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

Table of Contents

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.

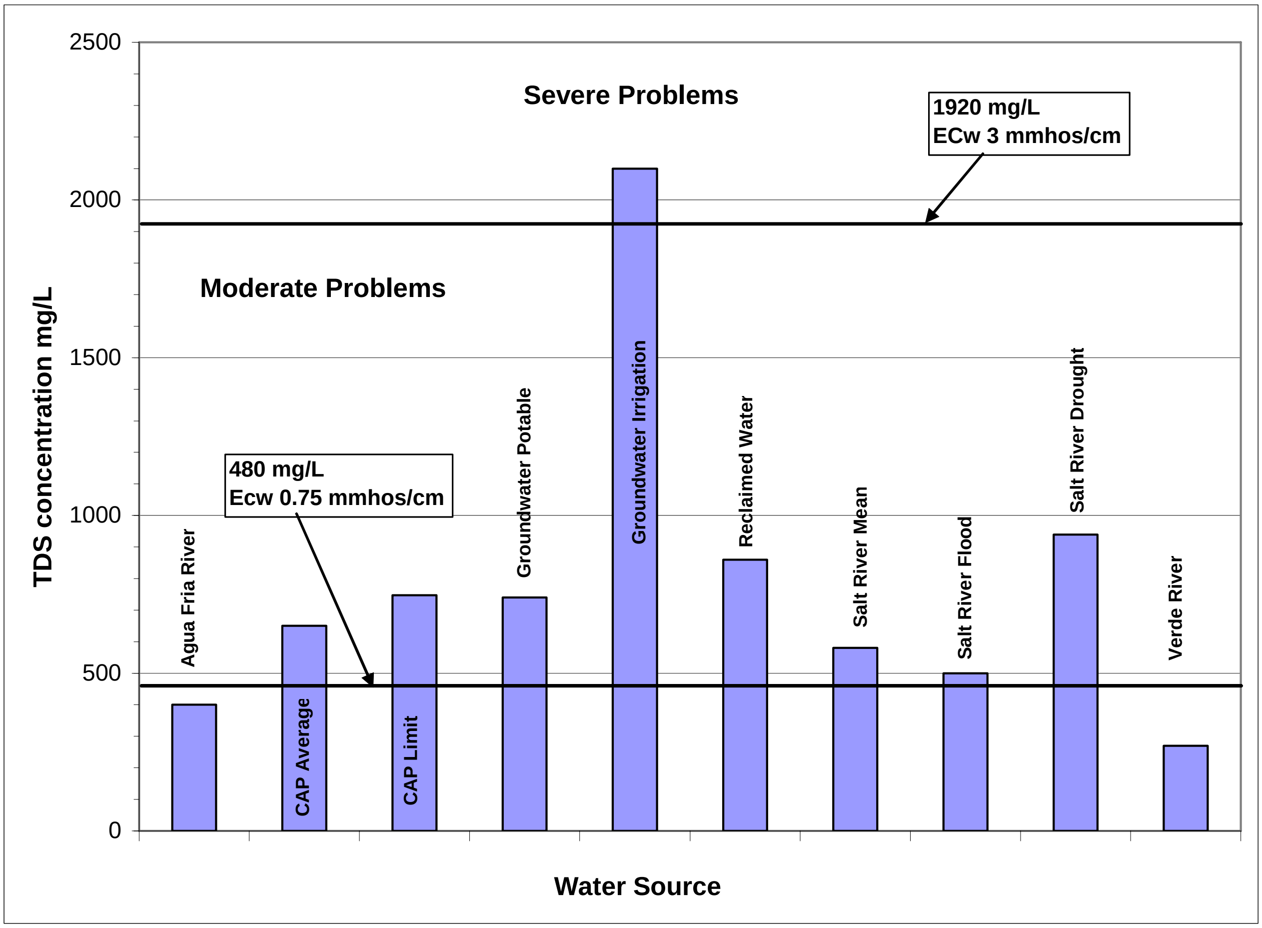

Figure 3-3: Water Quality Central Arizona

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).

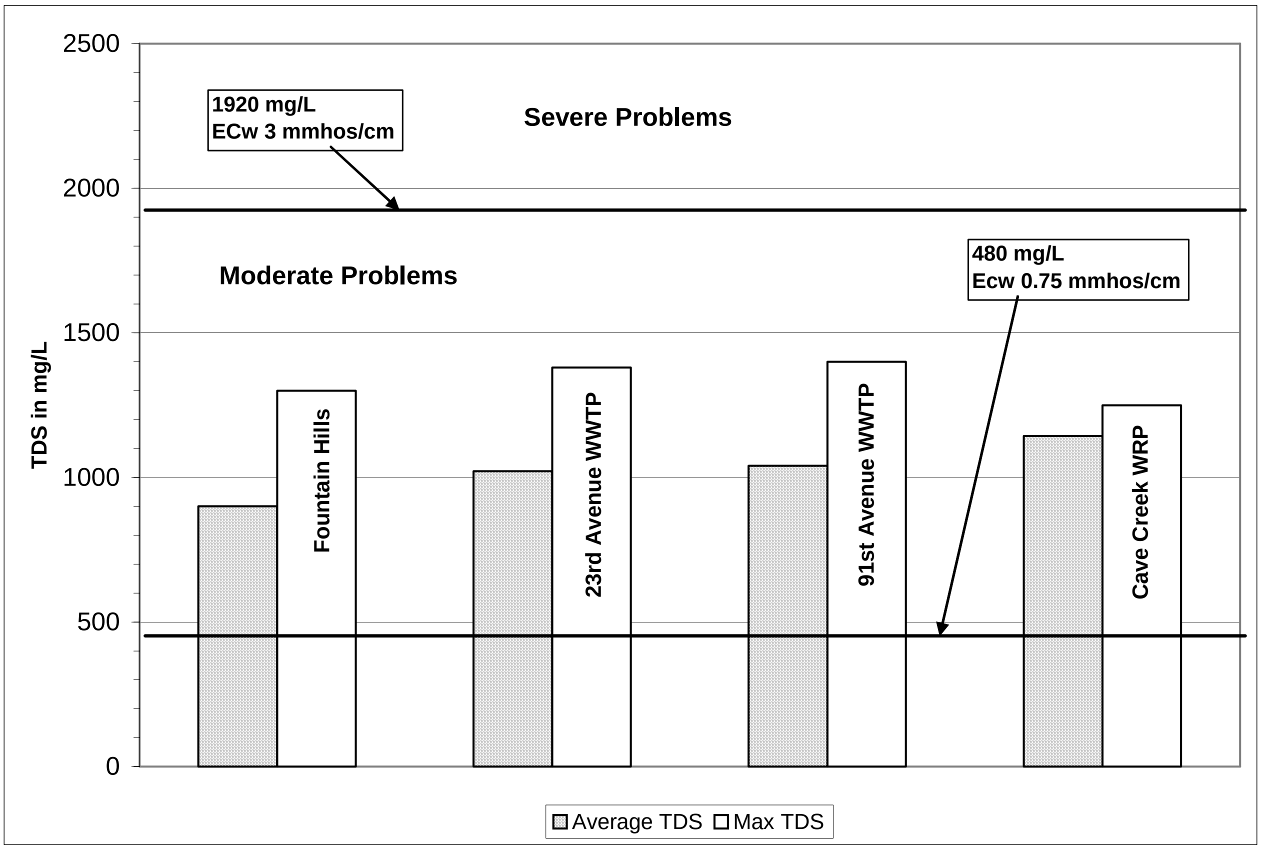

Figure 3-4: Water Quality at WWTPs

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.

7.0 References

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Appendix A
Numerical Analysis of Options

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

PHASE II PLANNING REPORT – APPENDIX A

Numerical Analysis of Options

This appendix contains a write up of each analysis that was performed for the Options that were deemed not to contain a "fatal flaw", as discussed in Section 2.0 of the Central Arizona Salinity Study (CASS) Planning Sub-Committee Report (Report), The Options were analyzed using the criteria developed by the CASS Planning Sub-Committee (Sub-Committee) and described in Chapter 3 of the Report. Cost estimates of the microfiltration (MF)/reverse osmosis (RO) facilities with evaporation ponds for concentrate disposal were made using the spreadsheet cost model developed by Reclamation for the Sub-Committee. The cost estimates provided in this appendix are accurate enough for reconnaissance level planning purposes, but not for construction purposes.

Analysis for Section 4.0: Preventing Salts from Entering Central Arizona

The following assumptions were used for analyzing the salinity control options presented in Section 4.0.

1. For the purposes of this study, Colorado River water is assumed to have a TDS concentration of 650 mg/L, which is equivalent to the 30-year average of TDS at Lake Havasu. The TDS of the Salt River varies at different locations, and the value used at any given location is stated in the text.

2. Evaporation ponds are the concentrate disposal/management approach for treatment options under consideration in this set of salinity control evaluations.

3. Costs included in these evaluations result primarily from the cost model developed in 2004 by the U.S. Department of Interior Bureau of Reclamation (Reclamation). This cost model utilizes cost curves developed in the Reclamation's 2004 *Appraisal Evaluation* entitled Reverse Osmosis Treatment of Central Arizona Project Water for the City of Tucson .

4. Efficiency is assumed to be 85 percent on all RO applications.

5. Replacement of water resources lost in the concentrate reject stream is assumed to be Indian Lease (IL) water at $1,700 per acre-foot (AF).

Several different treatment options were considered for reducing salt concentrations in Colorado River water, but only those options that would benefit central Arizona were selected for review.

4.1.2.1 Option: RO Facility Constructed at Davis Dam on the Colorado River

Description: This option consists of constructing a 2,050-million gallon per day (MGD) RO plant on the Colorado River at Davis Dam to treat a portion of river flow and send the permeate back into the river. Discharging the permeate back into the river, will cause a blending of the permeate and untreated river water, effectively reducing the TDS in the permeate. The reduction of salts would benefit central Arizona, southern California, and Mexico. Davis Dam was selected as the location to build the RO facility because of its location upstream from both the Central Arizona Project (CAP) aqueduct system and the California Colorado River Aqueduct. The Colorado River mean flow at Davis Dam is 9,883 MGD(15,290 cubic feet per second [cfs]), with an average TDS concentration of 650 mg/L over the last 30 years.

Concentrate disposal would be accomplished through evaporation ponds on U.S. Bureau of Land Management (BLM) land, which is located within five miles of Davis Dam. The water losses could be subtracted from the total river flow and not any individual allocation.

Institutional Considerations: Significant environmental permitting may be required for the construction of a RO plant adjacent to the river. An Arizona Aquifer Protection Permit (APP) from the Arizona Department of Environmental Quality (ADEQ) would be required for the construction and operation of the evaporation pond. APP requirements for evaporation pond liners are project-specific and will depend primarily on the chemical characteristics of the concentrate and depth to groundwater. If the land for the evaporation ponds, or any pipelines or conveyances, were to be located on federal lands, or the construction of this facility is federally-funded, National Environmental Protection Act (NEPA) regulations would have to be followed.

Water Resource Utilization: This option decreases water supply from the Colorado River due to loss in the concentrate disposal. This lost water will not be easily accepted by any of the Colorado River Basin States, the United States (U.S.) Federal government or the Mexican government, especially during drought periods.

Technical And Operational Feasibility: Although this facility is technically feasible, it would be extremely expensive to construct and operate due to its enormous size. The evaporation ponds are too large to be practical at 111 square miles to reduce the Colorado River by just 100 mg/L TDS. An alternative concentrate disposal method would be required, such as a pipeline to the Gulf of California.

Environmental/Public Acceptability: Reducing the salt content in the Colorado River would be readily accepted by the public, however, the loss of 15 percent of the water, estimated to be approximately 307 MGD, to concentrate management would be unacceptable. The Lower Colorado River Multi-Species Conservation Program (MSCP), a multi-agency effort to conserve and recover endangered species, may oppose this idea because of the reduction in water that would result in the river. Additionally, disposing of the concentrate would require over 100 square miles of evaporation ponds which may create environmental problems and concerns.

Benefits/Risks of Salinity Control/Reduction Option: Beneficiaries of a this option would be all Colorado River users below the RO facility, including CAP-supplied central Arizona, southern California metropolitan areas, farmers in Coachella and Imperial Irrigation Districts, and Mexico. The benefits would be through longer life in household appliances, better crop yields, longer life in water treatment facilities, and similar saved costs associated through the reduction of TDS. Central Arizona would see $15 million in savings for the reduction of 100 mg/L TDS in the Colorado River.

Economic/Financial Feasibility: For a reduction in TDS of 100 mg/L, the capital costs for a MF/RO plant would be approximately $1.85 billion. Capital costs for evaporation ponds would cost on the order of $5.65 billion. Total annual O&M would is estimated at $300 million. This idea is not financial feasible.

