assessment and Management ASCE manuals and Reports on Engineering Practice No. 71, Kenneth K. Tanji, editor, 1990

CENTRAL ARIZONA SALINITY STUDY --- PHASE I

Technical Appendix S

Trends in Membrane Technology

INTRODUCTION

The Central Arizona Salinity Study (CASS) was initiated to evaluate the magnitude of the salinity issue in the central Arizona and Tucson areas and to develop an appropriate regional management strategy. Membrane treatment for drinking water and wastewater removes and concentrates impurities, including salts, which must be discharged as a waste product of the treatment process. Municipal and industrial water users in Arizona are currently using membrane technology that produces a salty concentrate. Membrane technology improvements and increasing cost effectiveness could increase membrane use and the associated concentrate discharge. As a result, trends in membrane technology will have an impact on salinity issues in central Arizona. The purpose of this White Paper is to provide a brief overview of trends in membrane technology, its use in central Arizona, and the relation to salinity issues.

CENTRAL ARIZONA SALINITY STUDY OVERVIEW

CASS is evaluating the magnitude of the salinity issue in central Arizona, because salinity is known to be a potential issue related to some water supplies. Salinity in water supplies can reduce agricultural crop yields, impact residential use by causing taste issues and reducing household appliance life, and increase industrial costs for advanced water treatment of process and cooling water. The primary source of salinity in central Arizona and Tucson is the water supply, which includes the Central Arizona Project (CAP), the Salt and Verde Rivers, and the Gila River that average approximately 650, 480, and 600 mg/l total dissolved solids (TDS), respectively.

Average annual salt accumulations are significant. For example in the Phoenix metro areas, approximately 1.5 million tons of salts are imported and 0.4 million tons of salts are exported. This results in an accumulation of an estimated 1.1 million tons of salt per year. Approximately 0.5 million tons of salt accumulate annually in the Pinal County area, and CAP utilization in the Tucson area results in the importation of approximately 65,000 tons annually.

The Maricopa Association of Governments 208 Water Quality Management Plan Update (October 2002) recently reiterated salinity concerns in the region:

> *Another important issue impacting groundwater quality in the MAG planning area is salinity. All waters used for irrigation, urban as well as agricultural, contain salts. Excess irrigation water is applied to irrigated plants to prevent accumulation of salts in the root zone, and surface water and effluent containing dissolved salts are recharged to the groundwater through percolation basins and wells. Much of this salt quantity is being imported to the MAG area in our water supplies from the Salt River and the Central*

Arizona Project (Colorado River). The potential effects and management of salt accumulation in south-central Arizona are addressed in two recent papers: "Accumulation and Management of Salt in South Central Arizona", Bouwer, 1999; and "Where do the salts go?," Cordy and Bouwer, USGS Fact Sheet, June 1999.

The Management Plan summarized the primarily long-term impacts of the shallow groundwater. These impacts include the degradation of water quality in the aquifers utilized for municipal water supplies and increased salinity in the waterlogged and shallow-groundwater areas.

CASS initiated this evaluation of membrane treatment technology, because membranes are currently used in the area and may have increased use in the future. Concentrate has typically been discharged to surface waters, municipal wastewater treatment plants or pumped to deep aquifers via deep well injection. To a lesser extent, other options have been land disposal or evaporation ponds. Apart from the salinity of the concentrate discharge, other issues becoming increasingly important are the contaminants present in the reject stream. In some cases it is becoming necessary to treat the concentrate for these contaminants before disposal.

MEMBRANE TREATMENT PROCESSES

Membrane treatment processes are used for treating potable water, treating wastewater for reclamation and reuse, and treating both industrial process source and wastewater. Membrane technology removes constituents that cannot be effectively removed with conventional treatment such as dissolved solids, organic chemicals, and other inorganic chemicals such as nitrate.

There are five primary types of membrane treatment:

- Microfiltration (MF)
- Ultrafiltration (UF)
- Nanofiltration (NF)
- Reverse osmosis (RO)
- Electrodialysis (ED)

Each of these processes is described briefly as follows:

Microfiltration (MF): a physical separation process applied to removing particulates, typically down to bacterial sizes. Virus removals are relatively low. Organics and other dissolved substances are not removed. Pore sizes are 0.1 μm or greater.

