Central Arizona Salinity Study

Phase II - Planning Report

September 2006

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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i. Definitions

Acre-foot - The volume of water required to cover an acre of land to a depth of one foot, or 325,851 gallons.
Blowdown - Wastewater flow from cooling towers containing concentrated salts from the original feed water.
Brackish Water - Saline water with a salt concentration ranging from 1,000 mg/l to about 25,000 mg/l.
Brine - Water saturated with, or containing a high concentration of salts, usually in excess of 36,000 mg/l.
Brine Concentrators - Equipment that separates pure water from a saline or brine solution.
Concentrate – Water and concentrated salts rejected by RO membranes or other desalination processes. The concentrate also contains other chemical constituents that were dissolved in the source water.
Concentrate Management - The process of disposing of concentrate in an environmental and economical manner.
Crystallizers - Equipment that separates crystalline solids of one or more salts from brine solution.
Deep Well Injection - Process where concentrate or treated wastes are discharged through a properly designed well into a geologic stratum at depth.
Desalination - Process of removing salts from water sources.
Dewvaporation - An emerging technology that is an energy-efficient water purification process through an evaporation/condensation cycle.
Effluent - Treated wastewater.
Emerging Contaminants - Synthetic or naturally occurring chemicals or any microorganism that is not commonly monitored in the environment but has the potential to enter the environment and cause known or suspected adverse ecological and/or human health effects.
Evaporation Ponds – A concentrate disposal method using ponds to evaporate the water leaving behind the salts for land disposal.
Injection Well - A well that puts water or waste into the ground under pressure.
MGD - Million gallons per day. 1 MGD is equivalent to 1,120.14 acre-feet per year.
Mil - Measurement equal to one-thousandth of an inch.
mmhos/cm – millimhos per centimeter; a measurement of electrical conductivity
Nanofiltration - A membrane system that separates divalent charged ions from monovalent ones. Sometimes referred to as “low pressure RO”.
Palo Verde Nuclear Generating Station – A plant converting nuclear energy to electricity located 50 miles west of Phoenix, Arizona, sometimes referred to as Palo Verde.
Permeate - The desalted water produced from RO and other processes.
Recharge - Artificially putting water into the aquifer via recharge basins or injection wells.
Reclaimed Water/Reuse - Treated wastewater used for irrigation and other suitable non-potable purposes.
Specific Conductance - Expression for the capability of a particular solution to conduct electricity. It is a method of estimating salinity and is easier to assess than total dissolved solids because it can be measured in real time.
Vadose Zone - Designation of the layer of the ground below the subsurface but above the water table.

ii. Acronyms

ADWR – Arizona Department of Water Resources
ADEQ – Arizona Department of Environmental Quality
AF – acre-foot; acre-feet
AF/yr – acre feet per year
BLM – Bureau of Land Management
CAP – Central Arizona Project
CASS – Central Arizona Salinity Study
CASI – Central Arizona Salinity Interceptor
cfs – cubic feet per second
CRBSCP – Colorado River Basin Salinity Control Program
ECe – electroconductivity of soil saturate extract
ECw – electroconductivity of irrigation water
EPA – Environmental Protection Agency
FY – Fiscal Year
GFD – gallons per square foot per day
GPD – gallons per day
GPG – grains per gallon
HERO – High Efficiency Reverse Osmosis
kW – kilowatt
kW/hr – kilowatt hour
MF - microfiltration
MGD – million gallons per day
mg/L – milligrams per liter
NF – nanofiltration
O & M – operations and maintenance
Reclamation – United States Bureau of Reclamation
RO –reverse osmosis
SAT – Soil Aquifer Treatment
SROG – Sub-Regional Operating Group, consists of the cities of Glendale, Mesa, Phoenix, Scottsdale and Mesa
SRP – Salt River Project
SRV – Salt River Valley
SSF – slow sand filter
TDS – total dissolved solids
TSS – total suspended solids
UF - Ultrafiltration
UPW – Ultrapure Water
USGS – United States Geologic Survey
WTP – water treatment plant
WWTP – wastewater treatment plant

EXECUTIVE SUMMARY

The Central Arizona Project (CAP) aqueduct system delivers 1.5 million acre-feet of Colorado River water into central Arizona every year and along with that water comes 1.3 million tons of salts. The Salt River carries an additional 400,000 tons of salts into the Phoenix metropolitan area. The Central Arizona Salinity Study (CASS) Phase I findings determined that approximately 1 million tons of salts accumulate annually in the Phoenix metropolitan area as a result of water importation and specific uses of water. The Tucson Active Management Area currently has a much lower annual salt loading rate since the importation of CAP water, its only surface water source, is relatively new to the area. Over time, the annual loading rate will increase as the Tucson metropolitan area continues to more fully utilize its CAP allocation to meet its renewable water requirements. Pinal County and the Gila River Indian Community import CAP water for irrigation. The salts accompanying the water used for irrigation ultimately end up in the groundwater beneath the agricultural lands.

The importation of large quantities of salts and the long term accumulation of salts in central Arizona has detrimental consequences and economic impacts to virtually all sectors of society including residential, commercial, industrial and agricultural. An economic analysis performed in CASS Phase I estimated that a reduction of 100 milligrams per liter (mg/L) of total dissolved solids (TDS) in both the Salt and Colorado rivers would result in a corresponding reduction of $30 million in economic costs to central Arizona.

The CASS Planning Sub-Committee was tasked with conducting a high level appraisal study on where salinity control would be most beneficial to central Arizona. The Planning Sub-Committee (Sub-Committee) evaluated salt removal options at different points within central Arizona's two main water supply watersheds: the Salt/Verde River and the Colorado River. A number of potential salt removal locations were considered, beginning with source waters and progressing downstream to locations along major rivers, canals, potable water treatment plants, and wastewater treatment plants; groundwater wells were also included. Costs and other feasibility considerations were evaluated for each option. A brief summary of the key findings is presented below.

Key findings of the Planning Sub-committee study include:

- The Colorado River Basin Salinity Control Program (CRBSCP) has already resulted in a reduction of over 750,000 tons of salt per year (65 mg/l TDS) in the Colorado River. This program is the most cost-effective of all of the options evaluated for salt removal by the Sub-Committee. About 50 percent of the targeted salinity control projects had been completed by the year 2000. Therefore, continuation and/or expansion of this program is recommended to achieve further salt reductions.

- Constructing large reverse osmosis (RO) plants on the Salt or Colorado rivers or along the CAP aqueduct to reduce the importation of salts into central Arizona would be extremely costly in terms of capital and annual operation and maintenance costs.

Environmental and public acceptability challenges exist for massive projects of this type. Concentrate disposal is a major concern for large inland desalting projects.

- Water losses of 15 percent or more with current RO processes present a challenge to the implementation of large surface water RO projects. Improvements are needed in RO technology that could reduce the water losses. Historically, these improvements have been in small increments over time but given the current national focus on salinity problems, improvements may occur more quickly.

- Breakthroughs are needed in concentrate management technology to make it more cost effective, less environmentally intrusive and less wasteful of precious water resources. Current technologies being used in Arizona are evaporation ponds, sewer disposal and, on a very limited scale, brine concentrators. Each of these current technologies has drawbacks. Emerging concentrate management technologies must be developed and proven before very large scale RO facilities can become cost-effective and environmentally acceptable.

- Most of the salts that are imported into central Arizona end up in the vadose zone or the groundwater. Salts that are leached into the vadose zone may eventually reach the water table. Depending on depth to water and water application, this may take many years.

- TDS concentrations in central Arizona's surface water supplies fluctuate with in a limited range defined by flood and drought watershed conditions. Groundwater and reclaimed water are sources where TDS concentrations will increase.

- Constructing RO facilities at existing potable surface water treatment plants (WTP) is a feasible option. Although it is not necessary to demineralize Arizona's surface water supplies for potable reasons, the advantage is that the salts are removed before they cause damages to the urban infrastructure. Some of the disadvantages of demineralizing surface water supplies are: 15 percent or more water losses on membrane treated water, RO is very energy demanding and, therefore, expensive to operate, and concentrate management issues still need to be resolved.

- Removing salts at some wastewater treatment plants (WWTPs) may be necessary for the effluent to be used for higher quality uses such as golf course irrigation and indirect potable reuse through recharge. RO treatment would only be required on the portion of the effluent needed for these high quality reuse applications. Concentrate could then be blended back into the WWTP effluent and used for low quality needs.

- Well head RO treatment becomes necessary when the groundwater resource is impaired and must be treated to meet demand. This is successfully being done at a few locations in central Arizona. Small scale well head treatment units can dispose of the concentrate into the sewer systems or evaporation ponds. However, sewer disposal has limits and may affect effluent uses. Smaller sized facilities have manageable costs and fewer environmental and public acceptability challenges. Salt removal closer to the point of use enables the level of salt removal and project costs to be tailored to meet the specific needs of water users.

- Once the salts have entered into the Colorado and Salt Rivers; costs, water losses and concentrate management issues are factors that indicate it is not economically feasible to demineralize the rivers and prevent the salts from entering central Arizona. A much more economically feasible approach is to allow the salts to enter central Arizona and manage them once they have arrived. The salts eventually end up in WWTPs and the groundwater and those are the locations where the salts should be removed. Once the salts are separated from the water, the salts should be permanently removed from the water cycle by being disposed in a environmentally sound manner. Regional concentrate disposal systems could be developed to prevent the salts from entering the water cycle again.