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

Conclusion: A RO plant to treat the Colorado River would have to handle two billion gallons per day and the cost to construct the plant would be approximately $2 billion. This 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 if the concentrate were to be transported to the Gulf of California. Overall, this alternative is rated very poor on technical/operational feasibility, economic/financial feasibility, environmental/public acceptability and water resource utilization.

4.1.2.2 Option: RO Facility Constructed at Mark Wilmer Pumping Plant

Description: This option consists of constructing a 400-MGD RO facility at the Mark Wilmer Pumping Plant to reduce salts in Colorado River water conveyed through the CAP aqueduct. This reduction of salts would benefit all of CAP water users and indirectly benefit people living in central Arizona. The Mark Wilmer Pumping Plant was selected as the location to build the RO facility because it offers some unique advantages. The Mark Wilmer Pumping Plant pumps approximately 1,939 MGD (or 3,000 cfs) of Colorado River water, which averaged about 650 mg/L TDS over the last 30 years. The concept of the RO facility would be to treat Colorado River water and blend with raw river water to produce the desired TDS in the water delivered by the CAP to central Arizona.

The RO plant would be designed as a one-stage membrane treatment facility. With the permeate flowing into the canal and the concentrate discharged to the Colorado River downstream of the plant. This scheme would reduce pressure requirements, which, in turn, would reduce energy consumption. However, the biggest savings in capital costs would be the elimination of a costly concentrate disposal scheme. There would be very little increase in TDS concentrations in the downstream river. Preliminary calculations indicate that the TDS concentrations in the Colorado River downstream of the plant ,where the concentrate was returned to the river, would increase by only 28 mg/L. Under most conditions this would not violate the standard set by the Colorado River Basin Salinity Control Forum of 747 mg/L TDS for this location.

Institutional Considerations: Significant environmental permitting may be required for the construction of a RO plant adjacent to the river. Water users downstream, especially the Imperial Irrigation District (IID), may not approve of this option because it will increase the salinity of the Colorado River, potentially leading to reduced crop production for farmers in the Imperial and Coachella Valleys. The Mexican government may be opposed to this option, although it should not violate the Colorado River water quality agreement with Mexico.

Water Resource Utilization: This option does not lose any water through concentrate management, which is one of the benefits of this option. Water that flows to Mexico or irrigation in southern California (IID) will be of poorer quality but the water which goes to central Arizona will be of better quality.

Technical and Operational Feasibility: Technically, this option has some advantages, thousands of tons of salts would not be pumped with the water from Mark Wilmer pumping plant or through the many pumping plants between the Colorado River and Tucson. Less energy would be required for a RO facility at this site because the plant would be a one-stage RO plant. Power is readily available. Concentrate management would be inexpensive because the concentrate would immediately re-enter the Colorado River. The disadvantage of this option is that the design of the RO plant would take significant effort because of site limitations.

Environmental/Public Acceptability: This option will potentially cause conflict amongst other Colorado River users, especially California and Mexico because of the increase of salinity resulting from concentrate being returned to the river. The Lower Colorado River Multi-Species Conservation Program may consider this project to be detrimental to the Colorado River.

Benefits/Risks of salinity control/reduction option: The major benefit would be the reduction of salt entering central Arizona which indirectly would benefit all of central Arizona water users. All CAP water users would benefit directly by receiving better quality water, reduced salinity related damages and better re-use of the water.

Economic/Financial Feasibility: It is estimated that the cost of this MF/RO facility would be close to $500 million. Costs may more because of the difficult terrain and small area where the MF/RO plant could be constructed. O&M costs are estimated to be $55 million annually.

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

Conclusion: The concept of constructing and operating a RO facility at Mark Wilmer Pumping Plant would be beneficial to central Arizona because of the prevention of salts entering the study area. Use of this existing site reduces the capital cost by approximately 50 percent because the need for constructing evaporation ponds for concentrate management is eliminated. Secondly, there is no loss of water resources to concentrate disposal because the concentrate is blended back into the Colorado River. Thirdly, energy costs would be lower because of reduced pressure requirements in the RO facility and thousands of tons of salts would not be pumped with the water delivered to central Arizona.

It is estimated that the RO facility at Mark Wilmer Pumping Plant would cost about $470 million and annual O&M costs would be about $55 million. These combined costs are much higher than the annual benefits of about $15 million with the reduction of 100 mg/L TDS in the CAP waters. As with all the large sized options, the capital and O&M costs are exorbitant. This option is rated very poor for Economic/Financial Feasibility and marginal for Environmental/Public Acceptability.

4.1.3.2 Option: RO Facility Constructed on the Salt River and Roosevelt Lake

Description: This option consists of constructing a 47 MGD RO facility on the Salt River, just upstream of the flood zone of Roosevelt Lake for the purpose of preventing salinity from entering central Arizona, specifically the Phoenix metropolitan area. The mean flow for the Salt River at this location, since 1914, has been 585 MGD. The TDS concentration in the Salt River varies according to wet and dry cycles. In 1983, a wet year, the Salt River, at the same location, had an average TDS of 800 mg/L and a total flow of 1.3 million AF. In the year 2000, a dry year, the Salt River at this location had an average TDS of 2280 mg/L with a total flow of .66 million AF. The RO facility would desalinize water during low flow conditions when the TDS was high. For the purposes of this study, an average flow of 585 MGD was used for the river with an average TDS concentration of 1,540 mg/L.

A cursory review of land uses in the area of the Salt River and Roosevelt Lake indicates that there is land available to build the required 1,600 acres of evaporative ponds for concentrate disposal.

Institutional Considerations: Significant environmental permitting may be required for the construction of a RO plant adjacent to a major, perennial river. In addition, the Willow Fly Catcher inhabits many areas around the lake.

Water Resource Utilization: Approximately 1 percent of the Salt River flow at this location would be lost to concentrate disposal for every 100 mg/L reduction in TDS.

Technical and Operational Feasibility: Construction of a RO facility at this location would be feasible because of access to roads and power. Operation of the plant would require significant effort to maintain due to the variations in TDS concentration.

Environmental/Public Acceptability: There are no environmental "fatal flaws" that are known at this point in time. The size of the evaporative ponds for concentrate disposal could be an issue for some people and organizations.

Benefits/Risks of Salinity Control/Reduction Option: Beneficiaries would be SRP customers and, indirectly, the Phoenix metropolitan area because of less salt entering into the Phoenix groundwater.

Economic/Financial Feasibility: Reducing the TDS concentration from 1,540 mg/L to 1,440 mg/L with these flows would require a MF/RO facility of approximately 47.2 MGD capacity. The capital costs for such a plant would be approximately $80 million, as shown below in Table 4.3. The evaporation ponds would cost an additional $156 million. O&M on the entire facility would be about $7.28 million. Annualized costs over 50 years at a 6 percent interest would be about $23.24 million.

Salt reductions of this magnitude would have annual savings in the Phoenix metropolitan area of about $15 million.

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

Conclusion: The salinity level is high at this point on the river and would be an ideal place to treat the water because the land is flat and access roads are available for constructing the facility. Power could easily be brought to the site.

The most expensive capital costs would be the evaporation ponds. An alternate method of concentrate disposal or more water extracted from the concentrate so the ponds could be reduced in size would reduce the costs.

This RO facility and evaporation ponds may be feasible if the capital costs could be reduced. Currently benefits would be about $15 million annually and the annualized capital and O&M costs would be about $23.24 million.

4.2.1.1 Option: RO Facility Constructed Along the CAP Canal in Western Arizona

Description: This option consists of constructing a 400 MGD RO facility along the CAP canal, possibly near Bouse Wash. This facility would reduce the salts in the CAP water delivered to central Arizona. Bouse Wash was selected because although it is isolated, it is near Interstate 10, which would provide easy access to the site. The CAP canal carries approximately 1,939 MGD (3,000 cfs) at 650 mg/L TDS (on average). The concept of this RO facility would be to treat a portion of the CAP water and blend it back to produce better CAP water for CAP customers.

Institutional Considerations: Normal environmental permitting would be required for the construction of a RO plant and evaporation ponds. As stated in Section 4.1.2.1, an APP would need to be obtained for the construction and operation of evaporation ponds. If the land for the evaporation ponds, or any pipelines or conveyances, were to be located on federal lands, or the construction of this facility is federally-funded, NEPA regulations would have to be followed.

Water Resource Utilization: This option will reduce the total amount of water delivered through the CAP canal by approximately 3 percent, which may not be considered the best use of imported water.

Technical and Operational Feasibility: This option would be relatively easy to construct from a technical point of view due to the easy access to the site, flat land, and a proven technology. The evaporation ponds would be extremely large, however, there are large amounts of open desert to construct them.

Environmental/Public Acceptability: The public may not be opposed to this option since they would be receiving water of better quality, however, it may be difficult to justify the destruction of large amounts of desert environment for the construction of evaporation ponds.

Benefits/Risks of salinity control/reduction option: Beneficiaries of this alternative would consist of all central Arizona CAP water users. Central Arizona would receive annual savings because of the lowered TDS. These savings would be longer life for household appliances, better crop yields, longer life for water treatment facilities and higher quality reuse water, etc.

Economic/Financial Feasibility: The cost of the MF/RO facility would be close to a $500 million and evaporation ponds are estimated to cost over $1 billion. The high costs on for the evaporation ponds are due to the cost of land and double lining the ponds. Estimated costs reflect a worst-case scenario and may be reduced if land trade agreements could be agreed upon with Bureau of Land Management (BLM). O&M costs for the MF/RO facility and the evaporation ponds would be close to $60 million annually. The benefits of reducing the CAP TDS by 100 mg/L is approximately $15 million therefore, the cost benefit ratio is not favorable.

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 - Summary of Costs for RO Facility on CAP in Western Arizona

Conclusion: Construction costs for the RO facility constructed on the CAP canal in western Arizona would be high due to the size, but the location would make the construction accessible. The amount of area required for evaporation ponds would be very large and would be very expensive if a double-liner system were required for aquifer protection. Possible land trade agreements with the BLM, who owns large tracts of land in the immediate area, could reduce the cost of the land required for the evaporation ponds. The topography, which consists of flat, desert lands broken by dry washes, would make for easy construction of both the MF/RO facility and the evaporation ponds.

This option rates very poor for economic/financial feasibility and poor for environmental/public acceptability because of the size of the evaporation ponds. The total size of evaporation ponds for just 100 mg/L reduction in TDS would be nearly 22 square miles. Water lost to concentrate disposal would be approximately 3 percent of the total CAP water supply.

4.2.2.1 Option: RO Facility Constructed on the Salt River at Granite Reef Dam

Description: This option consists of constructing an RO facility at the Granite Reef Dam to treat Salt River water. This 80 MGD RO facility would ensure that water low in TDS was delivered year around. A RO facility at this location would only require operation when SRP was delivering higher TDS water. Evaporation ponds for this project could be located on land owned by the Salt River-Pima Maricopa Indian Community.

Institutional Considerations: An APP would be required for the construction and operation of the evaporation ponds. Negotiating for land use for concentrate disposal with the Indian Community may be difficult. Other concentrate disposal options most likely would be necessary.

Water Resource Utilization: The concentrate produced from this RO plant would be about 3 percent of the flow of the Salt River. These losses may not be acceptable to SRP and the other users of the river.

Technical and Operational Feasibility: Designing and operating this plant would be difficult due to the fluctuations in TDS. It would have to be designed to handle higher TDS at lower flows and lower TDS at higher flows. It would also have to operate at higher flows when the Salt River was the primary delivered water and lower rates when the Verde River was the primary delivered water. For this evaluation, the low and high TDS concentrations of 700 and 1,000 mg/L, respectively, were analyzed for costs.

The location would have easy access for construction activities and power would be easily brought to the site. Operationally, the facility would have to be designed so the rare flood events do not damage it. Technically, this plant would be easy to construct and maintain.

Environmental/Public Acceptability: Aside from concentrate disposal issues, there are no environmental issues that are known at this time. If this plant was reducing 1,000 mg/L TDS water at a flow of 283 MGD to a 500 mg/L TDS quality (federal secondary Maximum Contaminant Level), it would take 9.2 square miles of evaporation ponds to dispose of the concentrate.

Benefits/Risks of salinity control/reduction option: Beneficiaries would be SRP customers and, indirectly, the entire Phoenix metropolitan area because of less salt entering into the Phoenix ,groundwater and environment.