Ultrafiltration (UF): also essentially a physical separation process. Pore sizes are 0.01 μm or greater. UF achieves some macromolecular removal as well as particulates.

Nanofiltration (NF): also called low pressure reverse osmosis. These membranes are designed for selectively removing multivalent ions such as calcium and magnesium – hence the terminology "softening membranes." Monovalent ions are poorly rejected by nanofiltration; therefore, osmotic pressures are relatively low and operating pressures are lower than in RO applications. Nanofilters are increasingly applied for the removal of larger organics, such as color and NOM substances.

Reverse osmosis (RO): RO is a semipermeable membrane process that relies on diffusivity to remove dissolved solids. RO introduces water to the membranes at a pressure that is greater than the osmotic pressure to reject electrolytes into the "reject" flow or concentrate. Monovalent ions – such as sodium and chloride - are typically targeted. Increasingly, trace organic compounds are targeted, including endocrine disruptor chemicals. A newer trend is selective ion removal from groundwater, such as fluoride, nitrate, and arsenic.

Electrodialysis/Electrodialysis Reversal (ED/EDR): ED/EDR is also a semipermeable membrane process, but it removes dissolved solids through polarity-selective membranes that remove dissolved solids through an electrical charge. Application of an electrical charge to the membranes attracts (removes) ions based on polarity and produces a dilute (treated) and concentrated (concentrate) waste stream.

This evaluation focuses on NF, RO, and ED/EDR because these processes remove dissolved organics and salts to produce a concentrate that can contribute to salinity issues in receiving waters. MF and UF primarily remove solids and do not produce similar concerns with reject disposal.

MEMBRANE TECHNOLOGY AT MUNICIPAL AND INDUSTRIAL TREATMENT FACILITIES

The climate and limited water resources in central Arizona puts a priority on the effective use of water supplies. In addition, source water quality and more stringent regulatory requirements have prompted higher levels of treatment for municipal and industrial water and wastewater resources.

Municipal Use

Multiple municipal drinking water and wastewater facilities currently use membrane treatment. Regional municipal facilities were contacted as part of this evaluation to identify the types of current membrane use and anticipated future use (Table 1.)

Industrial Use

Industrial water users must use water efficiently to grow and stay competitive. In addition, specific industries, such as the medical and semiconductor industries, have more stringent requirements for process water and typically need very high quality water. For example, high-tech industries often require "ultrapure" water. As a result, RO is currently being used to provide ultrapure water, which is then typically followed by a polishing treatment step. These water supply and water quality factors led to the current use of membrane technology, specifically NF and RO, by industry in the region. With the current industrial use of RO, concentrate from the treatment process is typically discharged to municipal wastewater treatment facilities.

Industry costs for water supply, treatment, and disposal can be significant, averaging on the order of $15/1,000 gallons (varies with raw water supply). With water supply limitations and emphasis on water conservation, industrial water users need to get the most value from their water supplies. This has led to using NF to treat RO reject to produce more useable water. (RO removes 99% of the salts and NF is used to remove hard salts). This treatment train can be applied if the water supplier caps water supply quantities. Another example of current membrane use to produce more water and reduce costs is the use of UF applied to treated wastewater effluents, to produce reusable water and reduce wastewater volumes. In this example, solids removed by the UF process are dewatered to produce a solid cake for disposal.

Industrial water use can be significant. In 2002, the City of Phoenix supplied 20 million gallons of water to 58 manufacturer and industrial users that were in the top 1,000 water users in the City of Phoenix. In general, manufacturing water users direct about 32% of water to cooling, 29% to water treatment and regeneration (wastewater treatment), and the remainder to process water. Tucson Water indicated that industrial and commercial users utilized approximately 100,000 acre-feet of water in 2000.