1. INTRODUCTION

1.1 Background

The Central Arizona Project (CAP) aqueduct system delivers 1.5 million acre-feet (AF) of Colorado River water into central Arizona every year and along with that water comes 1.3 million tons of salts. The Salt River carries an additional 400,000 tons of salts into the Phoenix metropolitan region. The long term accumulation of salts in central Arizona has negative consequences and economic impacts to virtually all sectors of society – residential, commercial, industrial and agricultural. Phase I of the Central Arizona Salinity Study (CASS) quantified those impacts and calculated that the economic benefit to central Arizona would be approximately $30 million annually by reducing the total dissolved solids (TDS) concentration in both the Salt River and the Colorado River by 100 milligrams per liter (mg/L).

To meet the water demands for Arizona's growing population, water must be used more than once. Effluent must remain a viable water resource for irrigation of crops and turf and for indirect potable use through recharge. Brackish groundwater must be transformed into a potable water resource. In addition, the brine concentrate resulting from advanced water treatment must be reprocessed to recover additional water prior to safe and environmentally sound disposal of the salts. The underlying issue is that salinity is not only a water quality issue, but more importantly salinity is a water resource issue.

1.2 Purpose of Planning Sub-Committee Report

The CASS Planning Sub-Committee (Sub-Committee) was tasked with conducting a high level appraisal study on where salinity control would be most beneficial to central Arizona. This study chose to evaluate reverse osmosis (RO) as the treatment for the removal of TDS and evaporation ponds for concentrate disposal. In addition to looking at alternatives for managing salts, the Sub-Committee was also tasked with defining the detrimental consequences of the long term accumulation of salts in central Arizona if "No Action" were taken to manage salinity.

The high level appraisal analysis was conducted by analyzing the importation of salts with the imported Salt River and Colorado River water. There are two basic strategies to managing the salts entering into central Arizona:

- Prevent the salts from entering central Arizona.
  - Salinity management strategies include support of the Colorado River Basin Salinity Control Forum and preventing salts from entering central Arizona by removing them from the rivers or the canals with massive regional desalting plants.
- Manage the salts after they reach central Arizona.
  - Salinity management strategies include removing the salts with smaller local desalting plants at the water treatment plants, wastewater treatment plants, or after it enters the groundwater through well head RO treatment units.

1.3 Methodology of Study

The Planning Sub-Committee was formed from volunteers of the larger CASS Technical Committee and includes:
Keith Larson, Arizona American, Sub-Committee Chair
Brandy Kelso, City of Phoenix
Thomas Poulson, Bureau of Reclamation
Harold Thomas, Brown and Caldwell
Karen LaMartina, Tucson Water
Ralph Marra, Tucson Water
James Peterson, Town of Oro Valley
David Iwanski, City of Goodyear
Val Danos, AMWUA
Laura Chavez, Brown and Caldwell
Frank Turek, PBS&J

The Sub-Committee met on a monthly basis, beginning in March 2004 and established a goal of writing a report to identify "where it would be most effective to manage the salts that are imported into central Arizona." The early meetings consisted of establishing criteria for evaluation of the alternatives, identifying what alternatives could be used to manage salinity, and assigning members of the Sub-Committee to develop these alternatives. Subsequent meetings were used to evaluate researched alternatives based on the criteria developed and cost/benefit analysis. The draft Planning Sub-Committee report was presented to the CASS Technical Committee in May 2005 for comments. The final Planning Sub-Committee report was presented to the Technical Committee in July 2005 for inclusion into the Final Report of CASS Phase II.

2.0 ALTERNATIVE DEVELOPMENT AND ASSESSMENT CRITERIA

The CASS Planning Sub-Committee developed a list of viable alternatives at different locations to manage salinity. To pare down this list, each alternative was evaluated by criteria developed by the Sub-Committee. The major categories of the evaluation criteria consisted of:

- Institutional Considerations
- Water Resource Utilization,
- Technical and Operational Feasibility,
- Environmental/Public Acceptability,
- Benefits of Salinity Control/Reduction
- Economic/ Financial Feasibility.

Under each major category, minor relevant points were listed and used as reminders for the evaluators. Table 2-1 lists the evaluation criteria.

Institutional Considerations
Conformance with Groundwater Code
Conformance with rules concerning inter-basin transfer of groundwater
Conformance with surface water rights
Conformance with Clean Water Act/NPDES/surface water quality standards
Conformance with NEPA/EIS elements
International and Tribal Issues
Conformance with land uses
Water Resource Utilization
Additional water resource made available
Preserves existing supplies
Water resource lost through concentrate management
Technical and Operational Feasibility
Project features technically feasible
Concentrate management considerations
Operational flexibility
Site access
Adaptability to changing conditions
Operational flexibility to changing TDS targets
Operational flexibility in addressing emerging contaminants
Reliability of technology
Efficiency of operation/treatment capability
Timeliness -implementation schedule compared to need
Environmental/Public Acceptability
Existing habitat impacts
Visual impacts
Biologic resource impacts
Cultural resources impacts
Air quality impacts
Public acceptability
Concentrate management
Institutional sensitivity
Benefits/Risks of salinity control/reduction
Potential salt reduction amount
Prevention of salinity entering groundwater system
Removal of salts from groundwater system

Regional benefits to central Arizona water users
Benefits/risks to CASS participants
Benefits/risks to agricultural water users
Benefits/risks to turf irrigation water users
Benefits/risks to commercial/industrial users
Benefits/risks to water providers
Benefits/risks to residential water users
Non-acceptability of water supply
Economic/Financial Feasibility
Economic assessments verses beneficiaries
Project features financially feasible
Near-term (20-year) economic feasibility
Long-term economic feasibility

Table 2-1: Evaluation Criteria

Members of the Sub-Committee evaluated each alternative using the above evaluation criteria as a guide. An important part of this evaluation was to identify any "fatal flaws" in the alternatives. Identification of one or more "fatal flaws" for an alternative resulted in its removal from further consideration.

An economic evaluation was prepared only for the alternatives that required further study. Summaries of the analyses are in Appendix A. To ensure all alternatives were compared similarly, the Planning Sub-Committee chose one desalination method, reverse osmosis, and one concentrate disposal method, evaporation ponds, to evaluate costs of the selected alternatives. Both of these methods are currently being used in Arizona for desalination and concentrate disposal. There was no assumption made that these would be the actual methods used for any given alternative; rather, they were only selected to ensure the alternatives were analyzed similarly.

A spreadsheet cost model was developed for estimating the costs for implementing desalination at the different locations. The costs for each alternative were calculated using the spreadsheet model for consistency. The model calculates costs using the following information, which is input for each analysis: amount of water to treat, initial TDS of untreated water, required TDS of treated water, length of pipeline for concentrate disposal, size of pipe, cost of land, and cost to clear the land. The actual cost of the membranes, electricity, interest rates, building materials and other variables were held constant for each analysis. The spreadsheet cost model then calculates the capital and operation and maintenance (O&M) costs for microfiltration/reverse osmosis (MF/RO) facilities and the capital and O&M costs for the evaporation ponds. The model assumed that evaporation ponds would be double-lined to protect the groundwater from brine concentrate and that the ponds would eventually be closed in place. The model also used MF for pre-treatment for all the alternatives except in wellhead treatment alternatives. The source of data used for the spreadsheet model was the *Reverse Osmosis Treatment of Central Arizona Project Water for the City of Tucson* report by BOR (January 2004) and *Membrane Concentrate Disposal: Practices and Regulation Final Report* by Michael C. Mickley (September 2001).

Table 2-2 is the list of alternatives which were considered. A "No" in the center column indicates that there was a "fatal flaw" in this alternative and an economic analysis was not performed. The right hand column is a brief comment on the "fatal flaw."

Location of Alternative	Additional Study needed?	The Reason Why No Additional Study
Colorado River Watershed		
Colorado River Basin Salinity Control Forum	Yes	
Reverse Osmosis Facility at Blue Springs (salt springs)	No	Not feasible because of tribal sovereignty issues.
Salt River and Verde River Watershed		
Salt River Basin Salinity Control Program	No	Not applicable because of conditions on watershed.
Reverse osmosis facility on White River (salt springs)	No	Not feasible because of tribal sovereignty issues.
Reverse osmosis facility on Verde River north of Horseshoe Lake	No	Verde River water already low in TDS
Colorado River and Central Arizona Project Canal		
Reverse osmosis facility on Colorado River at Davis Dam	Yes	
Reverse osmosis facility at Mark Wilmer Pumping Plant	Yes	
Reverse osmosis facility on Central Arizona Project canal in western Arizona	Yes	
Salt River and Salt River Project Canals		
Reverse osmosis facility on Salt River upstream of Roosevelt Lake	Yes	
Reverse osmosis facility on Salt River upstream Stewart Mountain Dam	No	Terrain not favorable for RO facility or concentrate disposal
Reverse osmosis facility on Salt River at Granite Reef Dam	Yes	
Other Central Arizona Rivers		
Best Management Practices for farming along Gila River upstream Ashurst Dam	No	Low benefit to the Phoenix metropolitan or Tucson areas
Reverse osmosis facility on Santa Cruz River	No	Santa Cruz contributes minor salt load to Tucson
Reverse osmosis facility on Agua Fria River	No	Agua Fria contributes minor salt load to Phoenix metropolitan area
Water Treatment Plant		
Reverse osmosis facility at WTP	Yes	
Waste Water Treatment Plant		
Reverse osmosis facility at WWTP	Yes	
Brackish Groundwater		
Reverse osmosis wellhead treatment	Yes	
Reverse osmosis centralized wellhead treatment	Yes	

Table 2-2: Salinity Management Alternatives

3.0 FUTURE WITH NO ACTION ALTERNATIVE

CASS Phase I established that approximately 1.3 million tons of minerals, in the form of TDS, are imported into central Arizona via the CAP aqueduct system. In addition, large amounts of salts enter into the water system from human activities and the Salt River. The focus of the Future With No Action alternative is to identify where the salts are accumulating and to assess potential future impacts. The Future With No Action assumes no new projects will be implemented to control or reduce the TDS in the source water or the TDS added by human activities.