Economic/Financial Feasibility: Reducing the TDS from 1,000 mg/L to 900 mg/L would take approximately a 80 MGD MF/RO facility. The capital costs for such a plant is estimated to be $120 million. The evaporation ponds would cost an additional $210 million and O&M on the entire facility would be about $11.6 million. Salt reductions of this magnitude would have annual savings in the Phoenix metropolitan area of about $15 million, but the Salt River TDS varies tremendously from decade to decade

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

Conclusion: This plant would require careful design and operation considerations because of the varying qualities of source water. This facility also rates poor economically and financially because the annualized costs over 50 years would be close to $34 million. Benefits to central Arizona would be less than $15 million. Agreements to dispose of concentrate on Tribal land may be difficult to acquire.

Section 5: Managing Salts in Central Arizona

Analysis for Section 5.1: Water Treatment Plants

The following assumptions have been made for potable water treatment alternatives:

1. For the purposes of this study, three different sizes of water treatment plants were analyzed for costs of salinity reduction: small (10 MGD); medium (50 MGD); and large (100 MGD). These sizes were selected because they reflect the range of average sizes of water treatment plants in central Arizona.

2. Source water is assumed to have a TDS concentration of 650 mg/L, regardless of whether it was actually CAP water or other surface water, with reductions in salinity evaluated at 100 mg/L increments to a minimum TDS concentration of 450 mg/L.

3 Evaporation ponds are the assumed concentrate management approach for all enhanced treatment options under consideration in this set of salinity control evaluations. The associated length of pipelines to transport concentrate to required evaporation ponds is assumed, for purposes of these evaluations, to be 20 miles in the Phoenix metropolitan area and 10 miles in the Tucson metropolitan area. Using the categories defined in the cost model developed by the Reclamation (see Assumption No. 4 below), land type is assumed to be "Ag lands, undeveloped land, desert near City" for the Phoenix area with brush ground cover. Pipeline construction through the Phoenix area is assumed to be in a congested area. The City of Tucson currently owns a considerable amount of land (approximately 22,000 acres in Avra Valley) that could be potentially available for evaporation pond construction; therefore, no additional land costs are assumed in the Tucson area cost projections. Ground cover on the Tucson lands is assumed to be brush and pipeline construction is assumed to be in a sparsely populated area.

4. Costs included in these evaluations result primarily from the cost model developed in 2004 by the U.S. Department of Interior Bureau of Reclamation (Reclamation). This cost model utilizes cost curves developed in the Reclamation's 2004 *Appraisal Evaluation* entitled Reverse Osmosis Treatment of Central Arizona Project Water for the City of Tucson .

5. Efficiency is assumed to be 85 percent on all RO applications.

6. Replacement of water resources lost in the brine reject stream (concentrate) is assumed to be Indian Lease (IL) water at $1,700 per acre-foot.

5.1.1 One-Stage Microfiltration (MF) Pretreatment Followed by RO

Description: This option would consist of utilizing MF pretreatment and RO filtering. The brine concentrate would be discharged to evaporation ponds. The overall treatment process is shown below in Figure 1.

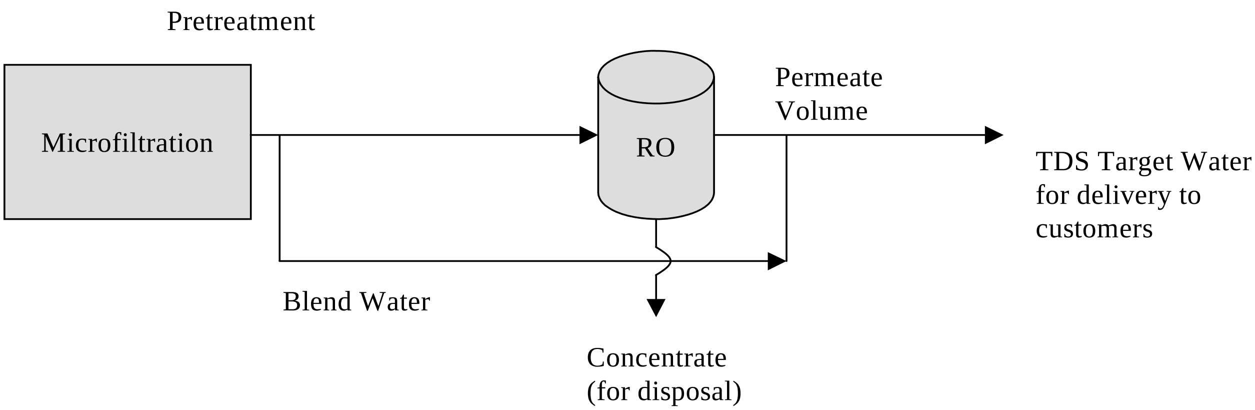


Figure 1: MF Pretreatment Followed by RO

Institutional Considerations: An APP would be required for the construction and operation of the evaporation ponds.

Water Resource Utilization: The MF pretreatment followed by RO option results in a high quality of water with 95 percent removal of salts. The volume of water treated and level of treatment (i.e. TDS target) result in varying water resource losses. However, this evaluation assumes 85 percent efficiency with significant water loss (15 percent) to concentrate through the RO process. The projected loss of water could potentially be decreased through enhancements to the RO process, such as the DewVaporation process or HERO™ technology, or application of other new technology. Table 1 reports the range of water volume and TDS targets for small, medium and large potable water treatment plants. The volume of water required to be treated through RO is shown in the column labeled “RO Plant Size”, which is derived by adding the permeate and concentrate volumetric flow rates. “Blend Volume” refers to that volume of water that would not be treated through the RO process but would be blended back with the “Permeate Volume” to achieve the desired TDS target. (See Figure 1.) These volumes are consistent for treatment plants regardless of whether they are located in Phoenix or Tucson. However, due to differences in average rainfall and evaporation rates, the size requirement for the evaporation pond area may vary between these locations and is reported separately in Table 6.

Overall Plant Capacity and TDS (in mg/L)	RO Plant Capacity (MGD)	Blend Volume (MGD)	Permeate Volume (MGD)	Concentrate Volume (MGD)	Pond Area (acres)	
					Phoenix	Tucson
10 MGD/ 550	2.07	7.93	1.76	0.31	72	78
10 MGD/ 450	4.02	5.98	3.42	0.60	140	151
50 MGD/ 550	10.36	39.64	8.81	1.55	362	388
50 MGD/ 450	20.10	29.90	17.09	3.02	701	753
100MGD/ 550	20.73	79.27	17.62	3.11	723	777
100MGD/ 450	40.20	59.80	34.17	6.03	1,402	1,507

Table 6: Target TDS

Technical and Operational Feasibility: With MF pretreatment, the water would have high reliability and consistency with the needs of RO. This approach could also have the flexibility needed to address other treatment concerns that might emerge over time. Such flexibility would depend on a modular treatment train design where treatment components could be added to address water quality concerns as needed.

Environmental/Public Acceptability: While environmental impacts and public acceptability of modifications at existing plants for purposes of adding RO treatment will vary by specific site, the primary potential concern with this option will more likely relate to concentrate management. Construction of larger facilities, through modification of existing plants, may cause various neighborhood and environmental concerns relative to the specifics of existing facilities. Those concerns might include potential or perceived impacts on neighboring properties (buffering potential), land availability, if expansion is required, associated costs, and such operational issues as noise, traffic, and chemical storage. Potential public concerns with concentrate management issues include conveyance pipeline construction and prospective evaporation pond locations. These concerns will likely focus on cost and disturbance of habitat and/or loss of panoramic view, or viewshed. The size and costs of such facilities will vary on a case-by-case basis. Also, costs associated with final disposal could add considerable expense to cradle-to-grave concentrate management.

Benefits/Risks of Salinity Control/Reduction Option: This evaluation categorized the various risks and benefits of the salinity control option in terms of positives and negatives as follows:

+ A high degree of salinity control would be achieved providing better quality water.
+ This option would provide better reliability than conventional treatment processes that rely on either conventional filtration or cartridge filters as RO pretreatment.
- Raw water quality with variable high turbidity would require extra operational vigilance using MF.

Economic/Financial Feasibility: Cost estimates vary for the Phoenix and Tucson metropolitan areas due to a number of factors, including land costs and location of treatment facilities in relation to potential concentrate disposal sites. Table 7 provides the estimated total construction costs for the range of treatment facilities evaluated for both the Phoenix and Tucson areas.

Overall Plant Capacity / TDS Target (in mg/L)	Phoenix Area	Tucson Area
	$ Millions	
10 MGD/ 550	25.24	18.05
10 MGD/ 450	36.89	28.10
50 MGD/ 550	75.01	59.73
50 MGD/ 450	129.55	104.98
100 MGD/ 550	132.83	107.74
100 MGD/ 450	239.26	194.93

Table 7: Estimated Total Construction Costs

Table 8 provides a 20-year annualized total of capital and operational costs assuming a 6 percent interest. Figure 2 displays these costs in graphical format.

Overall Plant Capacity / TDS Target (in mg/L)	Phoenix Area	Tucson Area
	$ Millions	
10 MGD/ 550	3.07	2.41
10 MGD/ 450	4.71	3.9
50 MGD/ 550	9.95	8.54
50 MGD/ 450	17.51	15.24
100 MGD/ 550	17.97	15.65
100 MGD/ 450	32.67	28.59

Table 8. Total Annualized Capital and Operational Costs

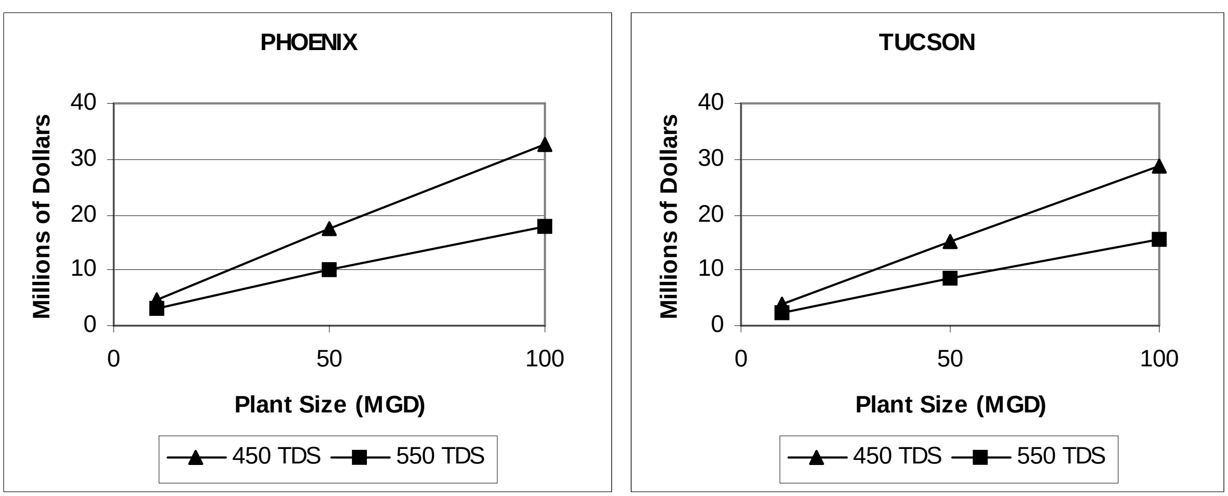


Figure 2. Annualized Costs MF-RO Option for Phoenix and Tucson

Table 9 lists the 20-year annualized capital and operational costs related to each phase of this treatment option, which consists of MF pretreatment followed by RO treatment with concentrate disposal to evaporation ponds. MF and RO costs, plus evaporation ponds and replacement of concentrate reject water, are based on inputs to the cost model assembled by the Reclamation for this project.

	Phoenix Area		Tucson Area	
Overall Plant Size/ TDS Target:	MF	RO, Evap & Water (IL)	MF	RO, Evap & Water (IL)
	$ Millions			
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 9. Annualized Capital and Operational Costs by Pretreatment and Treatment Phase

Conclusion: This option analyzed the feasibility of potable water treatment utilizing MF as pretreatment for RO with concentrate discharged via pipeline to evaporation ponds. 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.

5.1.2 Conventional Filtration Plus Cartridge Filter Pretreatment Followed by RO

Description: This option consists of a two-stage pretreatment, using conventional filtration as the first stage then feeding the water through cartridge filtration as a second stage. Conventional filtration consists of a series of processes including coagulation, flocculation, sedimentation, and filtration. The pretreated water would then be fed into an RO plant for desalination with the concentrate discharged via pipeline to an evaporation pond. The overall treatment train is portrayed schematically in Figure 3. This alternative seeks to take advantage of existing treatment facilities with modifications for adding RO treatment for salinity control. While this option may not be feasible for a new plant, it may be reasonably incorporated into existing potable water treatment plant facilities being modified for enhanced treatment.