Table 1. Current Membrane Use at Regional Municipal Facilities

Treatment Facility	Current Drinking Water Membrane Use	Current Wastewater Membrane Use	Comments
Anthem Community	MF (1 mgd)	MF (0.5 mgd)	Dispose water concentrate to land/irrigation. Dispose wastewater concentrate to recycle.
City of Buckeye	EDR (0.9 mgd)		Dispose concentrate to surface.
City of Chandler	No current membrane use.	Industrial RO (2.8 mgd)	
City of Glendale	UF (1 mgd)		Dispose backwash to WWTP.
City of Mesa	No current membrane use. Water supply: Salt River (100-500 ppb TDS)	No current membrane use.	Don't anticipate need for membranes for water or wastewater treatment.
City of Peoria			
City of Phoenix	No current membrane use.	No current membrane use.	Don't anticipate need for membrane treatment in next 10 years unless costs decrease significantly. Membranes would most likely be considered for wastewater treatment before drinking water treatment.
City of Pine	NF (0.04 mgd)		Dispose concentrate to surface.
City of Scottsdale		MF/RO (12 mgd)	Dispose of concentrate through recycling.
City of Tempe	No current membrane use Water supply: Salt River and limited groundwater	Kyrene WWTP will be upgrading to membrane ultrafiltration to replace the filters and clarifiers	Don't anticipate need for RO membranes unless SRP quality changes or technology becomes a lot less expensive.
City of Tolleson	EDR (1 mgd)		Dispose concentrate to WWTP.
Fountain Hills		MF (2 mgd)	Dispose concentrate to WWTP.
Randolph Park		UF (3.1 mgd)	
State Prison-Lewis	EDR (1.5 mgd)		Dispose concentrate to evaporation pond.
Yuma Desalting Plant	RO (72 mgd)		Dispose concentrate to surface water.

Notes:
Treatment facilities were contacted for this evaluation but at the time of this draft not all facilities had responded to provide the most current information. mgd – million gallons per day

Trends in Membrane Use for Industrial Water Users

For industries to grow in the future, they need more power and water or must increase efficiency of water use and process technologies. Trends in water treatment for industry in central Arizona can be summarized as follows:

- Increasing use of treatment trains with a combination of treatment processes
- Treating wastewater for another use such as cooling water (a consideration for this practice is that if a regulated water or waste stream is mixed with unregulated water, it all becomes regulated).
- As salinity in water supplies increase, industry will continue to add membrane treatment processes and other purification processes to extend water supplies.
- Industry growth is difficult to predict, because it is impacted by many factors, particularly the economy. However, previous industrial growth in Arizona over the past decade has demonstrated an 18% increase in employment from 1991 to 2001; the gross state product grew 246% due to Arizona manufacturers over the same period.

MEMBRANE TECHNOLOGY TRENDS

Trends in membrane technology will have an impact on salinity issues in central Arizona, as a result of increased membrane use and associated concentrate discharge. Membrane technology improvements and increasing cost effectiveness, including higher efficiency in membrane systems, reduced energy and membrane costs, and the development of selective and low fouling membranes could result in an increase in the use of membrane technology.

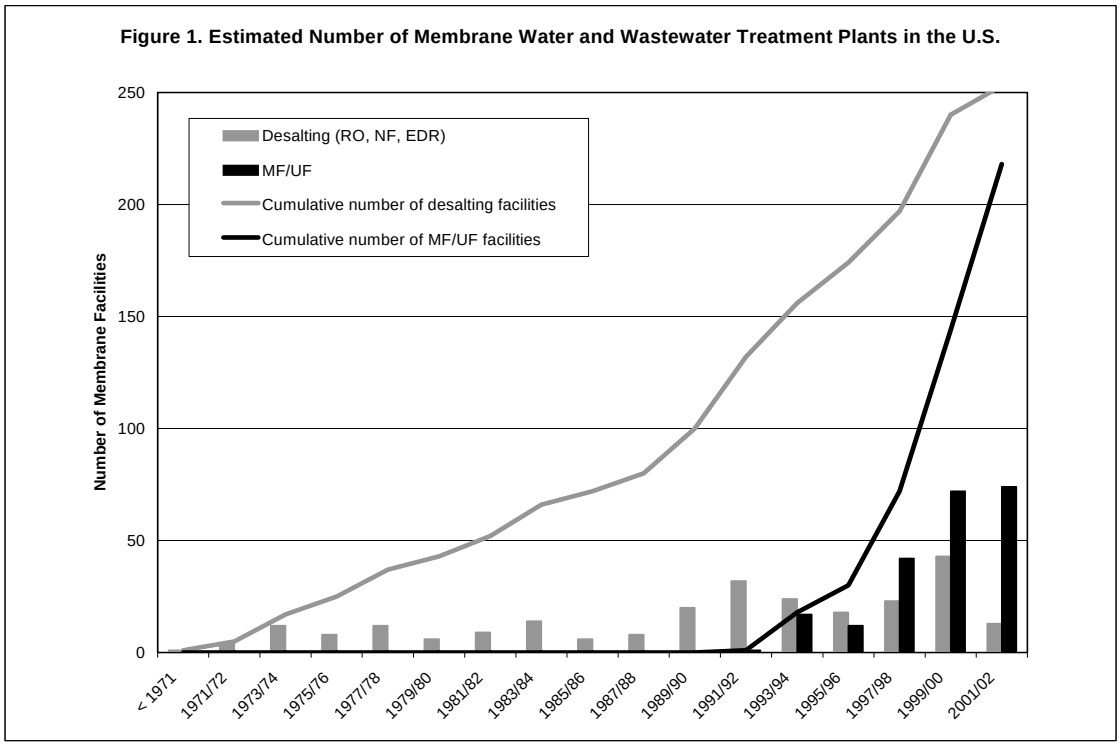
The recent Desalination Roadmap[1] released by the US Bureau of Reclamation emphasizes that membrane technologies are effective in removing contaminants from impaired waters ranging from natural salts to synthetic chemicals. In addition, the Roadmap states that membrane technology can 'create' new water from impaired sources such as brackish groundwater, impaired rivers, and at wastewater treatment plants.