Principal water sources in the central Arizona area include surface water, groundwater and reclaimed water. These sources are used to supply the demands of residential, commercial, industrial and agricultural water users. As a part of the identification of potential future salinity impacts, flow sheets were prepared to track water use paths to identify where salinity is increasing and to identify where salinity may be accumulating. The Salinity Flow Charts for the Phoenix and Tucson metropolitan areas are incorporated as Figure 3-1 and Figure 3-2 and are used to provide a visual aid to assess future salinity impacts.

In central Arizona, the principle surface water sources are the Salt River, Verde River, Agua Fria River, Gila River and Colorado River water imported via the CAP aqueduct system. A review of the historic TDS concentrations (City of Phoenix, 2005) showed there is a degree of change in the TDS depending on the conditions in the watersheds: drought year, high TDS concentration; surplus year, low TDS concentration. Colorado River TDS measured at Parker Dam averages about 650 mg/L as verified in CASS Phase I. The TDS limit for the Colorado River water at Parker Dam set by the CRBSCP is 747 mg/L TDS. The Agua Fria River, with an average TDS concentration of about 400 mg/L (Central Arizona Salinity Study [CASS], 2003), is a relatively small water source and changes in TDS concentration will have little impact on the total TDS load entering central Arizona. The Verde River has low TDS concentration, averaging about 270 mg/L (CASS, 2003). Water from the Gila River is used primarily for agricultural irrigation and does not impact the Phoenix or Tucson metropolitan areas. The Salt River is the surface water source with the greatest potential to have a large variation in TDS concentration. In a median flow year, the TDS concentration in the Salt River is about 580 mg/L. During flood periods, the TDS decreases to 500 mg/L or even lower; however, the data show that during drought periods the TDS has increased to 1,000 mg/L and higher (CASS 2003). Salt River water is blended with both Verde River water and Colorado River water before it is delivered to water users so the full impact of the elevated TDS in the Salt River is diluted by the other water sources. TDS concentrations in surface water sources will vary within a range and are not anticipated to continually increase or decrease in the future.

The TDS concentration in groundwater varies greatly throughout the central Arizona area, ranging from 200 mg/L to more than 5,000 mg/L in some locations (Arizona Department of Water Resources [ADWR], 2004). TDS concentrations in the groundwater in central Arizona will increase very slowly over time with the importation of salts because eventually the majority of the salts ends up in the groundwater through recharge and irrigation. Certain aquifers, such as those located below recharge basins or agricultural lands irrigated with effluent, will tend to increase in salinity more than other areas. Because of this, some residential, commercial and industrial water users who are provided groundwater will be subjected to increases in TDS in the future.

In the Phoenix metropolitan area, residential outdoor water use is approximately 50 percent of total residential water use. In the Tucson metropolitan area, where there is a much stricter water use policy, residential outdoor water use is less. The majority of residential outdoor water is used for landscaping, of which most is consumptively used by the vegetation. The plants use the water but leave the salts behind in the root zone. This results in the accumulation of salts in the soil. Over a long period of time, depending on depth to groundwater and water application, the salts accumulating in the soils beneath residential and commercial/industrial areas will percolate down to the water table and increase the TDS concentration of the groundwater. However, these salts will be spread over a large area and do not represent an immediate concern.

TDS concentrations in reclaimed water depends on the TDS of the wastewater entering the WWTPs. Indoor water use adds salts into the water in the process of using it. The water is discharged into the sewer at about 300 to 500 mg/L TDS (City of Phoenix, 2005) above the initial water received. A significant contributor of salts is residential water softeners. Currently, 26 percent of all homes in the Phoenix metropolitan area have water softeners (Insight & Solutions, Inc., 2004). Each water softener adds about 40 pounds of salts (primarily sodium chloride) into the sewer system each month. Using data on water softener use in the Phoenix metropolitan area (Insight & Solutions, Inc., 2004) Reclamation calculated that salts from residential water softeners contribute approximately one-quarter of the 300 to 500 mg/L increase of TDS to the WWTPs. In new homes being built in the Phoenix metropolitan area, there is a 50 percent probability that they will have a water softener. Because of increased water softener use, TDS concentration will continue to increase in the WWTPs. Large regional WWTPs have enough water to dilute the elevated TDS to some degree, however, small water reclamation plants built in growth areas sometimes do not have the quantity of water needed to dilute the TDS.

Agricultural lands receive surface water, groundwater and reclaimed water for irrigation. Agriculture can and does use higher TDS water than urban users. Farmers in the Buckeye Irrigation District, west of Phoenix, use groundwater and reclaimed water with high TDS concentrations for irrigation. High TDS water has two major economic impacts; the first is that crop yield will be reduced and the second is that additional water will be needed to leach the salts through the soils. Most of the irrigation water applied to crops is consumptively used by the vegetation leaving the salts in the root zone. But unlike urban exterior water use, farmers apply additional water for the purpose of leaching the salts to below the root zone. Approximately, 20 percent of water use in commercial irrigation operations is used to leach the salts from the root zone. The TDS concentration in the leaching water will be several times that of the original source water. The high TDS water will eventually reach the groundwater table. The long term regional impacts associated with agricultural irrigation include TDS increases in groundwater and degradation of water quality due to fertilizer application. As agriculture gives way to urbanization, the groundwater beneath the former agricultural areas will need advanced water treatment before use.

Most golf course managers desire water with a TDS concentration less than 1,200 mg/L to avoid salinity damage to the turf, particularly the greens. Currently, several WWTPs in the Phoenix metropolitan area produce effluent in the 1,200 mg/L TDS range. Water use on golf courses is strictly controlled by the Arizona Department of Water Resources (ADWR) Third Management Plan goals, and many golf courses are required to use effluent.

In portions of central Arizona, reclaimed water with concentrations greater than 1,000 mg/L may not be suitable for groundwater recharge because it could have negative impacts on the groundwater quality. If recharged effluent is significantly higher in TDS than the receiving groundwater, then there could be a noticeable taste difference when this water reaches the nearest potable water well.