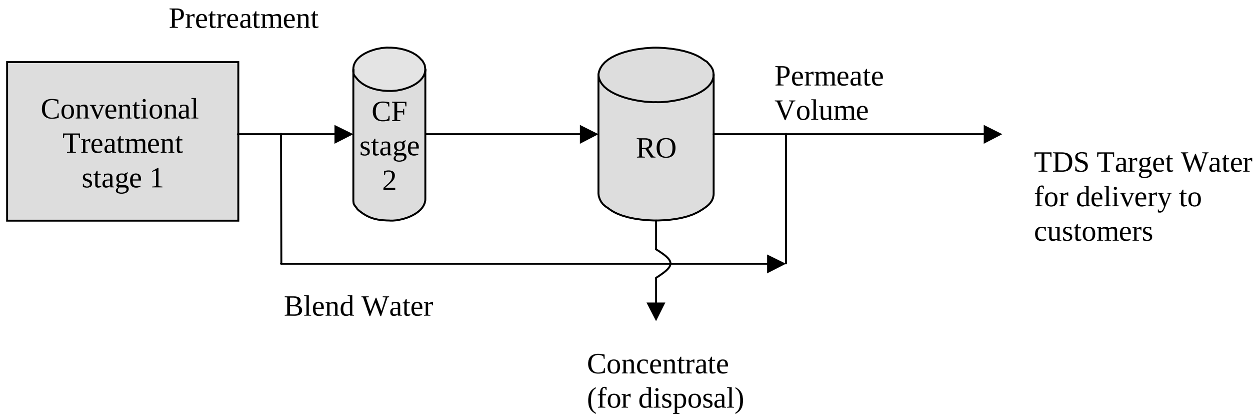


Figure 3: Conventional Filtration Treatment/ Cartridge Filtration Pretreatment Followed By RO

Institutional Considerations: This option, using conventional filtration treatment followed by cartridge filtration, then RO, is generally acceptable within the Institutional Considerations criteria with no significant issues. As stated previously, an APP would need to be obtained for the construction and operation of evaporation ponds. If the land for the evaporation ponds, or any pipelines or conveyances, were to be located on federal lands, or the construction of this facility is federally-funded, NEPA regulations would have to be followed.

Water Resource Utilization: This option results in a high quality product water with 95 percent removal of salts. The volume of water treated and level of treatment (i.e. TDS target) result in varying water resource losses; however, this evaluation assumes 85 percent efficiency with significant water loss (15 percent) to concentrate through the RO process. The projected loss of water could potentially be decreased through enhancements to the RO process such as the new DewVaporation™ or HERO™ technology, or other new technology. Table 1 lists the range of water volume and TDS targets for small, medium and large potable water treatment plants with the volume required to be treated through RO shown in the second column. "Blend Volume" refers to that volume of water that would not be treated through the RO process but would be blended back with the "Permeate Volume" to achieve the desired TDS target. *See Figure 3.* These volumes are consistent for potable treatment plants regardless of whether they are located in Phoenix or Tucson. However, due to differences in average rainfall and evaporation rates, the sizing requirements for the evaporation ponds will vary between locations and is shown separately in Table 10.

Overall Plant Capacity and TDS Target (mg/L)	RO Plant Capacity (MGD)	Blend Volume (MGD	Permeate Volume (MGD)	Concentrate Volume (MGD)	Pond Area (acres)	
					Phoenix	Tucson
10 MGD/ 550	2.07	7.93	1.76	0.31	72	78
10 MGD/ 450	4.02	5.98	3.42	0.60	140	151
50 MGD/ 550	10.36	39.64	8.81	1.55	362	388
50 MGD/ 450	20.10	29.90	17.09	3.02	701	753
100MGD/ 550	20.73	79.27	17.62	3.11	723	777
100MGD/ 450	40.20	59.80	34.17	6.03	1,402	1,507

Table 10: Potential Pond Size and Effluent Volume Treated Based on Plant Capacity and Target TDS

Technical and Operational Feasibility: This option, using conventional filtration and cartridge filter pretreatment followed by RO, may have the flexibility needed to address other treatment concerns that might emerge over time. This flexibility would depend on a modular treatment train design where treatment components can be added to address water-quality concerns as needed.

Technical and Operational Feasibility: Using only conventional filtration treatment as roughing filters would not provide water of sufficient quality for RO. Even following the first stage with cartridge filtration may not provide desired results on a consistent basis. Some conventional treatment plants may not be able to consistently provide product water that would be suitable for efficient RO treatment even if the cartridge component is added to the treatment train. It may be that the cartridges have to be replaced so frequently to avoid membrane fouling that the operational efficiency of this option would be compromised.

Provided operational issues with filtration prove acceptable, this approach could have the flexibility needed to address other treatment concerns that might emerge over time. This flexibility would depend on a modular treatment train design where treatment components can be added to address water-quality concerns as may be required.

While unlikely to be the design choice for a new plant, this approach is technologically feasible and allows utilization of existing facilities by adding treatment trains to meet additional water quality concerns such as salinity control.

Environmental/Public Acceptability: While environmental impacts and public acceptability of modifications on existing plants for purposes of adding RO treatment will vary by site, the primary potential concern with this option will more likely relate to concentrate management. Construction of larger facilities, through modification of existing plants, may cause various neighborhood and environmental concerns relative to the specifics of existing facilities. Those concerns might include potential or perceived impacts on neighboring properties (buffering potential), land availability, if expansion is required, associated costs, and such operational issues as noise, traffic, and chemical storage. Potential public concerns with concentrate management issues include the construction of conveyance pipelines and evaporation ponds. These concerns will likely focus on cost and disturbance of habitat and/or viewshed. The size and cost of these facilities will vary on a case by case basis. Also, costs associated with final disposal could add considerable expense to cradle-to-grave concentrate management.

Benefits/Risks of Salinity Control/Reduction Option: This criteria was used to evaluate and categorize the various risks and benefits of each salinity control option in terms of positives and negatives. For this specific option, the positive and negative issues are as follows:

> + This option would utilize existing treatment facilities as part of the treatment process.
> + A high degree of salinity control would be achieved providing better quality water.
> - If a new plant were to be designed to accomplish salinity reductions, this option would not be chosen.
> - This may be an inefficient process since it seeks to salvage existing infrastructure at the potential cost of treatment efficiency.

Economic/Financial Feasibility: Cost estimates vary between the Phoenix and Tucson metropolitan areas due to a number of factors including land costs and location of treatment facilities in relation to potential concentrate disposal sites. This option allows utilization of existing facilities, which are assumed to already be using conventional filtration treatment, being modified to add RO treatment. Because of that, in this option, capital construction costs would primarily consist of the addition of cartridge filters, the RO plant, pipeline and evaporation pond construction, with minor capital costs related to modification of the existing facility. Modification costs could vary considerably based on the specific facility and are not included in the cost estimation. Table 11 provides the total capital cost for construction of the cartridge filtration, RO system, evaporation pond, and associated pipelines and conveyances for the range of treatment facilities evaluated for both the Phoenix and Tucson areas.

As discussed in the Technical and Operational Feasibility criteria, some conventional treatment plants may not be able to consistently provide product water that would be suitable for efficient RO treatment even if the cartridge component is added to the treatment train. It may be that the cartridges have to be replaced so frequently to avoid membrane fouling that the cost effectiveness (Economic Feasibility) of this option would be compromised.

Overall Plant Size / TDS Target (mg/L)	Phoenix Area	Tucson Area
	$ Millions	
10 MGD/550	20.91	13.72
10 MGD/450	29.96	21.17
50 MGD/550	61.76	46.48

50 MGD/450	108.29	83.72
100 MGD/550	111.43	86.35
100 MGD/450	204.84	160.52

Table 11: Estimated Total Construction Costs

Table 12 provides an estimate of 20-year annualized total capital and operational costs assuming a 6 percent interest. Figure 4 portrays these same costs in graphical format.

Overall Size Plant / 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 12: 20-Year Annualized Estimated Total Capital and Operational Costs

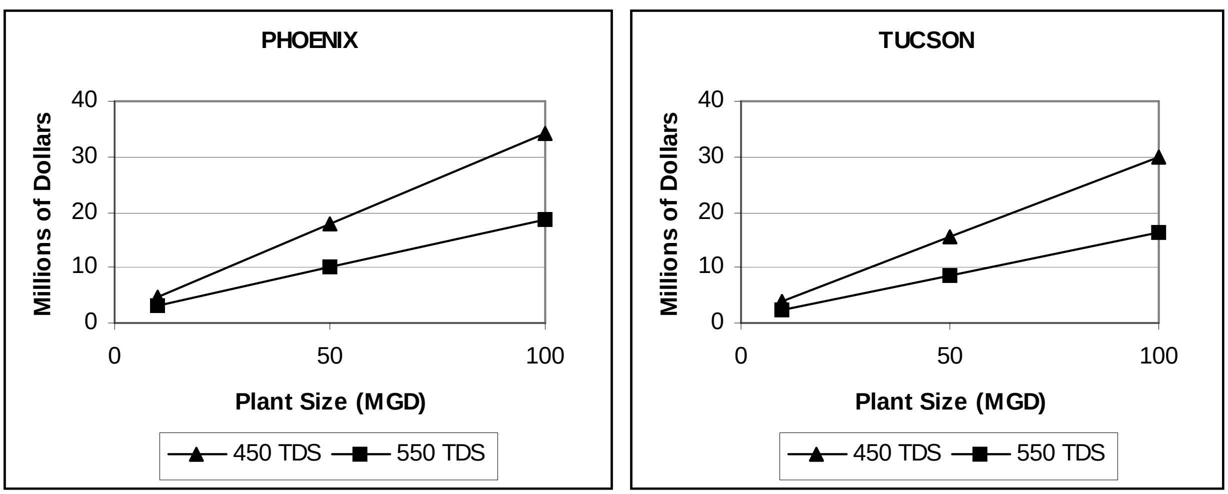


Figure 4: Annualized Costs for the Conventional Filtration Treatment/Cartridge Filtration/RO Option for Phoenix and Tucson

Table 13 below separates out the 20-year annualized capital and operational costs related to each phase of this treatment option, i.e. Stage 1 conventional filtration, Stage 2 cartridge filtration, and followed by RO, with the resultant concentrate being disposed of in evaporation ponds. The operational costs and minor capital modification costs for conventional treatment facilities were based on the Reclamation's *Appraisal Evaluation* report (2004); industry cost curves were modified by Tucson Water. Estimated costs for the RO system, evaporation ponds, and replacement of concentrate reject water are based on inputs to the cost model assembled by Reclamation for this project. Assumed interest rate is six percent and costs include the replacement of lost water resource as well. Replacement of cartridge filters was assumed to be five times per year.

	Phoenix Area			Tucson Area		
Overall Plant Size /TDS Target (mg/L)	Conventional Treatment	Cartridge Filtration	RO System, Evaporation Ponds, and Water Replacement (IL)	Conventional Treatment	Cartridge Filtration	RO, Evap & Water
	$ Millions					
10 MGD/550	0.17	0.14	2.68	0.17	0.14	2.02
10 MGD/450	0.32	0.26	4.04	0.32	0.26	3.23
50 MGD/550	0.83	0.68	8.52	0.83	0.68	7.11
50 MGD/450	1.61	1.32	15.03	1.61	1.32	12.76
100 MGD/550	1.66	1.36	15.43	1.66	1.36	13.11
100 MGD/450	3.23	2.64	28.22	3.23	2.64	24.14

Table 13: Annualized Capital and Operational Costs by Pretreatment and Treatment Phase

Conclusion: This option consisted of utilizing conventional filtration techniques, including sand and coagulation, followed by cartridge filtration as pretreatment for RO. The RO process requires very low suspended particulate concentrations to avoid fouling the membrane surfaces. As direct feed to RO, conventional filtration alone will likely not provide water of sufficient quality to guarantee efficient operation of RO treatment on a consistent basis. The choices made in pretreatment greatly impact the operational costs and effectiveness of RO treatment and may impact the concentrate stream as well.

5.1.3 Potable Treatment with Salinity Control: Conventional Filtration/Coagulation Plus MF Pretreatment Followed by RO

Description: This option evaluated the pretreatment process in which conventional direct filtration treatment were used as the first stage , an MF system would be used for the second stage filtering, then the pretreated water would be sent through an RO plant for desalinization. The brine concentrate would be discharged via pipeline to an evaporation pond. While it is doubtful that this option would be a design feature in a new plant, it may be reasonably incorporated into existing potable water treatment plant facilities being modified for enhanced treatment. The treatment process for this option is shown below in Figure 5.

