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.

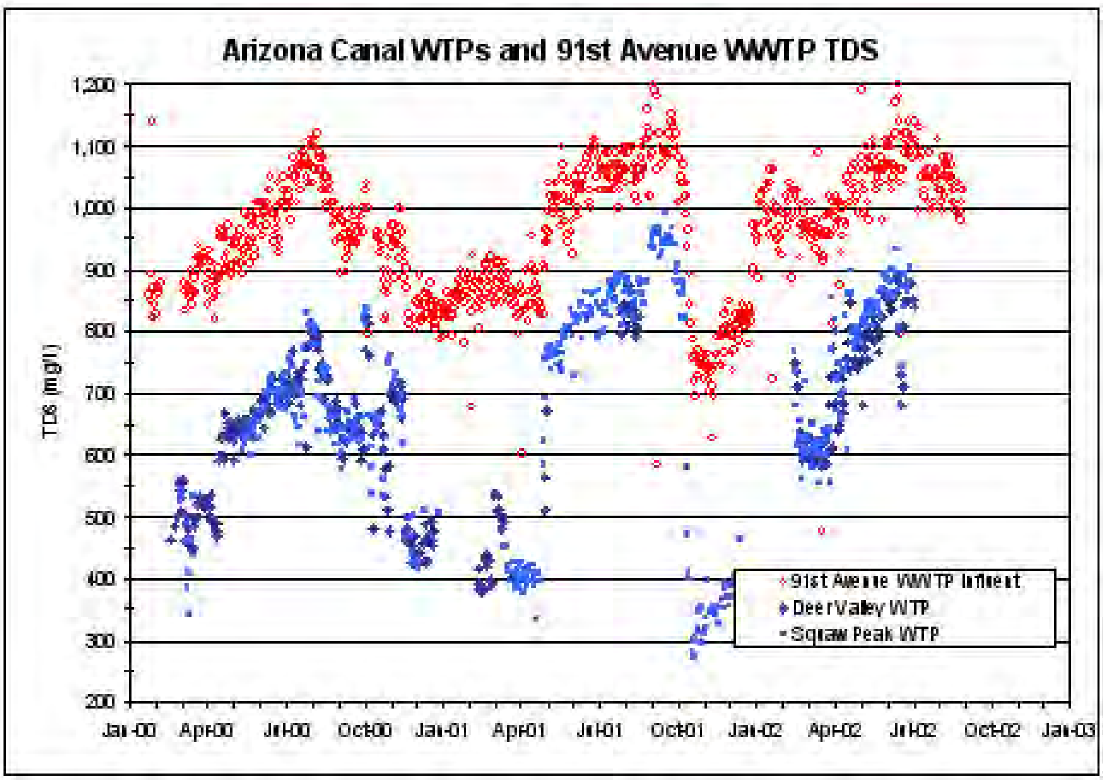

Figure 3-1. Source-Water TDS at Water Treatment Plants and Effluent TDS at 91st Avenue Wastewater Treatment Plant

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.