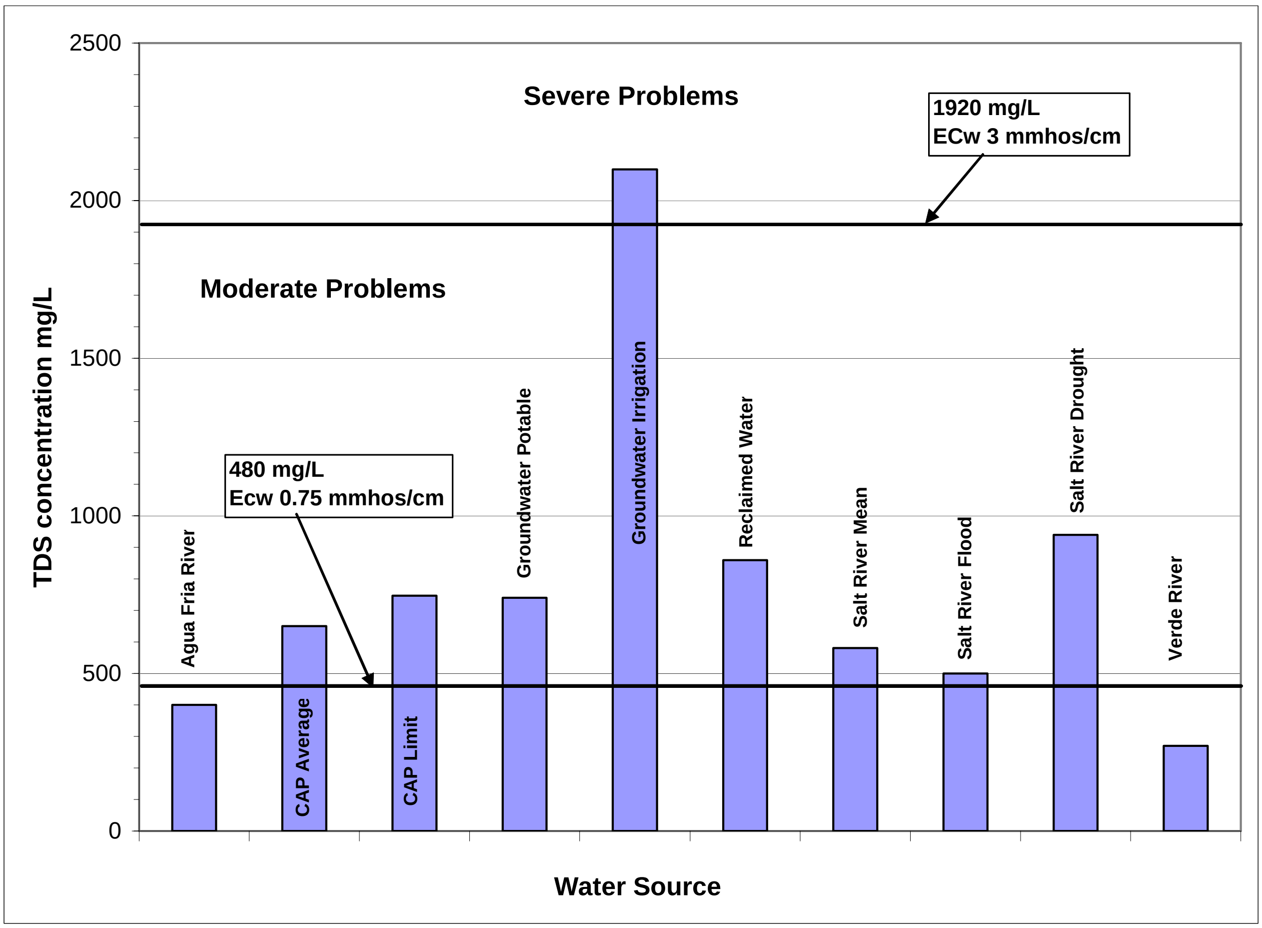

Figure 3-3: Water Quality Central Arizona

The suitability of water for irrigation is not based solely on the TDS concentration of the water supply; it is also based on the salinity of the soil and the salt tolerance of the plants. The salinity of the water is expressed as mg/L of TDS, and in agricultural studies it is referred to as the electroconductivity of the water (ECw), expressed as millimohos per centimeter (mmhos/cm). When considering the toxicity of irrigation water to plants, TDS of less than 480 mg/L is not considered to be a problem. Water with a TDS concentration between 480 and 1,920 mg/L could cause moderate problems, such as stunted plant growth and a decrease in crop yield, depending on the plant sensitivity. Water with a TDS concentration greater than 1,920 mg/L is considered to present severe problems to salt sensitive plants. Most of the surface water used in central Arizona have TDS concentrations in the lower portion of the Moderate Problems range (Figure 3-3). Groundwater in certain areas, particularly areas where historical agricultural irrigation has occurred, can be in the Severe Problem range. Most of the reclaimed water produced in the Phoenix area is in the middle portion of the Moderate Problems range (Figure 3-4).

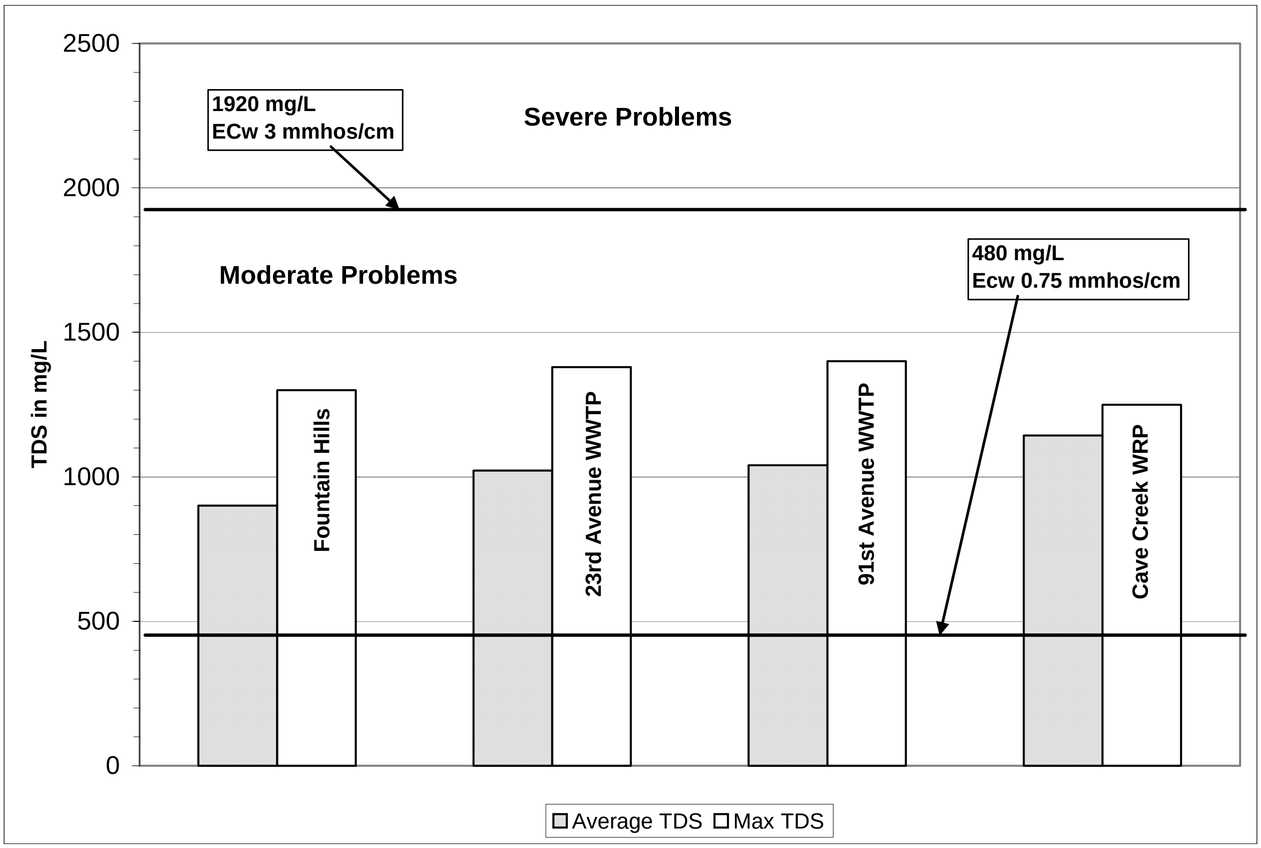

Figure 3-4: Water Quality at WWTPs

Soil salinity is the other major factor. Soil salinity is measured by calculating the electroconductivity of the soil saturation extract (ECe), the fluid obtained from saturated soil. This is measured in the laboratory, and is stated in units of mmhos/cm. Using the Phoenix area as an example, most of the soils have an average ECe of 1 to 4 mmhos/cm and a maximum of 8 mmhos/cm (Soil Conservation Service [SCS], 1977). There are some soils with an average ECe of 4 to 8 mmhos/cm and a maximum of 60 mmhos/cm (SCS, 1977). The following table shows the plant response to soil ECe.

ECe (mmhos/cm)	Plant Response
0 to 2	Mostly negligible
2 to 4	Growth of sensitive plants may be restricted
4 to 8	Growth of many plants restricted
8 to 16	Only tolerant plants can grow satisfactorily
Greater than 16	Only a few, very tolerant plants grow satisfactorily

Table 3-1: Electroconductivity of Soil

If the salinity in soil increases, the ECe increases. An increase in ECe can impact the growth of crops, turf and landscaping plants. The degree of potential impact is dependent on a number of factors, including the ECe of the soil, the TDS of the irrigation water, and the salt tolerance of the plants. In areas with low ECe soils and low ECw irrigation water, the potential impacts may not be detected for decades. In areas with higher ECe soils and high ECw water, such as areas recharged with reclaimed water, the impacts may be immediate.

In summary, the Future With No Action Alternative analyses indicated the water sources most likely to increase in TDS concentrations are reclaimed water and groundwater. The groundwater will increase in TDS because it is the final repository of most of the imported salts. The reclaimed water TDS will increase due to an increase in human activities, such as water softener usage, increased membrane usage, and increased use of cooling towers, that add salts to the sewer system The TDS in these water sources may increase to the point where they are not suitable for some uses. This will put pressure on society to seek other water sources to replace the impaired water resources.

In increase in TDS concentration in the water will produce impacts that are easier to quantify than the impacts due to the accumulation of salts in the soils.   It is thought by some members of the Planning Sub-committee that salts accumulating in the soil below the root zone is a relatively safe place for them. However, the salts may eventually reach groundwater, although it may take many years depending on water application and depth to groundwater.

4.0 PREVENTING SALTS FROM ENTERING CENTRAL ARIZONA

Central Arizona receives surface water from several major watersheds: the Colorado River, the Gila River and the Salt River watersheds. These watersheds encompass large areas, with zones where naturally occurring salts enter into the rivers. In addition to the naturally occurring salinity increases, some human activities increase the salinity of the river systems. This section discusses the Salinity Management Alternatives evaluated by the CASS Planning Sub-Committee, and listed in Table 2-2, and presents the advantages and disadvantages, feasibility, and costs of each alternative.

4.1 Watersheds and Rivers

Most of the salinity problems seen in central Arizona originate from two watersheds: the Colorado River and the Salt River watersheds. The Colorado River basin is divided into the Upper and Lower Colorado basins. The upper basin includes portions of Colorado, Wyoming, Utah, and New Mexico; the lower basin includes portions of Nevada, Arizona, California, and New Mexico. The lower Colorado River is the reach from Lee's Ferry to the international boundary with Mexico. Water in the lower Colorado River is stored in a series of five lakes (Powell, Mead, Mohave, Havasu and Martinez) for Arizona, California, and Nevada. Water from the first four of these dams serve the Phoenix metropolitan area, Pinal County, and the Tucson metropolitan area. Water in the Salt River system is stored in a series of four lakes (Roosevelt, Apache, Canyon, and Saguaro) and serves the Phoenix metropolitan area.