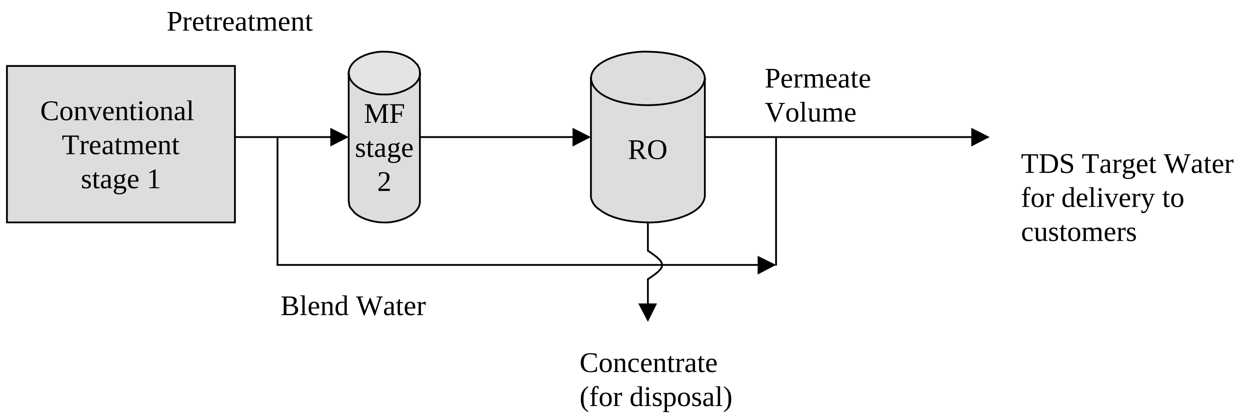


Figure 5: Conventional Filtration / MF Pretreatment Followed By RO

Institutional Considerations: An APP would need to be obtained for the construction and operation of evaporation ponds. If the land for the evaporation ponds, or any pipelines or conveyances, were to be located on federal lands, or the construction of this facility is federally-funded, NEPA regulations would have to be followed.

Water Resource Utilization: This option would result in a high quality water with 95 percent removal of salts. The volume of water treated and level of treatment (i.e. TDS target) would result in varying water resource losses, however, this evaluation assumes 85 percent efficiency with significant water loss (15 percent) to concentrate through the RO process. The projected loss of water could potentially be decreased through enhancements to the RO process, such as the DewVaporation process or HERO™ technology, or other new technology. Table 14 reports the range of water volume and TDS targets for small, medium and large potable water treatment plants with the volume required to be treated through RO shown in the column labeled "RO Plant Size" derived by adding the permeate and concentrate volume rates. "Blend Volume" refers to that volume of water that would not be treated through the RO process but would be blended back with the "Permeate Volume" to achieve the desired TDS target. *See Figure 5.* These volumes are consistent for treatment plants regardless of whether they are located in Phoenix or Tucson. Due to differences in average rainfall and evaporation rates, requirements for pond area may vary between these locations and is reported separately in Table 14.

Overall Plant Size and TDS Target (mg/L)	RO Plant Capacity (MGD)	Blend Volume (MGD)	Permeate Volume (MGD)	Concentrate Volume (MGD)	Pond Area (acres)	
					Phoenix	Tucson
10 MGD/550	2.07	7.93	1.76	0.31	72	78
10 MGD/450	4.02	5.98	3.42	0.60	140	151
50 MGD/550	10.36	39.64	8.81	1.55	362	388

50 MGD/450	20.10	29.90	17.09	3.02	701	753
100MGD/550	20.73	79.27	17.62	3.11	723	777
100MGD/450	40.20	59.80	34.17	6.03	1,402	1,507

Table 14: Targeted Water Qualities

Technical and Operational Feasibility: Adding MF as a second stage pretreatment provides water that will have a high degree of consistency and quality to operate RO efficiently.

This approach could have the flexibility needed to address other treatment concerns that might emerge over time. This flexibility would depend on a modular treatment process design where treatment components can be added to address water quality concerns as needed.

Environmental/Public Acceptability While environmental impacts and public acceptability of modifications on existing plants for purposes of adding RO treatment will vary by specific site, the primary potential concern with this option will more likely relate to concentrate management. Construction of larger facilities, through modification of existing plants, may cause various neighborhood and environmental concerns relative to the specifics of existing facilities. Those concerns might include potential or perceived impacts on neighboring properties (buffering potential), land availability if expansion is required, associated costs, and such operational issues as noise, traffic, chemical storage and the like. Potential public concerns with concentrate management issues include conveyance pipeline construction and prospective evaporation pond locations. These concerns will likely focus on cost and disturbance of habitat and/or viewshed, and the size and costs of such facilities will vary on a case by case basis. Also, costs associated with final disposal could add considerable expense to cradle-to-grave concentrate management.

Benefits/Risks of salinity control/reduction option

This salinity control option was evaluated in terms of positives and negatives. The positives and negatives for this option are as follows:

+ This option would utilize existing treatment facilities as part of the treatment train process.
+ A high degree of salinity control would be achieved providing better quality water.
+ This option would provide better reliability than conventional treatment train which relies on cartridge filters as stage 2 pretreatment
- If a new plant were to be designed to accomplish salinity reductions, this option would not be chosen.
- This option may be an inefficient process since the treatment process seeks to salvage existing infrastructure at the potential cost of treatment efficiency.

Economic/Financial Feasibility Cost estimates vary between the Phoenix and Tucson metropolitan areas due to a number of factors including land costs and location of treatment facilities in relation to potential concentrate disposal sites. This option seeks to utilize existing facilities being modified to add RO treatment and would not be a design feature in a new facility.

Therefore, capital construction costs would primarily consist of the addition of MF, the RO plant, pipeline and evaporation pond construction, with minor capital costs related to modification of the existing facility. Modification costs could vary considerably based on the specific facility and are not included in the cost estimate. Table 15 provides only the total capital cost for the MF, the RO, the pipeline, and evaporation pond elements of this option for the range of treatment facilities evaluated for both the Phoenix and Tucson areas.

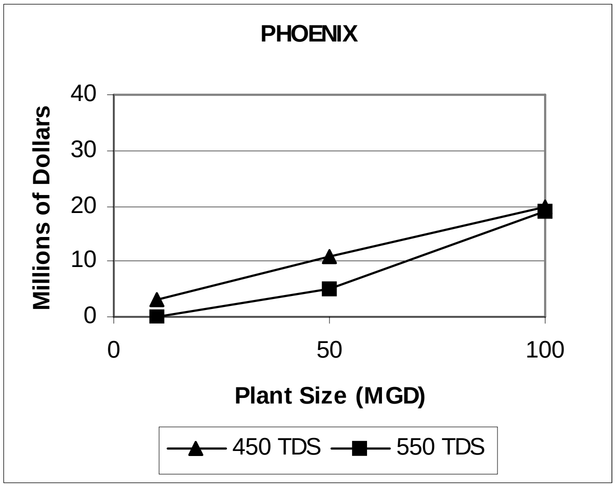
Overall Plant Size / TDS Target (mg/L):	Phoenix Area	Tucson Area
	$ Millions	
10 MGD/550	25.24	18.05
10 MGD/450	36.89	28.10
50 MGD/550	75.01	59.73
50 MGD/450	129.55	104.98
100 MGD/550	132.83	107.74
100 MGD/450	239.26	194.93

Table 15: Estimated Total Construction Costs

Table 16 provides a 20-year annualized total cost of capital and operational costs assuming a 6 percent interest. Figure 6 shows these same costs in graphical format.

Size Plant and TDS Target (mg/L)	Phoenix Area	Tucson Area
	$ Millions	
10 MGD/550	3.24	2.58
10 MGD/450	5.03	4.22
50 MGD/550	10.78	9.37
50 MGD/450	19.12	16.85
100 MGD/550	19.63	17.31
100 MGD/450	35.9	31.82

Table 16: Total 20-Year Annualized Capital and Operational Costs



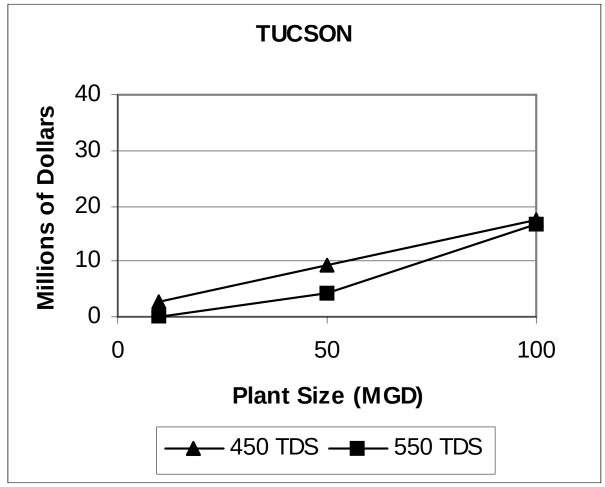


Figure 6: Annualized Costs for Conventional Filtration/MF Pretreatment Followed By RO Option for Phoenix and Tucson.

The 20-year annualized capital and operational costs related to each phase of this treatment option, which includes conventional filtration, followed by MF pretreatment, final RO treatment, and the construction costs for the evaporation ponds, are broken out in Table 3b. For this evaluation, operational costs and minor capital modification costs for conventional treatment facilities were based on the January, 2004 Reclamation *Appraisal Evaluation* entitled Reverse Osmosis Treatment of Central Arizona Project Water for the City of Tucson and industry cost curves as modified by Tucson Water. MF and RO costs including evaporation ponds and replacement of concentrate reject water are based on inputs to the cost model assembled by Reclamation for this project.

	Phoenix Area			Tucson Area		
Overall Plant Size / TDS Target (mg/L):	Conventional Treatment	MF	RO, Evap & Water	Conventional Treatment	MF	RO, Evap & Water
	$ Millions					
10 MGD/550	0.17	0.39	2.68	0.17	0.39	2.02
10 MGD/450	0.32	0.67	4.04	0.32	0.67	3.23
50 MGD/550	0.83	1.43	8.52	0.83	1.43	7.11
50 MGD/450	1.61	2.48	15.03	1.61	2.48	12.76
100 MGD/550	1.66	2.54	15.43	1.66	2.54	13.11
100 MGD/450	3.23	4.45	28.22	3.23	4.45	24.14

Table 17: Annualized Capital and Operational Costs by Pretreatment and Treatment Phase

Conclusion: This option seeks to take advantage of existing potable water treatment facilities with the addition of RO treatment for salinity control. To maximize RO treatment efficiency, use of direct filtration as a “roughing filter” followed by MF for pretreatment was analyzed. This option has higher costs but has the reliability of MF as a pretreatment for RO.

5.1.4 Soil Aquifer Treatment (SAT) Plus Cartridge Filtration as Pretreatment Followed by RO

Description: This option is composed of three filtering stages: Stage 1 utilizes the natural filtering effects of a soil aquifer treatment, perhaps via surface spreading recharge basins. Soil aquifer treatment is a process whereby partially-treated effluent is allowed to infiltrate through the soil, or vadose zone, to the groundwater. The vadose zone acts as a natural filter and removes essentially all suspended solids, biodegradable materials, bacteria, viruses, and other microorganisms. Significant reductions in nitrogen, phosphorus, and heavy metals concentrations can also be achieved. Stage 2 of this option would consist of subsequent recovery of the SAT-treated waters followed by cartridge filtration to ensure water of sufficient quality for RO treatment. The brine would be discharged to evaporation ponds.

The overall treatment process for this option is shown below in Figure 7 where the RO plant is but one component of the treatment process.

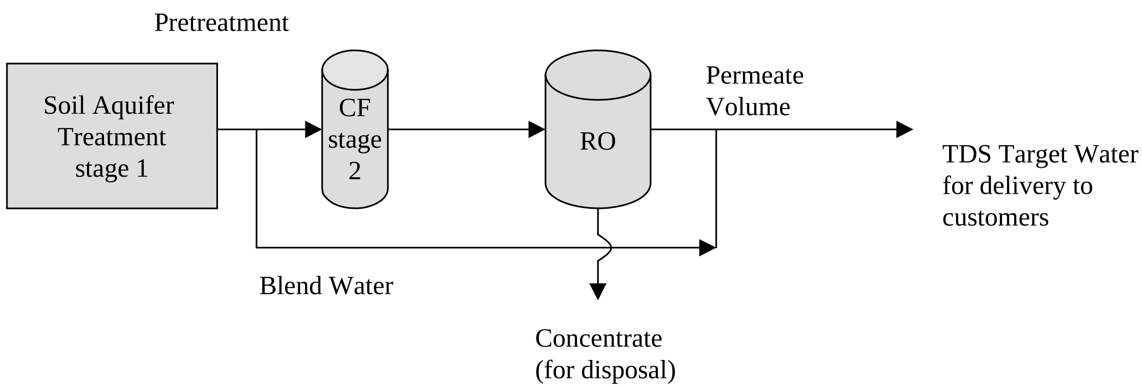


Figure 7: SAT Followed by Cartridge Filtration and RO

Institutional Considerations: An APP would be required for the construction and operation of the SAT infiltration basins, in addition to the brine concentrate evaporation ponds. If the land for the SAT basins and/or the evaporation ponds, or any pipelines or conveyances, were to be located on federal lands, or the construction of this facility is federally-funded, NEPA regulations would have to be followed.