Increase in Membrane Use Nationwide

The use of membrane technology has increased over the past 30 years (Figure 1). In the past 10 years the number of RO, NF, and EDR treatment plants in the U.S. has increased from 132 to 253. During this same period MF and UF treatment plants in the U.S. increased from one to 218. It is difficult to estimate the number of membrane facilities that may be constructed in the future, but it is estimated that an additional 30 new membrane treatment plants will be online in the next two years in the U.S. However, no new membrane facilities are anticipated in Arizona before

[1] U.S. Bureau of Reclamation, Sandia National Laboratories. 2003. Desalination and Water Purification Technology Roadmap - A Report of the Executive Committee.

2004. This may be due to the difficulty of concentrate disposal in this region compared to other areas of the country.



Source: Mickley & Associates, June 2003

Higher Efficiency in Membrane Systems

Ongoing research targeting the structure of membranes will result in higher efficiency in membrane systems. For example, computational fluid dynamics applied to membrane feed channels could result in reduced fouling. Advances in nanofiltration (NF) and reverse osmosis (RO) membrane processes will contribute to the increase in membrane efficiency. Within the next 10 years, it is likely that the size of NF or RO plants will be up to 250 mgd, from 40 mgd today. The main drivers for this development are inadequate fresh water sources, increasing soluble contaminants such as endocrine disruptors, reduced costs, and new, larger module designs. Future membrane research may also lead to oxidant resistant membranes, biofilm resistant membranes, and membranes that can operate in a wider pH range.

Reducing Costs

Significant research has been done on reducing costs in membrane technology. One example is the use of turbine energy recovery devices and pressure work exchangers to reduce energy costs for high pressure RO applications. Another example is the use of larger membrane elements such as the 60-inch long 17-inch diameter elements currently under trial at the Scottsdale Water Campus. Essentially these larger elements could increase the throughput per element by up to six

times compared with existing 8-inch elements thereby providing a more compact and less costly installation.

In general, the increasing use of membranes has the indirect effect of reducing costs. For example, current capital costs for a MF or UF 20 mgd treatment facility ranges from $0.20 to $0.30 per gallon per day (gpd). Within 5 to 10 years this could decrease to $0.10 to $0.15/gpd. Similarly, within ten years, reverse osmosis costs could be on the order of $0.25 to $0.45/gpd.

Selective Membranes

Ongoing research is leading to membranes targeted at specific ions or organics, thereby avoiding the more expensive "bulldozer" approach of removing all contaminants in cases where this may not be necessary or desirable. Specific selective membranes allow particular contaminants to be sought out while permitting others to pass through the membrane. As a result, the number of pollutants and their concentrations in the reject stream will be reduced. For brackish and seawaters, selective ion removals are probably not appropriate. In this case, research into low fouling membranes may help to increase recoveries thereby reducing the volume of reject streams.

Advances are continuing in retarding scaling and fouling of membranes. For example, silica scale inhibitors allow operation on waters with relatively high silica contents, which previously was not possible without significantly reducing recoveries.