4.1.1 Alternative: Support the Colorado River Basin Salinity Control Program

The Colorado River is the primary domestic water supply for approximately 27 million people in the seven Colorado River basin states and also provides irrigation water for more than 3.5 million acres of farmland within the basin. Additionally, 1.5 million acre-feet is delivered annually to Mexico in accordance with the Mexican Water Treaty of 1944.

Colorado River headwaters in the Rocky Mountains have a TDS concentration of about 50 mg/L, whereas the TDS concentration of the Colorado River near Yuma, Arizona, typically ranges between 700 to 800 mg/L. About one half of the salinity in the Colorado River comes from natural processes and the other half can be attributed to human uses and activities, such as trans-basin diversions and agriculture irrigation in the upper basin. It is estimated that current economic damages in the lower basin states are about $330 million per year due to this increase in salinity.

The U.S. Environmental Protection Agency (EPA) required development of water quality standards for salinity in the Colorado River in 1972. The basin states formed the Colorado River Basin Salinity Control Forum (Forum) in 1973 to develop these standards including numeric salinity criteria and a basin-wide plan of implementation for salinity control which EPA subsequently approved.

In 1974, Congress enacted the Colorado River Basin Salinity Control (CRBSC) Act and subsequent amendments. Title I of the CRBSC Act addresses the U.S. commitments to Mexico established by agreement of the International Boundary and Water Commission. This agreement addressed the quality of water deliveries to Mexico pursuant to the Mexican Water Treaty of

1944. It also authorized the construction, operation and maintenance of a desalting facility located near Yuma, Arizona. Its purpose is to treat almost 100,000 acre feet of highly saline drainage water originating from the Wellton-Mohawk Irrigation and Drainage District and discharging the treated water into the Colorado River for delivery to Mexico at a quality consistent with the agreement's obligations. The desalting plant has not operated since 1993 because the agreement's obligations have been met without its operation.

Title II of the CRBSC Act created the Colorado River Basin Salinity Control Program (CRBSCP) and directed the Department of the Interior and the Department of Agriculture to manage the river's salinity, including salinity contributed from public lands which are located in the upper basin states. The law directed that preference be given to those projects which are most cost-effective, ie. they obtain the greatest reduction in salinity per dollar spent.

The CRBSCP was created to reduce salinity by preventing salts from dissolving and mixing with the river's flow. The CRBSCP is a long-term, interstate and interagency public/private partnership effort being carried out to reduce the amounts of salts in the River and its associated impacts in the basin. Naturally occurring sources of salinity, such as Paradox Valley, Colorado, are being controlled at the point source. In Paradox Valley, a natural, extremely salty underground brine is intercepted, treated, then injected into deep wells. Human-influenced increases in salinity due to irrigated agricultural activities in the upper basin are primarily controlled via irrigation improvements and vegetation management to reduce excess irrigation water, which would transport salts vertically and laterally into the river.

The CRBSCP is a partnership effort between agriculture producers, Federal agencies and the seven Colorado River basin states. Collectively, the program is reducing the amount of salt in the Colorado River while water usage continues to increase. While it is hard to know exactly, the CRBSC Forum estimates that the combined efforts of the salinity control program have resulted in the control of up to 1,000,000 tons of salt per year or 100 mg/L TDS (Forum, 2005). The reduction of 100 mg/L TDS on the Colorado River results in lowering annual salinity related costs in central Arizona by approximately $15 million. About 50 percent of the targeted salinity control projects had been completed by the year 2000; the plan of implementation calls for the control of the remaining amounts of targeted salt over the next two decades.

While significant progress has been made through the combined efforts of the Colorado River basin states and federal agencies, much more remains to be accomplished in reducing the salt loading in the river. The CRBSCP has not been implemented as originally envisioned for two major reasons. While the on-farm programs have been generally successful, the lack of adequate federal funding has precluded the BOR from implementing source control from various naturally occurring point sources in the upper basin. Secondly, the Bureau of Land Management has not established salinity control as a major priority in its management of the federal lands for which it is responsible.

Additional areas to address in the CRBSCP include: funding to continue to operate and construct new salinity control projects, increased efforts to educate water users about the salinity control program, and a long-term commitment by all the partners to control salinity for sustained use of the river. Continued funding of the CRBSCP by the federal government and existing local partners is recommended to achieve the salt reductions of a fully implemented program.

4.1.2 Colorado River

The Colorado River basin covers an area of 242,000 square miles and extends 1,400 miles from the Rocky Mountains to the Gulf of California. Flows out of Lake Mead are on the order of 15,000 cubic feet per second (cfs) but the flow can vary considerably due to power generation, weather patterns and irrigation needs. The 30-year average concentration of TDS in the Colorado River at Lake Havasu is around 650 mg/L, but varies plus or minus about 100 mg/L depending on excessive wet years or dry years. Because of the volume of water, the removal of significant amounts of salt from the river is a very daunting task.

4.1.2.1 Alternative: RO Facility on the Colorado River at Davis Dam

This alternative would entail construction of a 2 billion gallon per day (gpd) RO plant located on the Colorado River at Davis Dam to treat a portion of river flow and blend the permeate back into the river to reduce the TDS. This reduction of TDS would benefit central Arizona, southern California, and Mexico. A RO plant to treat the Colorado River water would cost close to $2 billion to construct. This huge plant would produce 300 MGD of concentrate, which equates to about 100 square miles of evaporation ponds for concentrate disposal or an 11-foot diameter pipeline to transport the concentrate to the Gulf of California. This alternative was determined to not be feasible based on the size, cost, and the loss of water resources estimated at 300 MGD.

Change in TDS	Required Treatment Size (MGD)	Capital				O&M			Annualized Total (Million $)
		MF plant (Million $)	RO plant (Million $)	Evaporation Pond (Million $)	Pipeline (Million $)	MF Plant (Million $)	RO plant (Million $)	Evaporation Pond (Million $)	
100	2,048	$549.5	$1,315.5	$5,649.3	$38.6	$113.1	$166.5	$28.3	$818.40
200	3,973	$873.7	$2,415.2	$10,909.0	$52.7	$219.4	$322.8	$54.6	$1,563.30
300	5,785	$1,136.6	$3,408.8	$15,889.0	$59.7	$319.0	$470.0	$79.5	$2,259.20

Table 4-1: Summary of Costs for RO Facility on Colorado River at Davis Dam

4.1.2.2 Alternative: RO Facility at Mark Wilmer Pumping Plant

The Mark Wilmer Pumping Plant (formerly Havasu Pumping Plant) is located on the Colorado River, and is the initial and largest pumping plant along the CAP aqueduct system, pumping approximately 1,939 MGD (3,000 cfs) of Colorado River water. The Mark Wilmer Pumping Plant was selected as the location to build a RO facility because it offers some unique advantages. The concept of the facility would be to construct a one-stage RO treatment train. Fifty percent of the treated water would be permeate, which would be blended with raw river water to produce the desired TDS concentration in the water delivered by the CAP aqueduct system to central Arizona. The other fifty percent of the water, in a relatively low TDS concentration (approximately 1,300 mg/L TDS), would be returned to the Colorado River downstream of the plant. This would increase the TDS concentration in the downstream Colorado River by about 40 mg/L.

Use of this existing facility would reduce initial capital costs by nearly 50 percent because concentrate management is simplified. Secondly, because concentrate is blended back into the

Colorado River, there is no loss of water resources in concentrate disposal. Thirdly, energy costs would be reduced for two reasons: one, reduced pressure requirements in the RO facility, and two, thousands of tons of salts would not be pumped with the water delivered to central Arizona.

It is estimated that construction of the RO facility at Mark Wilmer Pumping Plant would cost approximately $470 million and annual O&M costs would be approximately $55 million. These combined costs are much greater than the annual benefits of $15 million that a reduction of 100 mg/L TDS in the CAP water would have on central Arizona. As with all the very large sized alternatives assessed in this study, the capital and O&M costs are significant.

Change in TDS	Required Treatment Size (MGD)	Capital			O&M		Annualized Total
		MF plant (Million $)	RO plant (Million $)	Pipeline (Million $)	MF Plant (Million $)	RO plant (Million $)	(Million $)
100	401.8	$175.73	$295.46	$2.06	$22.20	$32.70	$98.35
200	779.5	$279.42	$542.44	$3.14	$43.05	$63.38	$116.75
300	1135.02	$363.49	$765.59	$3.83	$62.69	$92.96	$264.53

Table 4-2: Summary of Costs for RO Facility at Mark Wilmer Pumping Plant

4.1.3 Salt River

The Salt River is the largest tributary to the Gila River and drains an area of approximately 5,980 square miles. The headwaters of the Salt River are the White and Black rivers, originating at elevations near 11,400 feet above mean sea level in the White Mountains. Surface water runoff from the upper Salt River watershed and its headwaters are of relatively good quality and low in dissolved solids. However, significant changes occur in the water quality by the time the Salt River enters Roosevelt Lake. A 20-mile stretch of river, beginning near the confluence of the White and Black rivers, is fed by a series of springs that are high in TDS. TDS concentrations in these springs are reportedly in the range of 1,600 mg/L to 17,600 mg/L (U.S. Geological Service, 1977). Sodium chloride is the primary component of the dissolved solids.