Water Resource Utilization SAT has the potential to enhance resource reliability through sub-surface storage water banking) thereby increasing operational flexibility during potential shortages, maintenance considerations with the CAP, or other potentially vulnerable sources of surface water supply. Volume of water treated and level of treatment (i.e. TDS target) result in varying water resource losses; however, this evaluation assumes 85% efficiency with significant water loss (15%) to concentrate through the RO process. The projected loss of water could potentially be decreased through enhancements to the RO process such as DewVap or HERO, or other new technology. Table 18 reports the range of water volume and TDS targets for small, medium and large potable water treatment plants with the volume required to be treated through RO shown in the column labeled "RO Plant Size" which is calculated by adding the permeate and concentrate volume rates. "Blend Volume" refers to that volume of water that would not be treated through the RO process but would be blended back with the "Permeate Volume" to achieve the desired TDS target. *See Figure 7.* These volumes are consistent for treatment plants regardless of whether they are located in Phoenix or Tucson. However, due to differences in average rainfall and evaporation rates, requirements for pond area may vary between these locations and is reported separately in Table 18.

Overall Plant Size / TDS (mg/L)	RO Plant Capacity (MGD)	Blend Volume (MGD)	Permeate Volume (MGD)	Concentrate Volume (MGD)	Pond Area (acres)	
					Phoenix	Tucson
10 MGD/550	2.07	7.93	1.76	0.31	72	78
10 MGD/450	4.02	5.98	3.42	0.60	140	151
50 MGD/550	10.36	39.64	8.81	1.55	362	388
50 MGD/450	20.10	29.90	17.09	3.02	701	753
100MGD/550	20.73	79.27	17.62	3.11	723	777
100MGD/450	40.20	59.80	34.17	6.03	1,402	1,507

Table 18. Potential Pond Size and Effluent Volume Treated Based on Plant Capacity and Target TDS

Technical and Operational Feasibility: Effective SAT depends primarily on permeable soils that provide high infiltration rates and a sufficiently deep aquifer. Vadose zones containing little or no clay layers and transmissive aquifers are also requirements for effective SAT. Available land with suitable SAT conditions would be critical for this option. If the vadose zone is suitable, SAT can offer considerable flexibility and adaptability to changing effluent conditions, such as water quality buffering and/or treatment of emerging contaminants. SAT has also been demonstrated to significantly reduce dissolved organic carbon in recharged surface waters, which in turn reduces the potential formation of trihalomethanes (THMs) and other disinfection byproducts. The ability of SAT to reduce the organic carbon in surface water sources may also prove instrumental in determining the method of secondary disinfection that would be required. SAT would provide a high level of technical reliability for providing a chemically stable source water to the RO component for final treatment.

If the hydraulic parameters of the aquifer and/or recovery well construction produces occasional slugs of highly turbid or sandy water, then the post-SAT recovered water could adversely impact RO membranes. Therefore, it would be prudent to add the option of cartridge filtration as a secondary pretreatment to protect the RO membranes from the occasional slugs of turbid/sandy water.

If salinity control was the only objective of a water treatment plant, SAT could potentially be too expensive of a pretreatment option to pursue. SAT as a pretreatment step is viable only if other water resource and operational objectives are important factors in providing potable supply.

Environmental/Public Acceptability: Due to the potential land requirements, public concerns could be raised with regard to environmental/cultural resource impacts or visual impacts. Those concerns might include potential or perceived impacts on neighboring properties (buffering potential), land availability if expansion is required, associated costs, and such operational issues as noise, traffic, and the like. Potential public concerns with concentrate management issues include conveyance pipeline construction and prospective evaporation pond locations. These concerns will likely focus on cost and disturbance of habitat and/or viewshed, and the size and costs of such facilities will vary on a case by case basis. Also, costs associated with final disposal could add considerable expense to cradle-to-grave concentrate management.

Benefits/Risks of salinity control/reduction option: This salinity control option was evaluated in terms of positives and negatives. The positives and negatives for this option are as follows:

+ SAT provides a flexible, reliable Stage 1 pretreatment option to RO.
- Water must be recharged only in areas where there are no contaminants in the soil profile or aquifer.
- To reduce potential for fouling RO membranes, cartridge pretreatment after well recovery would be necessary.

Economic/Financial Feasibility: Cost estimates vary for the Phoenix and Tucson metropolitan areas due to a number of factors including land costs and location of treatment facilities in relation to potential concentrate disposal sites. Estimated construction costs for an SAT facility with recovery capability is approximately $1 million per 1,000 AF of recharge capacity per year, excluding land costs. If salinity control was the only objective, SAT could potentially be too expensive of a pretreatment option to pursue, especially if the purchase of land for recharge facilities is required. SAT as a pretreatment step is viable if other water-resource and operational objectives are important factors in providing potable supply. Potentially high costs may accompany this option depending on land availability and proximity of recharge site to raw water source and to the treatment plant.

Table 19 provides a 20-year annualized total cost of capital and operational costs assuming a 6 percent interest and the SAT estimated capital costs described above. Figure 8 portrays these costs in graphical format.

Overall Plant Capacity/ TDS Target (in 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 19: Total Annualized Capital and Operational Costs for SAT / Cartridge Filtration Pretreatment Followed by RO Option for Phoenix and Tucson

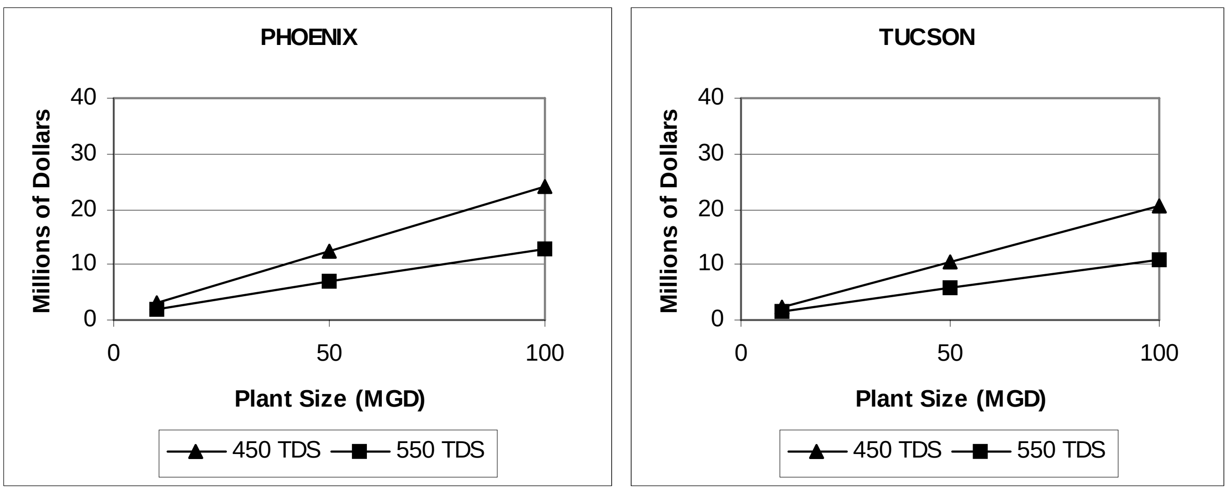


Figure 8: Annualized Costs for SAT / Cartridge Filtration Followed By RO Option for Phoenix and Tucson

Table 20 provides the 20-year annualized costs by each phase of this treatment option, which includes pretreatment consisting of SAT and cartridge filtration followed by RO. The brine concentrate would be sent to evaporation ponds for disposal. RO costs including evaporation ponds and replacement of concentrate reject water are based on inputs to the cost model assembled by Reclamation for this project. In this evaluation, operational costs and capital costs for construction of SAT and CF facilities were based on the January, 2004 Reclamation *Appraisal Evaluation* entitled Reverse Osmosis Treatment of Central Arizona Project Water for the City of Tucson and industry cost curves as modified by Tucson Water. Replacement of cartridge filters was assumed to be 5 times per year.

	Phoenix Area			Tucson Area		
Overall Plant Size/ TDS Target:	SAT	CF	RO,Evap & Water (IL)	SAT	CF	RO,Evap & Water (IL)
	$ Millions					
10 MGD/550	0.25	0.14	2.68	0.25	0.14	2.02
10 MGD/450	0.48	0.26	4.04	0.48	0.26	3.23
50 MGD/550	1.25	0.68	8.52	1.25	0.68	7.11
50 MGD/450	2.42	1.32	15.03	2.42	1.32	12.76
100 MGD/550	2.50	1.36	15.43	2.50	1.36	3.11
100 MGD/450	4.84	2.64	28.22	4.84	2.64	24.14

Table 20: Annualized Capital and Operational Costs by Pre-Treatment and Treatment

Conclusion: This option analyzed the feasibility of potable water treatment utilizing SAT and cartridge filtration as pretreatment for RO. RO requires very low suspended particulate concentrations to avoid fouling the membrane surfaces. SAT alone will provide highly reliable pretreatment filtration. Although, recovery wells could potentially produce slugs of highly turbid/sandy water which could adversely impact RO membranes. To mitigate against this possibility, it is considered prudent to add the option of cartridge filtration to protect the RO membranes.

5.1.5 Slow Sand Filter (SSF) Plus Cartridge Filtration as Pretreatment Followed by RO

Description: This option substitutes SAT with SSF for pretreatment followed by RO desalinization. A slow sand filter is comprised of a bed of fine sand that is supported by a layer of gravel. This filter media is confined in a box with openings at both ends allowing water to flow in and out, while operating on a top-down, gravity basis. The filtration process removes solids, precipitates, turbidity and in some cases bacterial particles that produce bad taste and odor.

The overall treatment process is shown in Figure 9 . Similar to the previous options, the brine concentrate is discharged via pipeline to evaporation ponds.

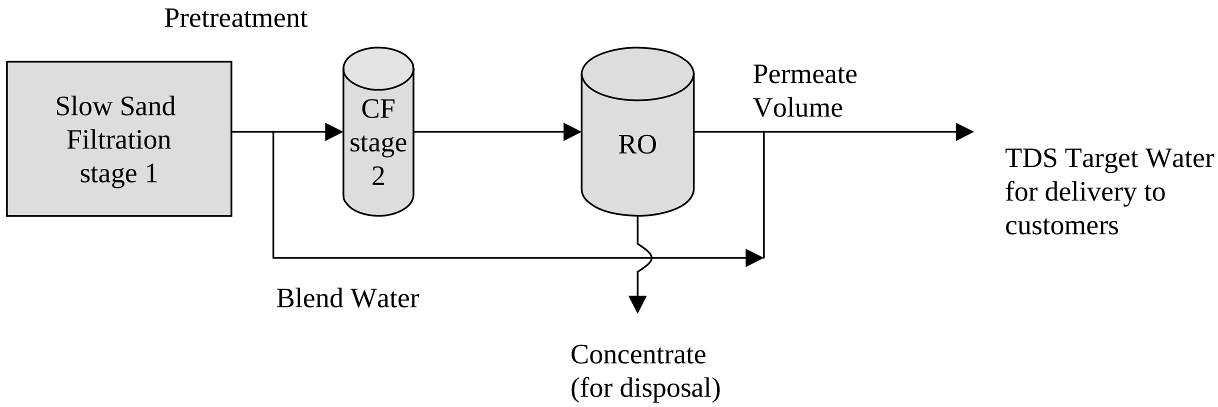


Figure 9: **SSF Pretreatment Followed By RO**

Institutional Considerations: An APP would be required for the construction and operation of the brine concentrate evaporation ponds. If the land for the evaporation ponds, or any pipelines or conveyances, were to be located on federal lands, or the construction of this facility is federally-funded, NEPA regulations would have to be followed.

Water Resource Utilization: Slow sand filtration, coupled with second stage cartridge filters and RO, results in a high quality of water with 95% removal of salts similar to other direct treatment options. Volume of water treated and level of treatment (ie TDS target) result in varying water resource losses; however this evaluation assumed 85% efficiency with significant water loss (15%) to concentrate through the RO process. The projected loss of water could potentially be decreased through enhancements to the RO process such as DewVap or HERO, or other new technology. Table 21 reports the range of water volume and TDS targets for small, medium and large potable water treatment plants with the volume required to be treated through RO shown in the column labeled "RO Plant Size" which is derived by adding permeate and concentrate volume rates. "Blend Volume" refers to that volume of water that would not be treated through the RO process but would be blended back with the treated "Permeate Volume" to achieve the desired TDS target. *See Figure 9.* These volumes are consistent for treatment plants regardless of whether they are located in Phoenix or Tucson. However, due to differences in average rainfall and evaporation rates, requirements for pond area may vary between these locations and is reported separately in Table 21.