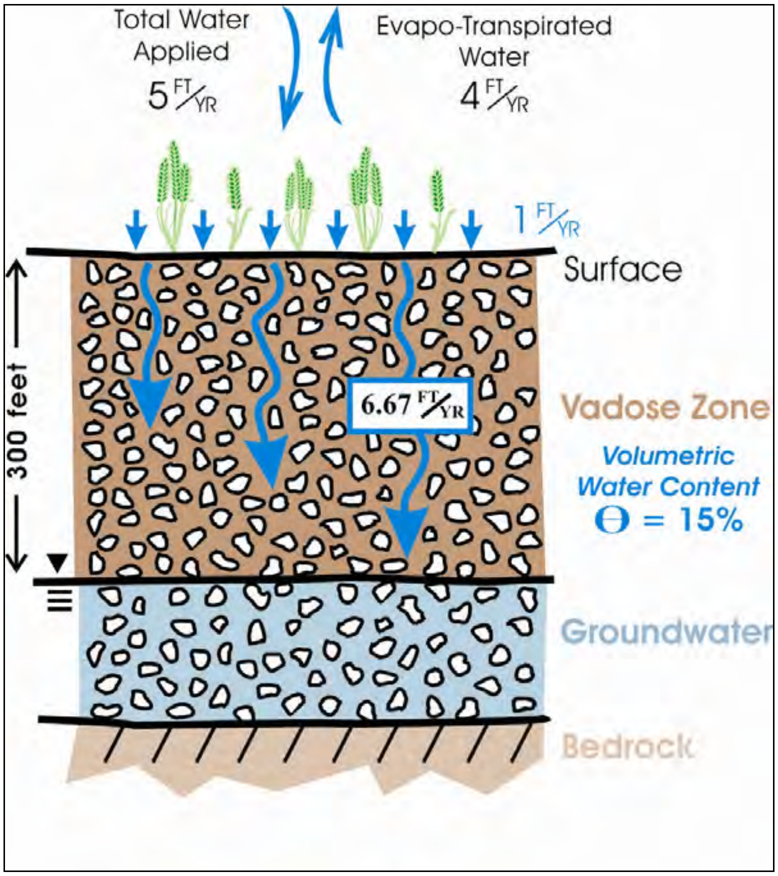

Figure 3-2. Agriculture and Salt Concentration

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.

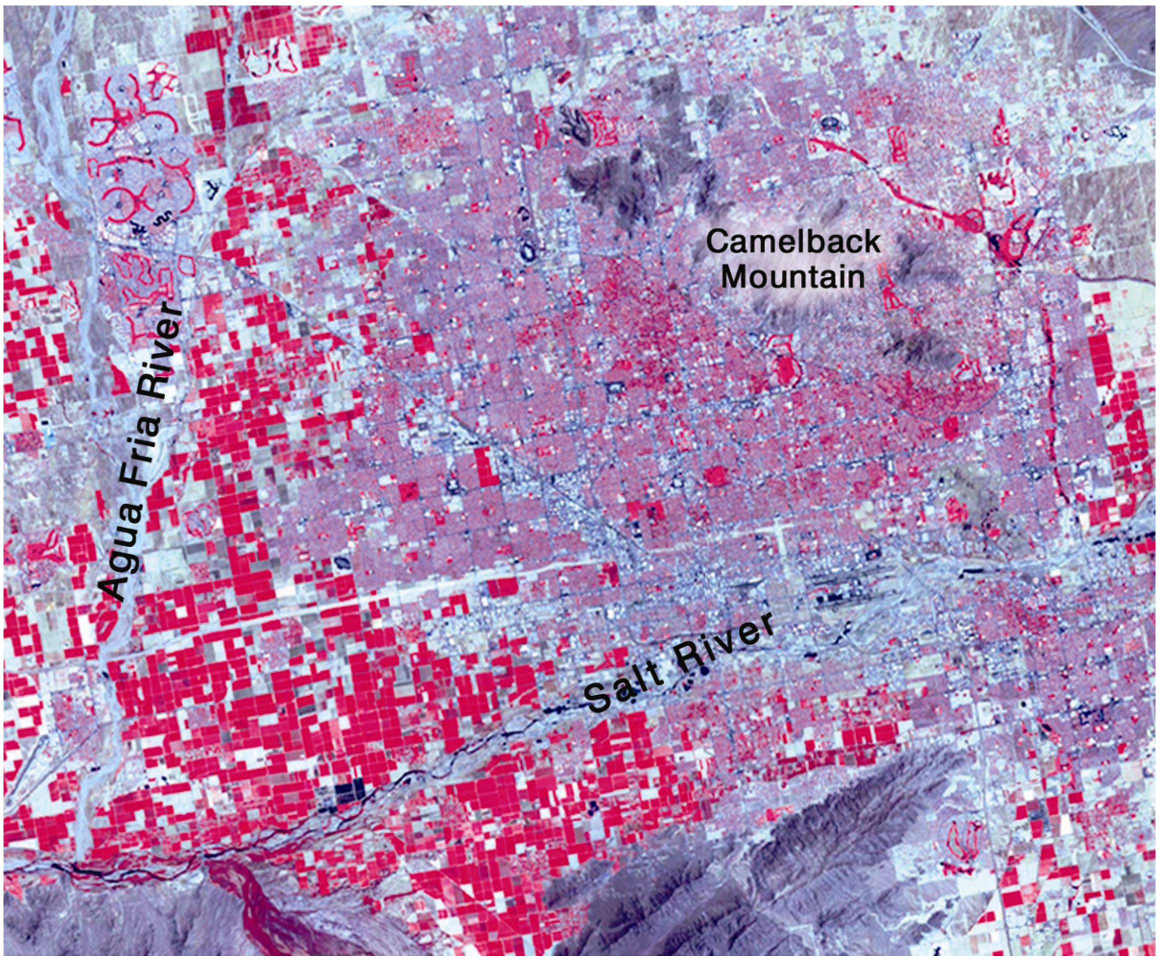

Figure 3-3. Infrared Image of Phoenix Metropolitan Area, 2000 (Red Indicates Irrigated Areas)

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.