4.1.3.1 Alternative: Create a Salt River Basin Salinity Control Program

Unlike the Colorado River, there is currently no governmental control program to prevent salts from entering the Salt River. The primary reason the Salt River is high in TDS is because of the salt springs, which are located on the White Mountain Apache Reservation. These springs add the vast majority of salts to the Salt River. A partnership with the White Mountain Apache Reservation would be needed to develop a plan to divert the salts coming from those springs from entering the Salt River.

4.1.3.2 Alternative: RO Facility located where the Salt River enters Roosevelt Lake

This alternative would consist of the construction of a 47 mgd MF/RO facility to be located on the Salt River, just upstream of the flood zone of Roosevelt Lake. This location would be an ideal place to locate a MF/RO facility because the land is flat and access roads are available. Power could easily be brought to the site.

Construction of the MF/RO facility would cost approximately $81 million and the evaporation ponds approximately $156 million. The annualized capital and O&M costs (6 percent over 50 years) would be about $23.24 million. Cost savings in central Arizona are estimated to be approximately $15 million, due to reducing the salt load on the Salt River by 100 mg/L TDS.

This alternative is close to being economically feasible. The loss of 15 percent of the water to the waste concentrate is a major drawback of an MF/RO facility treating surface water. Improving RO recovery or extracting additional water from the concentrate would increase the possibility of implementing this alternative.

Change in TDS	Required Treatment Size (MGD)	Capital				O&M			Annualized Total (Million $)
		MF plant (Million $)	RO plant (Million $)	Evaporation Pond (Million $)	Pipeline (Million $)	MF Plant (Million $)	RO plant (Million $)	Evaporation Pond (Million $)	
100	47.2	$39.25	$41.47	$156.20	$1.00	$2.61	$3.89	$0.78	$23.25
200	93.3	$93.30	$77.44	$307.67	$1.30	$5.15	$7.63	$1.54	$44.64
300	138.3	$138.30	$111.09	$455.55	$1.50	$7.64	$11.29	$2.28	$65.21

Table 4-3: Summary of Costs for RO Facility on Salt River at Roosevelt Lake

4.2 Conveyance Systems

The conveyance systems of concern are the CAP aqueduct system and the SRP canal system. Water from these systems is used for both agriculture and potable water delivery.

4.2.1 CAP Aqueduct

The CAP aqueduct is 336-miles long and designed to deliver 1.5 million AF of Colorado River water annually to central Arizona. The water is delivered to cities, agricultural lands and Native American tribes. The CAP aqueduct consists of the aqueduct, pumping plants, the New Waddell Dam, check structures, and turnouts. All of them are remotely controlled from the project headquarters located in north Phoenix. During winter months when electricity is less expensive, Colorado River water is pumped into and stored at Lake Pleasant (impounded by New Waddell Dam). During the summer months when electricity costs are greater, water is released from Lake Pleasant through the pump/generating plant producing electricity. The water then re-enters the CAP aqueduct to be delivered to customers.

4.2.1.1 Alternative: RO Facility on the CAP Aqueduct in the Western Arizona Desert

This alternative would consist of constructing a 400 mgd RO facility along the CAP aqueduct, perhaps where the CAP aqueduct crosses Interstate 10 in the Harquahala Valley, west of Phoenix. The topography in that area is flat desert lands with small desert dry washes, which would make for easy construction of both the MF/RO facility and the evaporation ponds.

Construction costs for the MF/RO facility are estimated to be approximately $470 million. In addition, construction costs for the associated evaporation ponds are estimated to be more than $1 billion. The high cost of the evaporation ponds is due to the amount of land, nearly 22 square miles, required to evaporate the concentrate produced from the 400 mgd facility. The primary components in the construction costs for the evaporation ponds are the land purchase costs and the double liner, probably high density polyethylene (HDPE). Possible land exchange agreements with the Bureau of Land Management (BLM), who owns large tracts of land in the immediate area, could reduce the cost of the land required for the evaporation ponds. Besides the considerable construction costs, water lost in evaporating the concentrate is estimated to be approximately 45,000 AF per year.

Annualized costs (6 percent over 50 years) for a MF/RO facility and evaporation ponds would be approximately $167 million while benefits to Central Arizona would be on the order of $15 million. Better technologies for RO efficiency and concentrate disposal are needed before this option could be considered.

Change in TDS	Required Treatment Size (MGD)	Capital				O&M			Annualized Total (Million $)
		MF plant (Million $)	RO plant (Million $)	Evaporation Pond (Million $)	Pipeline (Million $)	MF Plant (Million $)	RO plant (Million $)	Evaporation Pond (Million $)	
100	401.8	$175.73	$295.46	$1,088.24	$7.80	$22.20	$32.70	$5.44	$167.52
200	779.5	$279.42	$542.44	$2,113.90	$17.59	$43.05	$63.38	$10.59	$318.87
300	1135.02	$363.49	$765.59	$3,078.61	$26.00	$62.69	$92.96	$15.39	$460.07

Table 4-4: Summary of Costs for RO Facility on CAP in western Arizona

4.2.2 SRP Canal System

SRP includes a water service area of approximately 240,000 acres, surface water from the Salt and Verde rivers, and a network of 250 groundwater wells. Because the reservoirs on the Verde River system do not have flood control storage to accommodate spring runoff, water is released from the Verde River system during the winter months and from the Salt River system during the summer months. The Salt River has a higher concentration of TDS than the Verde River due to salt springs located along the Salt River. Surface water is delivered to the customers via the Arizona Canal on the northern portion of the service area or to the south through the South Canal. Groundwater wells are used to augment supplies when surface water does not meet demand.

4.2.2.1 Alternative: RO Facility located at Granite Reef Dam

This alternative consisted of the construction of a 75 mgd MF/RO facility that would be built near Granite Reef Dam which would deliver reduced TDS water to SRP customers. This RO facility would require careful design and operation because of the varying quantities and qualities of source water. Salt River water is usually delivered in summer and fall. The quality of the water varies depending if it is a wet year or a dry year. Verde River water is delivered during the winter to provide storage capacity in the reservoirs for the spring runoff. Verde River water is good quality and does not require de-mineralizing with RO.

Estimated construction costs for the Granite Reef Dam MF/RO facility would be $120 million; associated evaporation ponds would be an additional $210 million. The annualized costs (6 percent over 50 years) would be approximately $34 million. Annual benefits to central Arizona from this MF/RO facility are estimated to be approximately $15 million.

The closest location for the evaporation ponds would be on the Salt River Pima-Maricopa Indian Community land. Agreements to dispose of concentrate on tribal land may be difficult to acquire.

Change in TDS	Required Treatment Size (MGD)	Capital				O&M			Annualized Total (Million $)
		MF plant (Million $)	RO plant (Million $)	Evaporation Pond (Million $)	Pipeline (Million $)	MF Plant (Million $)	RO plant (Million $)	Evaporation Pond (Million $)	
100	76.95	$55.25	$64.90	$210.26	$1.73	$4.25	$6.30	$1.05	$34.00
200	149.63	$88.00	$119.41	$408.26	$2.94	$8.26	$12.21	$2.04	$64.37
300	218.38	$114.67	$168.89	$596.15	$4.53	$12.06	$17.79	$2.98	$92.72

Table 5 - Summary of Costs for RO Facility on Salt River at Granite Reef Dam

5.0 MANAGING SALTS IN CENTRAL ARIZONA

If the salts can not be effectively prevented from entering into central Arizona they must be managed after they arrive. The Planning Sub-Committee identified three points at which salinity could potentially be managed in central Arizona: (1) potable water treatment plants, (2) wastewater treatment plants and (3) the groundwater.

5.1 Water Treatment Plants

Water treatment plants are used in central Arizona to treat surface water to drinking water standards. Most water treatment plants are operated by the city in which the residents live but some are operated by private water companies. The decision to provide advanced water treatment for its customers would have to be decided by each water provider.

5.1.1 Alternative: Reduction of Salinity at Potable Water Treatment Plants

RO advance water treatment is a proven technology and is used when salinity is too high for potable purposes. RO, if properly maintained and operated, produces water that will meet all federal, state and local drinking water requirements. Reducing salts, and consequently, hardness, at the water treatment plants, reduces salinity damage in the residential, commercial and industrial sectors of society that use the treated water. Reducing salts at the water treatment plants also has the benefit of reduced salt loading at the WWTPs.

On the other hand, only about one-half of 1 percent of potable water use in the home is used for drinking. If RO was installed in a water treatment plant solely for palatability (taste), sufficient benefits may not be accrued to justify the cost. RO treatment requires specialized staff to operate and maintain the facilities; it is energy-demanding, and the energy requirement increases as the salinity increases. Any large scale RO facility at a water treatment plant needs an economical concentrate disposal system, which, at this time, there are no good solutions. The biggest drawback is that approximately 15 percent of the source water that is treated, is discarded with the rejected salts. In the arid southwest, it would be very difficult to justify a project that would lose a portion of the supply water for palatability reasons only.
RO requires careful pretreatment to prevent scaling or fouling of the membranes.
Five options for RO pretreatment were evaluated by the Planning Sub-Committee: (1) MF, (2) conventional treatment, (3) conventional and MF, (4) soil aquifer treatment (SAT), and (5) slow sand filtration (SSF). The choices made in pretreatment greatly impact the operational costs and effectiveness of RO treatment and may impact the concentrate stream as well.