Overall Plant Capacity / TDS (mg/L)	RO Plant Capacity (MGD)	Blend Volume (MGD)	Permeate Volume (MGD)	Concentrate Volume (MGD)	Pond Area (acres)	
					Phoenix	Tucson
10 MGD/550	2.07	7.93	1.76	0.31	72	78
10 MGD/450	4.02	5.98	3.42	0.60	140	151
50 MGD/550	10.36	39.64	8.81	1.55	362	388
50 MGD/450	20.10	29.90	17.09	3.02	701	753
100MGD/550	20.73	79.27	17.62	3.11	723	777
100MGD/450	40.20	59.80	34.17	6.03	1,402	1,507

Table 21. Target TDS

Technical and Operational Feasibility: SSF is considered applicable primarily for relatively high quality water supplies with low turbidity. Operation of SSF requires only the adjustment of water flow, the monitoring of head loss and turbidity, and periodic removing of a thick layer of particulates that forms on top of the filter. SSF provides only statistical removal of particles, based on particle size, allowing for some pass-through. Therefore, it is recommended that a cartridge filter follow the SSF.

SSF may require significant area if a large volume of water is to be pretreated. Hence, land availability may be a constraint when locating and sizing facilities.

Environmental/Public Acceptability: Due to the potential land requirements, public concerns could be raised with regard to environmental/cultural resource impacts or visual impacts. Those concerns might include potential or perceived impacts on neighboring properties (buffering potential), land availability if expansion is required, associated costs, and such operational issues as noise, traffic, and the like. Potential public concerns with concentrate management issues include conveyance pipeline construction and prospective evaporation pond locations. These concerns will likely focus on cost and disturbance of habitat and/or viewshed, and the size and costs of such facilities will vary on a case by case basis. Also, costs associated with final disposal could add considerable expense to cradle-to-grave concentrate management.

Benefits/Risks of salinity control/reduction option

This salinity control option was evaluated in terms of positives and negatives. The positives and negatives for this option are as follows:

+ This option provides a relatively low cost pretreatment alternative.
- The effectiveness of pretreatment depends on raw water quality.
- Because particulate removal is statistically based, this option will have some particulate pass-through, which can be reduced with second stage cartridge pretreatment prior to RO.

Economic/Financial Feasibility: Table 22 provides estimated total construction costs for the range of treatment plant sizes evaluated by the Sub-Committee for both the Phoenix and Tucson areas under the above-listed assumptions. Land purchase requirements may result in additional costs.

Reclamation Report 90 found that because of its relatively low capital and operating costs and low requirements for operator attention, SSF may be attractive to small water treatment plants, if adequate land is available and source waters are of sufficiently good quality.

Overall Plant Capacity/ TDS Target (in mg/L):	Phoenix Area	Tucson Area
	$ Millions	
10 MGD/550	23.94	16.75
10 MGD/450	32.99	24.2
50 MGD/550	76.93	61.65
50 MGD/450	123.46	98.89
100 MGD/550	141.77	116.69
100 MGD/450	235.18	190.86

Table 22: Estimated Total Construction Costs

Table 23 provides the 20-year annualized total costs including both capital and operational costs assuming a 6% interest. Figure 2 displays this information graphically. Figure 2 portrays these costs in graphical format.

Plant Size/ TDS Target (mg/L):	Phoenix Area	Tucson Area
	$ Millions	
10 MGD/550	2.92	2.26
10 MGD/450	4.49	3.68
50 MGD/550	9.69	8.28
50 MGD/450	17.30	15.03
100 MGD/550	17.77	15.45
100 MGD/450	32.77	28.69

Table 23: Total Annualized Capital and Operational Costs

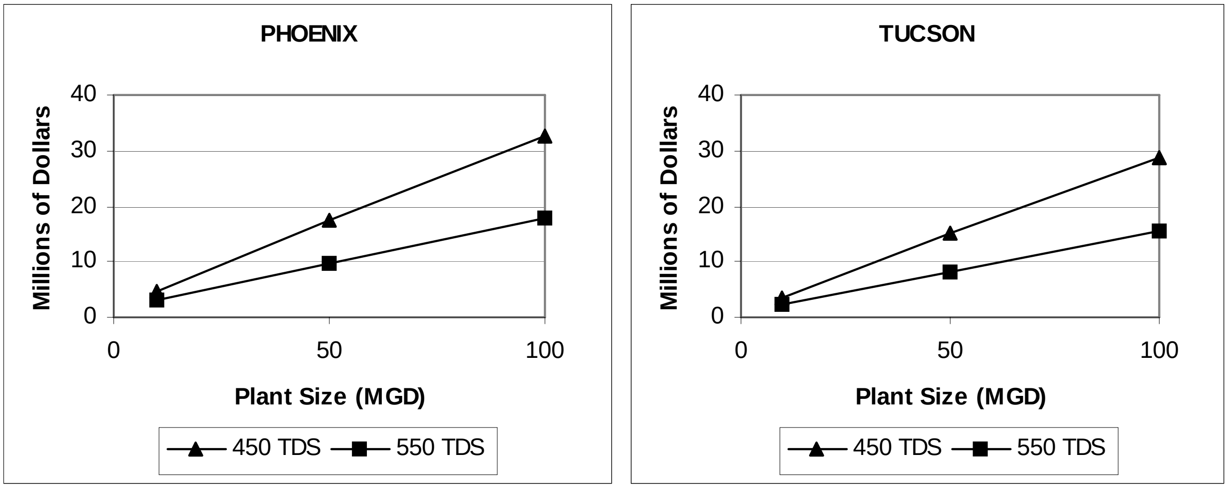


Figure 10: Annualized Costs for SSF and Cartridge Filtration Pretreatment Followed By RO

	Phoenix Area			Tucson Area		
Overall Plant Size/ TDS Target:	SSF	CF	RO,Evap & Water	SSF	CF	RO,Evap & Water
	$ Millions					
10 MGD/550	0.10	0.14	2.68	0.10	0.14	2.02
10 MGD/450	0.19	0.26	4.04	0.19	0.26	3.23
50 MGD/550	0.49	0.68	8.52	0.49	0.68	7.11
50 MGD/450	0.95	1.32	15.03	0.95	1.32	12.76
100 MGD/550	0.98	1.36	15.43	0.98	1.36	13.11
100 MGD/450	1.91	2.64	28.22	1.91	2.64	24.14

Table 24: Potential Pond Size and Effluent Volume Treated Based on Plant Capacity and Target TDS

Conclusion: This option analyzed the feasibility of potable water treatment utilizing SSF and cartridge filtration as a pretreatment option for RO to control salinity. The Sub-Committee evaluated a range of water treatment facilities with the basic characteristics of SSF as Stage 1 pretreatment with recovered water fed through cartridge filtration prior to the RO treatment.

Analysis for Section 5.2: Wastewater Treatment Plants (WWTPs)

The following assumptions were used for analyzing the Options discussed in Section 5.2:.

1. No microfiltration pretreatment would be required as the effluent is assumed to be filtered from the WWTP. If filtration is not done at the WWTP then microfiltration costs would have to be included.

2. Initial TDS was assumed to be 2,000 mg/L; analyzed at 200 mg/L changes

3. Land type was agricultural lands, undeveloped land, and/or native desert near City.

4. Vegetative ground cover was brush.

5. Pipeline conveying effluent to the evaporation pond was 20 miles in length.

6. Pipeline to the evaporation pond were constructed in a congested area,

5.2.1 Wastewater Treatment Plants

Description: This option looked at using RO membranes to reduce the TDS in WWTP effluent that would be permitted for reuse applications, such as turf irrigation, agricultural irrigation, artificial recharge, etc. The increase in TDS from water treatment plants to WWTPs is approximately 400 mg/L. It is anticipated that as more commercial and residential customers use water softeners, cooling towers, etc., the TDS will continue to increase to a point where reuse applications are infeasible. In addition, traditional wastewater treatment does not remove TDS.

For this option, it was assumed that wastewater would be treated by conventional filtration methods and that only a portion of the filtered effluent would be treated with RO to give a target TDS for specific reuse applications. The resultant RO concentrate would be disposed of in an evaporation pond.

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

It was assumed that this analysis could be applied to both new and existing WWTPs.

Institutional Considerations
There may be no institutional problems with this method of controlling salinity. As in similar options that utilized evaporation ponds, an APP would be required for the construction and operation of the ponds. If the land for the evaporation ponds, or any pipelines or conveyances,

was to be located on federal lands, or the construction of this facility is federally-funded, NEPA regulations would have to be followed.

Water Resource Utilization

A portion of the effluent will be lost to , and consequently, could not be used for reuse applications. The cost to replace this lost water is included in the cost evaluation.

Lower TDS effluent may allow for more reuse applications. For example, higher quality reclaimed water can be used golf course irrigation, landscape impoundments, or even spray irrigation of an orchard or vineyard., In the case of recharge facilities, the lower TDS may allow for more water to be recharged without degrading the groundwater.

Technical and Operational Feasibility

There are several items that need to be closely monitored when using RO at WWTPs, specifically constituents that can cause biofouling, suspended solids, and chlorination. Many of these issues can be remedied during design of a new facility, but for existing facilities changes may need to be completed to operate the RO at acceptable levels.

One drawback to this, or any, option utilizing evaporation ponds, is that the amount of land required for the ponds may not be available near existing WWTPs, and therefore, a pipeline may be required to convey the concentrate to a suitable location for the ponds. This may require the purchase of land and procurement of easements or right-of-way for these added facilities. In addition, existing WWTPs may not have space within the current plant boundaries for the addition of an RO facility.

Environmental/Public Acceptability

There are currently two major water treatment facilities that use this option for indirect potable recharge: the Scottsdale Water Campus (Arizona) and Water Factory 21 (California). In both cases, wastewater effluent is treated with RO membranes and then recharged into the vadose zone and recovered downgradient for potable uses. Based on the existence of these two facilities, it is anticipated that public acceptability of these types of reuse applications will be high.

The use of evaporation ponds may cause some concerns to the public, such as unsightliness of the ponds.

Benefits/Risks of RO Treated Effluent

The major benefit of using RO to treat a portion of effluent from a WWTP is that the treated effluent would have a relatively low TDS and could be used for several types of reuse applications, which would not be the case if the TDS were too high. For example, higher quality reclaimed water can be used golf course irrigation, landscape impoundments, or even spray irrigation of an orchard or vineyard.

Only a portion of the effluent would need to be treated with RO to meet the needs of the reuse application; the remaining effluent, which would be used for less demanding uses, would not be treated. For example, if you have a 5 MGD plant but only 1 MGD is required for recharge purposes, then only a portion of the effluent is treated to give 1 MGD at the target TDS.

Economic/Financial Feasibility
Using the model developed by the Reclamation (2004), the following chart was developed to show cost for incremental decrease of TDS for each of the three assumed plant sizes.

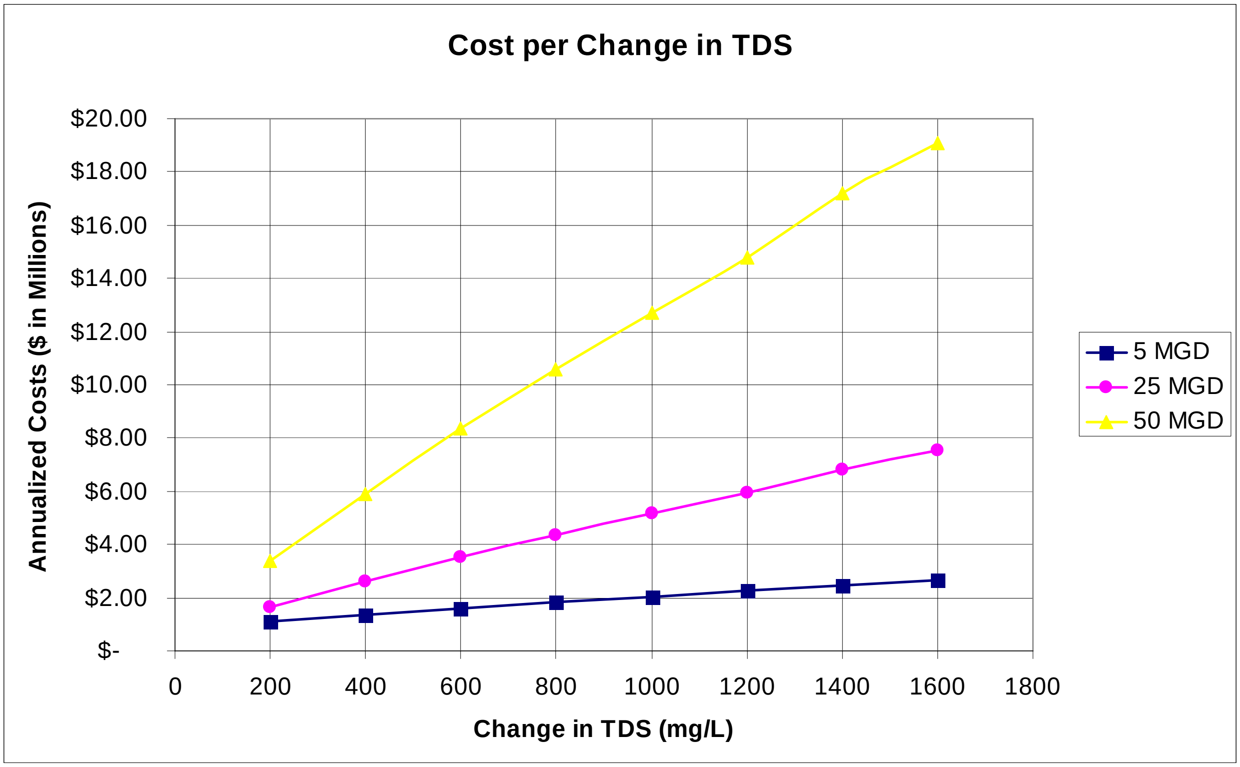


Chart 1

Chart 1 illustrates the following points:

- That annualized costs increase as the change in TDS increases and plant capacity increases. This is mainly due to the increased costs of evap. pond land and liner requirements.
- The annualized cost for smaller plants in relatively flat as TDS change increases.