Advances are also continuing regarding membrane chemistry. For example applications of NF technology have expanded from softening applications to synthetic organic (SOC) removals – particularly in Europe, and for color and/or the removal of DBP precursor materials. Advances in membrane chemistry also target the development of fouling resistant membranes and target the removal of organics. The objective here is to reduce the simultaneous rejection of inorganics, which produces a less aggressive finished water and reduces post treatment costs. The concentrate would also have a lower salinity and be easier to dispose of, for example to surface waters or for discharge to municipal wastewater treatment plants.

In 15 to 20 years, membrane technology may adjust removal capabilities based on the water supply quality and removal needs. Research and development may lead to membranes that can sense a contaminant differential across the membrane and automatically change performance and selectivity.

Improved Concentrate Disposal

Concentrate management includes the disposal, volume reduction, and beneficial use of brine or concentrate, which is primary byproduct of NF, RO, and ED/EDR. Concentrate disposal, reduction, and use will still be issues as the use of these membrane treatment technologies increase. In addition, this may be the deciding factor in the viability of membrane schemes in some cases. Experience at existing membrane treatment plants indicates that on the order of 20 percent of the treated flow can become concentrate discharge. Traditional concentrate disposal options may not be appropriate in all cases. Where possible, ocean disposal or deep well injection may still remain the most viable options. But in other cases, zero liquid discharge (ZLD) options may be the most economical. Potential alternatives for concentrate disposal include the following:

- **Deep well injection**—Concentrate is injected into subsurface formations to contain concentrate without contaminating groundwater. Well depths can range from 1,000 to 8,000 feet. Waste can never migrate out of the injection zone.
- **Discharge to surface water—**Concentrate is discharged through a pipeline to the ocean or other surface waters. Primary costs relate to constructing the conveyance and addressing permitting issues. Regulatory requirements continue to become more stringent to protect the beneficial uses of receiving waters.
- **Evaporation or solar ponds—**These facilities are more appropriate for facilities with smaller flows that are located in climates with high evaporation rates. The ponds can be constructed and maintained at a relatively low cost. However, ponds can be land intensive and require lining.
- **Spray irrigation**—Concentrate is land applied through sprinkler systems. This option requires an irrigation need in the area with vegetation that is tolerant of the concentrate or a diluted concentrate. A backup system for storage must also be in place when irrigation is not feasible (e.g., frozen or saturated ground). Monitoring is also required.
- **Discharge to local wastewater system—**This option requires permitting and fees through the local wastewater treatment plant. The wastewater treatment plant will consider how the discharge will affect treatment processes and its discharge permit.
- **Zero liquid discharge—**These options include **t**hermal brine concentrators, crystallizers, spray dryers, and solid landfill disposal. These options use evaporation to further concentrate the membrane concentrate. This requires a capital investment, as well as potentially high power and labor costs. These options typically require limited area and can enables a more efficient use of water.
- **Beneficial use** (e.g., irrigation, farming, solar pond, cooling water, manufacturing, agriculture, energy recovery, artificial wetland, aquaculture)

Some studies have shown that, in terms of capital costs, extensive pipelines to facilitate ocean disposal and installation of wells for deep well injection may be the highest cost followed by evaporation ponds. ZLD options may represent a lower capital cost amongst these options, but generally represent high O&M costs. ZLD options still require further development to reduce costs and to recover the water lost during the process. Research is currently underway,

particularly in Australia, where sequential precipitation of salts may produce commercial products which offset chemical and land disposal costs.

A 2001 study for the U.S. Bureau of Reclamation evaluated cost factors for concentrate disposal and provided tools for estimating preliminary costs[2]. Table 2 summarizes cost considerations for the above concentrate disposal options.

Table 2. Concentrate Disposal Cost Considerations

Deep well injection	Discharge to surface water	Evaporation Pond or Solar Ponds	Spray irrigation	Discharge to local wastewater system	Zero liquid discharge options	Beneficial Use
• Permitting • Pretreatment • Pumping • Well design and construction • Monitoring	• Permitting • Construction of conveyance and outfall • Pretreatment • Dilution water	• Permitting • Land area • Design and construction • Lining • O&M • Disposal • Monitoring • Contaminated ground cleanup	• Permitting • Land area • Conveyance and distribution • Pumping • Storage for nonirrigable periods • Dilution water • O&M	• Pretreatment • Pretreatment permitting • Conveyance • Dilution Water	• Equipment • Power • Additional labor • O&M • Disposal	• Varies depending on end use

Research into concentrate disposal is a key consideration for expanding membrane technologies. The most important improvements need to be made in reducing disposal costs. Research priorities identified in the Desalination Roadmap include discovering beneficial uses of concentrate. Additionally, reducing the quantity of concentrate produced will enable greater use of limited water supplies.