One-stage pretreatment relying on MF, followed by RO, is a proven method of operation for advanced water treatment. RO requires very low suspended particulate concentrations to avoid fouling the membrane surfaces. MF as a one-stage pretreatment step provides the reliability needed to meet the operational needs of RO. MF costs are approximately 14 to 16 percent of the total annualized costs of a MF/RO facility. Table 5-1 below presents the estimated costs for MF pretreatment. Estimated costs shown in Table 5-1 include construction costs for evaporation ponds and costs to lease water from Native American tribes to make up the 15 percent water losses. Tucson costs are lower because the City of Tucson own large amounts of land that could be used for concentrate disposal, eliminating the need to purchase land.)

	Phoenix Area		Tucson Area	
Overall Plant Size/ TDS Target (mg/L):	**MF**	**RO, Evap & Water (IL)**	**MF**	**RO, Evap & Water (IL?)**
	Cost in Million $			
10 MGD/550	0.39	2.68	0.39	2.02
10 MGD/450	0.67	4.04	0.67	3.23
50 MGD/550	1.43	8.52	1.43	7.11
50 MGD/450	2.48	15.03	2.48	12.76
100 MGD/550	2.54	15.43	2.54	13.11
100 MGD/450	4.45	28.22	4.45	24.14

Table 5-1: Annualized Costs (Capital and Operational) of a MF/RO Facility

Conventional filtration/coagulation, followed by a cartridge filter, then followed by RO is a method to use existing water treatment plants as a pretreatment to advanced water treatment. Because RO requires very low suspended particulate concentrations to prevent fouling the membrane surfaces, conventional filtration alone will likely not provide water of sufficient quality to guarantee efficient operation of RO treatment on a consistent basis. In order to maximize RO treatment efficiency, a two-stage process would be necessary whereby Stage 1 would consist of the use of direct filtration as a "roughing filter", followed by Stage 2, cartridge filtration.

Overall Plant Size/ TDS Target (mg/L)	**Phoenix Area**	**Tucson Area**
	$ Millions	
10 MGD/550	2.99	2.33
10 MGD/450	4.62	3.81
50 MGD/550	10.03	8.62
50 MGD/450	17.96	15.69
100 MGD/550	18.45	16.13
100 MGD/450	34.09	30.01

Table 5-2: Annualized (Capital and Operational) Costs of an Existing Conventional Treatment Plant With New RO Facility

The advantage of this two-stage pretreatment is that RO could be added to existing water treatment plants. RO facilities usually do not require a lot of space and could, in most cases, be integrated into an existing conventional water treatment plant. A pilot-testing program, which is done for all RO projects, would be needed to ensure this pretreatment would work for a particular site and source water quality. Annualized costs would be slightly less for an existing conventional WTP with a new RO facility as compared to a completely new MF/RO facility. Compare Table 5-2 to Table 5-1.

The use of conventional filtration/coagulation treatment as a "roughing filter" for Stage 1 pretreatment followed by MF as a Stage 2 could maximize RO treatment efficiency. This pretreatment process would take advantage of existing potable water treatment plants with the addition of RO treatment for salinity control. Cartridge filtering may be eliminated from the pretreatment but the cost of maintaining conventional treatment and MF/RO treatment may be excessive.

Soil aquifer treatment (SAT) refers to the additional treatment process that occurs when treated effluent percolates through the vadose zone and co-mingles with groundwater. SAT, used in conjunction with cartridge filtration, would provide a highly reliable pretreatment filtration. This option can reduce the operational costs of advanced water treatment because it eliminates more expensive pretreatment options. Drawbacks include possible physical characteristics of the aquifer and/or recovery well construction, which could potentially produce occasional slugs of highly turbid/sandy water that could adversely impact RO membranes. Cartridge filtration could be added as a Stage 2 pretreatment to protect the RO membranes from possible slugs of turbid/sandy water.

Overall Plant Size/ TDS Target (mg/L):	**Phoenix Area**	**Tucson Area**
	$ Millions	
10 MGD/550	2.00	1.48
10 MGD/450	3.10	2.45
50 MGD/550	6.84	5.66
50 MGD/450	12.46	10.52
100 MGD/550	12.81	10.82
100 MGD/450	24.08	20.51

Table 5-3: Total Annualized (Capital and Operational) Costs of a RO Facility Using SAT as Pretreatment

Slow sand filtering (SSF) is a simple filtering technique for removing suspended organic and inorganic matter by percolating treated effluent slowly through a bed of porous, fine sand. Similar to SAT, using SSF in conjunction with CF could be an inexpensive method of pretreatment for RO. A small pilot study by the BOR indicated that SSF is a good pretreatment for RO. The primary problem with SSF is that it requires a large amount of surface area (land) to move the volume of water through the SSF for a large advanced water treatment plant.

In conclusion, RO use at water treatment plants provides benefits to water quality, reduces damage to infrastructure from salts, and contributes to reduced salinity in WWTPs. Although, if RO is not necessary for potable reasons but only palatable reasons, it is an additional expense and reduces the water supply.

5.2 Wastewater Treatment Plants

When the TDS concentration in the effluent produced in central Arizona's WWTPs becomes so high that it can not be reused then the expense of advanced water treatment will be necessary. This is because the next source of water to replace the effluent will be even more expensive. The increase in TDS from water treatment plant to WWTP is approximately 300 to 500 mg/L (City of Phoenix, 2005). It is anticipated that as more commercial and residential customers use water softeners, cooling towers, etc. the TDS concentration in the WWTPs will continue to increase to a point where reuse applications are problematic.

The following two examples are current issues where effluent is almost unusable for the intended purpose. Example one: The golf course industry is using effluent for irrigation to reduce groundwater consumption and to meet the requirements of ADWR's Third Management Plan. The TDS concentration in effluent produced in many Phoenix area WWTPs is currently around 1,200 mg/L, which is above the ideal for golf course turf on greens or fairways. (Less than 450 mg/L TDS is preferred for turfgrasses [Haravandi, 2004]). Example two: Effluent that is recharged for indirect potable reuse must blend in unobtrusively with the ambient groundwater quality and, because of this, advanced water treatment may be necessary to reduce the TDS of the effluent.   In addition, RO treatment may be necessary from a public relations standpoint before effluent could be recharged for indirect potable reuse.

Managers, planners and engineers are also looking at methods to prevent salts from entering the WWTPs because it is less expensive to avoid the problem than fix it with advanced water treatment. New laws, methods and restrictions on sanitary sewer disposal could keep the salinity concentration in effluent stable.

5.2.1. Alternative: Reduction of Salinity in Effluent Leaving the WWTP

This option looked at RO membranes for the purpose of reducing TDS concentrations from treated effluent used for reuse applications, including recharge, turf irrigation, agricultural irrigation, indirect potable reuse and so on. For this option, wastewater would be treated by conventional methods with a portion of the filtered effluent being treated with RO to produce a target TDS for specific reuse applications. Multi-media filtration, which is known to work for pretreatment for RO, would consist of anthracite coal, silica sand, and fine and course garnet. The multi-media filters would meet the pretreatment needs and are less expensive then MF for large-scale RO operations. RO concentrate would be disposed of in an evaporation pond.

Three plant sizes (defined as small: 5 MGD, medium: 25 MGD, and large: 50 MGD) were evaluated to develop annualized costs for a given change in TDS concentration. Two assumptions were made: (1) that these plant sizes represent the amount of wastewater treated by conventional methods, and (2) a portion of the wastewater is treated by RO then blended with non-RO treated water to produce a target TDS for the entire wastewater effluent stream.

The concept of removing salinity in the effluent leaving the WWTP could be a cost-effective way to produce additional water for specific needs. Advanced water treatment with RO will be needed first at small WWTPs, which were designed not only to remove and dispose of pollutants in the wastewater but also to supply effluent for golf courses for irrigation. Smaller plants are hit harder by increases in salinity. There are several reasons for this, such as, the newer WWTPs are in new growth areas, which can have as much as 50 percent penetration of residential water softeners. The small WWTPs don't have the capacity to dilute inflows of high TDS discharge from the numerous residential water softeners.

One of the biggest problems to desalting at a WWTP is the disposal of the concentrate. Evaporation ponds, one of the most common methods, are very expensive on large scales, primarily because of land costs. To make this option more viable, an inexpensive, environmentally-sound disposal method that permanently removes the salts from the water cycle needs to be developed. Small WWTPs that send their effluent out for higher grade reuse uses, such as recharge and golf course irrigation, could dispose of the concentrate in the sewer for transport to a larger regional plant that uses its effluent for lower grade uses, such as commercial agriculture of salt tolerant crops and cooling applications. At the large WWTPs, if some of the effluent needs to be desalted for higher grade uses then it can be done there. Of course, a good solution for managing the concentrate needs to be in place.