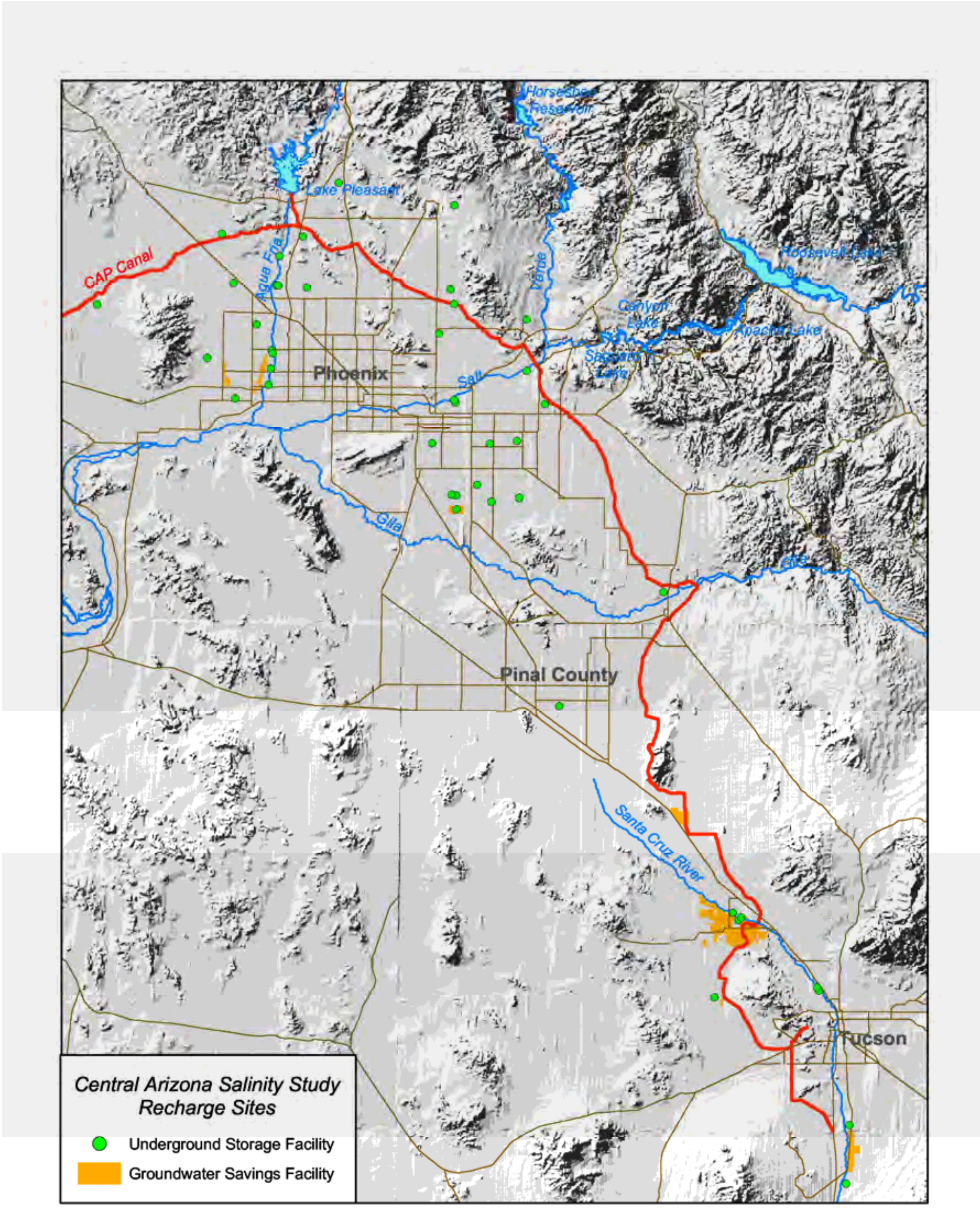

Figure 3-4. Groundwater Recharge Locations in Central Arizona

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.