2 Mickley, M. 2001. Membrane Concentrate Disposal: Practices and Regulation. Desalination and Water Purification Research and Development Program Report No. 69 for U.S. Bureau of Reclamation

CENTRAL ARIZONA SALINITY STUDY---- PHASE I

Technical Appendix T

LOCAL RESEARCH EFFORTS

Introduction

A substantial amount of research is occurring in the Phoenix Metro area under the umbrella of CASS. Most of this work is being funded by SROG, Reclamation or the City of Phoenix. The research, while applicable to other locations in Arizona or the United States, is focused on specific problems that need to be addressed in the Phoenix Metro area.

Constituents in Evaporation Ponds

In 2002 a study was initiated with Arizona State University to study the Palo Verde Nuclear Generating Station (NGS) evaporation ponds. For the past 20 years, the Palo Verde generating station has purchased reclaimed water from the 91st Avenue WWTP to use for cooling water. The water is treated further on-site for use in the cooling towers adjacent to the nuclear generators. The blowdown from the cooling towers, reflecting a concentration of 30 times the initial concentration, is discharged into two 250-acre storage ponds located on-site where evaporation is the main mechanism for disposal. The study will characterize the concentration and constituents of the brine. If there is a high concentration of brine in the pond, it is possible that natural density stratification has occurred. This would create a solar pond condition in which energy could be recovered from the lower level of the pond.

"Devaporation" Demonstration

The 23rd Avenue WWTP was selected as a test site for an enhanced water recovery membrane pilot project. The project will evaluate a reverse osmosis (RO) treatment facility as a method to improve the quality of treated effluent for reuse. The membrane product water will be blended with effluent from the plant. Quantities and concentrations will be studied to determine the most cost effective mix for reuse. Another potential goal of the study will be to evaluate enhanced water recovery systems. RO systems recover approximately 80 to 85 percent of the effluent resulting in a brine reject of 15 to 20 percent.

The "dewvaporation" system was developed by Dr. James Beckman at Arizona State University as a low cost method of further concentrating brine. The dewvaporation system will further concentrate the brine reject from the RO system by utilizing a continuous contact tower that uses evaporation and dew formation to separate water from brine. The system will be operated in series with the membrane system to increase water recovery. Of the liquids entering the system, 99 percent will be recovered. The ultimate

objective is an efficient large scale facility which generates the brine by-product in a crystallized form. Further potential for industrial and/or commercial applications for the dewvaporation system will also be evaluated.

Cooling Tower Discharge

In February 2003, the City of Phoenix initiated a contract with a consulting company to inventory cooling towers in the valley. Cooling towers concentrate salinity in the feed water and discharge it when the salinity reaches a specified level. It is estimated that industries use upward of 30% of their water for cooling. The purpose of the study is to inventory cooling towers and assess the volume and salt content of discharges sent to the City of Phoenix wastewater treatment plants. The study will focus on all cooling towers greater than 250 tons and then use this data to estimate the impact from the smaller tonnage towers.

Salinity Contributions from Residential Users (AWWARF-sponsored)

The City of Phoenix, along with several other western municipalities, is participating in a study of residential contributions of salinity. The research will use water flow meters and in-line devices to evaluate common household products and practices, and their impact on the sewer system. These devices will monitor both timing and the levels of TDS in wastewater. This will assist in identifying, for example, the role of water softener regeneration in TDS levels at treatment plants. Other participating cities include El Paso, Irvine Ranch, Monterey, and Santa Clara.

Concentrate Disposal

Once salinity is removed, it must be disposed of in an environmentally acceptable and cost-effective manner. Options considered include evaporation ponds, deep well injection and outfall lines to the ocean (where practical). The costs and environmental impacts of these solutions dictate a compelling need for research into creative solutions. These could involve development of solar ponds (which produce energy through varying salinity gradients) and/or means of converting the brine product into a marketable product. Several research efforts are planned or underway to address this compelling need.