Change in TDS	Capital Costs RO	Capital Costs Ponds	Capital Costs Total	O&M Costs RO	O&M Costs Ponds	O&M Costs Total	Annualized Cost
	5 MGD						
200	$ 0.77	$ 13.98	$ 14.75	$ 0.10	$ 0.07	$ 0.17	$ 1.12
400	$ 1.42	$ 16.11	$ 17.54	$ 0.15	$ 0.08	$ 0.23	$ 1.37
600	$ 2.03	$ 18.17	$ 20.20	$ 0.20	$ 0.09	$ 0.29	$ 1.60
800	$ 2.60	$ 20.15	$ 22.76	$ 0.24	$ 0.10	$ 0.34	$ 1.83
1000	$ 3.14	$ 22.07	$ 25.21	$ 0.28	$ 0.11	$ 0.39	$ 2.05
1200	$ 3.66	$ 23.93	$ 27.58	$ 0.32	$ 0.12	$ 0.44	$ 2.26
1400	$ 4.15	$ 25.72	$ 29.87	$ 0.36	$ 0.13	$ 0.49	$ 2.47
1600	$ 4.62	$ 27.45	$ 32.07	$ 0.40	$ 0.14	$ 0.54	$ 2.66
	25 MGD						
200	$ 3.35	$ 21.99	$ 25.35	$ 0.30	$ 0.11	$ 0.41	$ 1.64
400	$ 6.22	$ 33.48	$ 39.70	$ 0.54	$ 0.17	$ 0.71	$ 2.59
600	$ 8.88	$ 45.42	$ 54.30	$ 0.77	$ 0.23	$ 1.00	$ 3.55
800	$ 11.38	$ 55.35	$ 66.73	$ 0.99	$ 0.28	$ 1.27	$ 4.37
1000	$ 13.75	$ 64.94	$ 78.68	$ 1.20	$ 0.32	$ 1.53	$ 5.16
1200	$ 16.00	$ 74.20	$ 90.20	$ 1.41	$ 0.37	$ 1.78	$ 5.92
1400	$ 18.15	$ 85.66	$ 103.81	$ 1.61	$ 0.43	$ 2.04	$ 6.81
1600	$ 20.21	$ 94.33	$ 114.54	$ 1.81	$ 0.47	$ 2.28	$ 7.52
	50 MGD						
200	$ 6.33	$ 33.88	$ 40.20	$ 0.55	$ 0.17	$ 0.72	$ 3.39
400	$ 11.75	$ 56.85	$ 68.60	$ 1.02	$ 0.28	$ 1.31	$ 5.90
600	$ 16.77	$ 79.90	$ 96.67	$ 1.48	$ 0.40	$ 1.88	$ 8.37
800	$ 21.49	$ 99.75	$ 121.24	$ 1.93	$ 0.50	$ 2.42	$ 10.58
1000	$ 25.96	$ 118.93	$ 144.89	$ 2.35	$ 0.59	$ 2.95	$ 12.71
1200	$ 30.21	$ 137.47	$ 167.68	$ 2.77	$ 0.69	$ 3.46	$ 14.76
1400	$ 34.27	$ 161.70	$ 195.97	$ 3.17	$ 0.81	$ 3.98	$ 17.18
1600	$ 38.16	$ 179.04	$ 217.20	$ 3.56	$ 0.90	$ 4.45	$ 19.10

Table 5-4: Capital, O&M and Annualized Costs for WWTPs (Millions of Dollars)

5.3 Well Head Treatment

Brackish water, as defined in BOR's *Desalting Handbook for Planners* (2003), is "saline water with a salt concentration ranging from 1,000 mg/L to about 25,000 mg/L." It is estimated that the quality of brackish water in central Arizona ranges from 1,000 mg/l to 5,000 mg/l (ADWR, 2004). Some brackish water is currently being used for farming purposes, but for the most part, this water resource is not utilized because of high TDS concentration. In addition to treating brackish groundwater, water providers may choose to treat groundwater with salinity concentrations less than 1,000 mg/l, but greater than 500 mg/l, for aesthetic purposes.

5.3.1 Option: RO Wellhead Treatment at One Well

This option consists of treating brackish groundwater at the wellhead with RO and transporting brine concentrate to a regional evaporation pond for disposal. It is assumed that either new or existing wells could be used for RO wellhead treatment. Table 5-5 below presents the estimated costs for capital and O&M of an RO facility and associated evaporation ponds. The costs of a new well or refurbishing existing wells are not included in the table.

Design of the wellhead RO treatment would depend on the quantity and quality of brackish water. Pre-treatment of the groundwater would include filtration for sediment removal, and pH adjustment, if necessary. It is anticipated that the water would be blended to achieve a target TDS concentration; and, therefore, some water could bypass the RO treatment.

The cost of producing potable water from brackish groundwater sources is considerable but the cost of finding another source of water could be higher. If there were incentives to use brackish groundwater, such as not counting against a city's or town's groundwater use as prescribed by ADWR, then the cost of brackish groundwater would be justified.

Wellhead treatment at a single well is successfully being done at various locations in the Southwest, for example in Goodyear, Arizona, and El Paso, Texas. Due to high water demand, both cities put groundwater wells into operation even though only poor quality groundwater was available. Both cities dispose of the concentrate into the sewer systems. For small operations with large areas of land available, evaporation ponds may be inexpensive and relatively easy to maintain.

Change in TDS	Capital			O&M			Annualized
	RO Plant (Million $)	Pond (Million $)	Total (Million $)	RO plant (Million $)	Ponds (Million $)	Total (Million $)	Total (Million $)
RO Wellhead Treatment							
200	$0.23	$11.54	$12.51	$0.07	$0.06	$0.13	$0.93
400	$1.19	$12.10	$13.72	$0.08	$0.06	$0.16	$1.03
600	$0.60	$12.65	$14.80	$0.09	$0.06	$0.18	$1.13
800	$0.77	$13.16	$15.80	$0.10	$0.07	$0.20	$1.22
1000	$0.92	$13.65	$16.73	$0.11	$0.07	$0.22	$1.30

Table 5-5: Capital, O&M and Annualized Costs for a Single Brackish Groundwater Well

5.3.2 Option: Centralized Groundwater Treatment Plant

This option consists of treating brackish groundwater from several wells at a centralized water treatment plant with RO prior to adding water into the distribution system. Brine concentrate would be transported via pipeline to a regional evaporation pond for disposal. Pre-treatment for groundwater would include filtration for sediment removal and pH adjustment, if necessary. It is anticipated that the water would be blended to achieve a target TDS concentration and, therefore, some water could bypass the RO treatment.

The Town of Gila Bend has a wellfield from which groundwater is pumped to a centralized RO facility. The RO facility is located in an undeveloped area of the desert and produces about 1 MGD of permeate. Relatively small evaporativation ponds have been built to dispose of the concentrate. The RO facility was built because the only groundwater available for the Town of Gila Bend has an average TDS concentration range of 1,000 to 1,200 mg/L.

The advantage of a centralized RO facility over individual wellhead treatment facilities is economy of scale cost savings in both capital and O&M, as shown in Table 5-6 below.

Change in TDS	Capital			O&M			Annualized Total (Million $)
	RO Plant (Million $)	Pond (Million $)	Total (Million $)	RO plant (Million $)	Ponds (Million $)	Total (Million $)	
Centralized Well Treatment							
200	$1.67	$16.10	$21.14	$0.17	$0.08	$0.33	$1.70
400	$3.08	$21.01	$29.47	$0.28	$0.11	$0.54	$2.46
600	$4.37	$25.68	$37.09	$0.38	$0.13	$0.74	$3.17
800	$5.56	$30.98	$45.01	$0.48	$0.15	$0.93	$3.89
1000	$6.69	$35.24	$51.68	$0.58	$0.18	$1.11	$4.52

Table 5-6: Capital, O&M and Annualized Costs for a Multiple (4) Brackish Groundwater Wells

6.0 Conclusion

Two which can help a community decide if desalinization would right for them are:

- Will desalinization of existing impaired water resources reduce, postpone or eliminate development of new water supplies?
- Will desalinization of existing impaired water resources eliminate or reduce the demand on existing water supplies?

When considering the application desalinization technologies for surface water supplies, these guidelines are very appropriate. If desalinization technologies are being considered because of palatable rather than potable reasons, then the loss of water resources associated with the concentrate reject is probably not acceptable. Depending on the overall water budget, this lost water must be made up from the development of new surface water supplies or additional pumping of groundwater from aquifers.

When considering reclaimed water, desalinization still produces a concentrate stream; however, the water loss may be an appropriate trade off to enhance the reclaimed water quality of the remaining quantity. For example, if a reclaimed water facility is producing 10 MGD of reclaimed water and the TDS concentration is so high that it can not be used directly or indirectly through recharge, then there is a regional impact of 10 MGD loss of water. If the water is desalted and 15 percent is lost in the brine stream, this still provides 8.5 MGD of reusable water that will reduce demand of the potable water supplies.

Within central Arizona, there are certain areas that contain brackish groundwater that cannot be used for potable purposes. Desalinization this groundwater would produce a “new” water source for society. The 15 percent water loss to concentrate reject would be acceptable in this case because the water source could not be used without demineralization.

Improvements in RO, in regards to efficiency and the subsequent loss of water in the reject concentrate, is critical. There are two major reasons: one, water is limited in central Arizona and throwing away 15% with the reject concentrate is unacceptable water losses, and two, the less volume of reject concentrate produced, the less it will cost to management it. Concentrate management can be up to 50% or more of the cost of a large scale desalinization facility depending on circumstances. Concentrate management remains the number one issue to be resolved if new large scale desalting facilities are to be built in central Arizona to develop brackish groundwater reserves or to reduce TDS concentrations in the effluent produced by the WWTPs.

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