Table 25 summarizes the capital and O&M costs for the three plant sizes.

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 25

From Table 25, the following observations can be noted:

- Capital costs are driven by evaporation ponds.

Conclusion: It may be necessary to use advanced water treatment on a portion of the effluent currently being produced in Arizona's WWTPs. This option evaluated the use of RO treatment of a portion of the effluent prior to recharging the effluent to the vadose zone or aquifer. When the effluent can not be used for the intended purpose then the cost of advanced water treatment will be met because the next source of water to meet those needs will be more expensive. Currently, in the Phoenix metropolitan area, some of the water reclamation plants produce effluent that does not meet the minimum reuse standards.

Analysis for Section 5.3.1 and 5.3.2: RO Wellhead Treatment

The following section discusses the treatment of brackish groundwater using RO. Two options were evaluated . These options consisted of using RO treatment as either: (1) wellhead treatment for a single well or (2) centralized treatment for a number of wells, or well field. The following assumptions were made in analyzing RO treatment at the wellhead or at a centralized facility:

1. Brackish groundwater is assumed to have a TDS of 1,500 mg/L or greater;

2. Efficiency is assumed to be 85 percent on all RO applications;

3 Brine concentrate would be disposed of in evaporation ponds;

4. No MF pretreatment is required, but it is assumed that some sort of sediment removal system, such as cartridge filters, will be used prior to running water through the RO unit to prohibit sediment load on membranes.

5.3.1 RO Wellhead Treatment at One Well

Description: This option consists of treating brackish groundwater at the wellhead with RO and transporting the brine concentrate to a regional evaporation pond for disposal. It is assumed that either a new or existing well can be fitted with the RO unit, although some retrofitting may be required for an existing well.

Design of the wellhead RO treatment will depend on the quantity and quality of the brackish groundwater. For the purposes of this evaluation, the initial TDS concentration in the groundwater was assumed to be 1,500 mg/L and the pumping capacity of each well was 694 gallons per minute (gpm), or 1,120 acre-feet per year (1 MGD). Pretreatment for the groundwater consisted of filtration for sediment removal and pH adjustment, if necessary. It is anticipated that water will be blended to achieve the target TDS concentration; therefore some water will bypass RO treatment. The chart below estimates what quantities of permeate and concentrate would be required based on the above described assumptions to achieve the targeted TDS. Volume of concentrate is listed below and is dependent on the water quality that is targeted.

Target TDS (mg/L)	Bypass Volume (gpm)	Permeate Volume (gpm)	Concentrate Volume (gpm)
400	139	472	83
500	174	442	78
600	222	401	71
700	278	354	62

Table 26

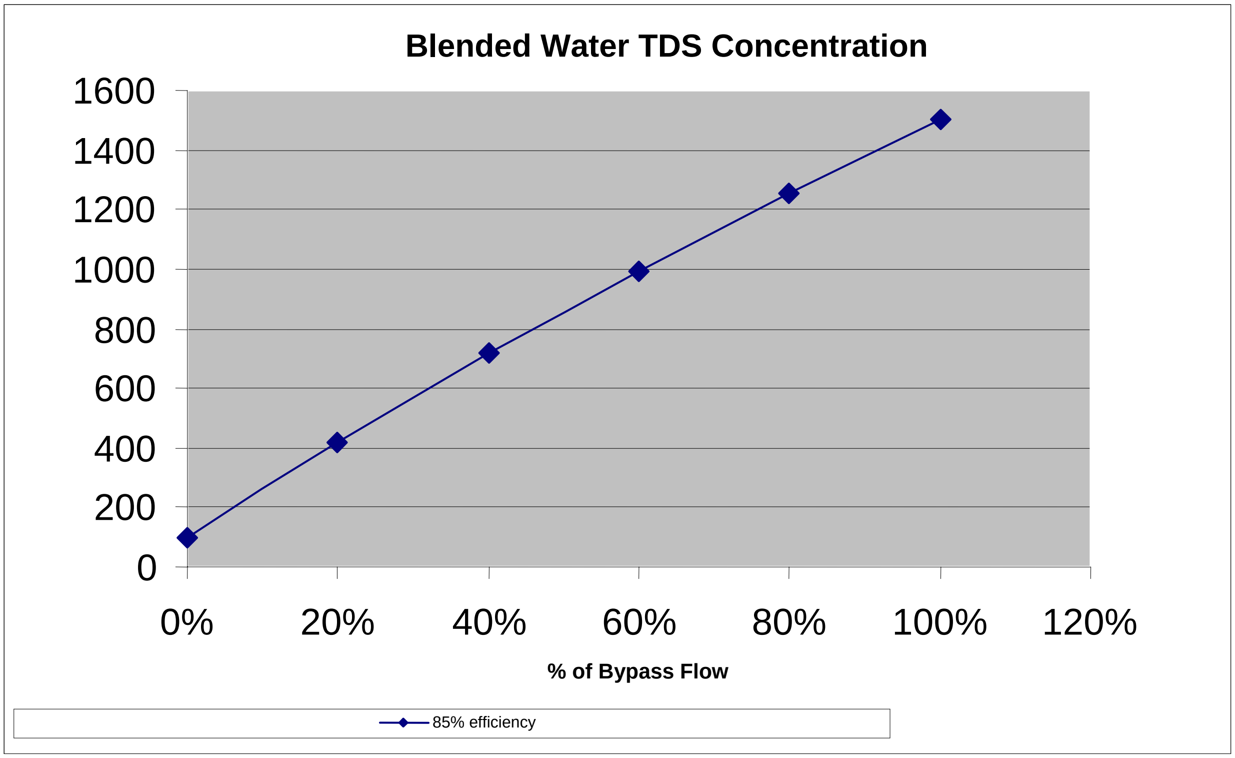


Chart 2

Institutional Considerations

RO treatment at the wellhead would be a feasible option, assuming the water provider has the water rights to pump within an area of brackish groundwater. A blending plan may require the approval of the state or county drinking water regulator and issues could arise with other water quality constituents that are concentrated in the RO process.

An APP would need to be obtained for the construction and operation of evaporation ponds. If the land for the evaporation ponds, or any pipelines or conveyances, were to be located on federal lands, or the construction of this facility is federally-funded, NEPA regulations would have to be followed.

Water Resource Utilization
RO treatment of brackish groundwater would be beneficial to water providers with this resource. This water can not be used without advanced water treatment however, the percentage of water lost to brine concentration is considerable. While all the water treated would count against a water user or providers groundwater pumping.

Technical and Operational Feasibility
Careful evaluation and sizing will be required to retrofit an older well with the discharge piping to accommodate an RO unit. Other operational considerations include that the well site may need to be enlarged in order to accommodate additional equipment; operation of the well may become more difficult because of membrane sensitivities; staff may require specific operational training; operational flexibility is reduced with blending to acquire a specific TDS target.

Environmental/Public Acceptability
Little or no public opposition would be expected from this option based on the number of existing RO treatment plants already in operation.

Little, if any, public opposition would be expected for the construction and operation of evaporation ponds based on the fact that there are many large evaporation ponds in existence in central Arizona. The only issues, of which may receive minor opposition, would include the unsightliness of large ponds, wildlife impacts, and removal of habitat.

Benefits/Risks of salinity control/reduction option
While the consequence of many of the salinity reduction options is the creation of a brine concentrate, the primary benefit of RO treatment at the wellhead for brackish water would be the rehabilitation, or restoration, and beneficial use of a valuable resource, the groundwater.

Economic/Financial Feasibility
The cost of implementing a wellhead RO treatment plant is feasible, especially if the water is necessary for a water provider to meet demands. As is the case with many of the options evaluated in this study, as the volume of brine concentrate increases, the cost of the treatment option also increases due primarily to the increase in land required for evaporation ponds.

Change in TDS	Capital			O&M			Annualized Total (Million $)
	RO Plant (Million $)	Pond (Million $)	Total (Million $)	RO plant (Million $)	Ponds (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 27

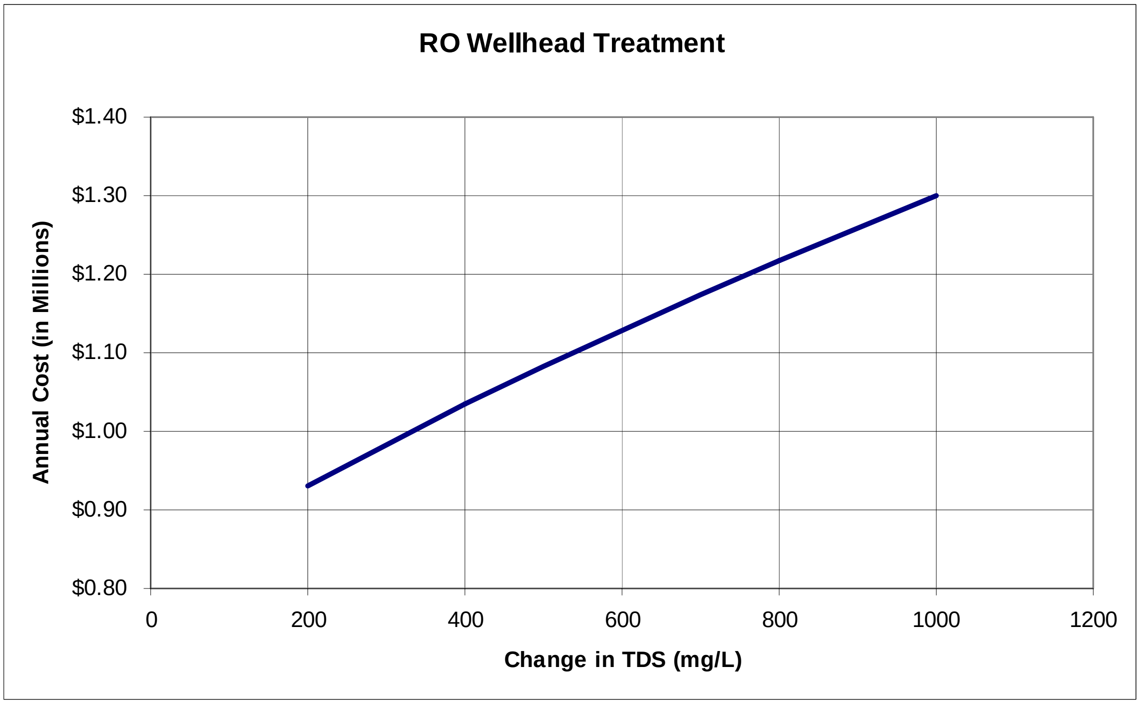


Chart 3

Conclusion: The cost of producing potable water from brackish 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 limits, then the cost of brackish groundwater would be justified.

When the current water sources are totally allocated then advanced treatment of brackish groundwater will become much more likely to happen.

The biggest drawback is the disposal of the concentrate. Small scale brackish groundwater plants can use evaporative ponds but evaporative ponds get expensive due to large land needs and also the cost of the double liners used to seal the ponds.

A case in point is the City of Goodyear, which is currently treating brackish groundwater by RO which comes from a single well. The City of Goodyear has had to address a couple of problems with the system. For one, the well is an old irrigation well and, due to construction, pulls in high amounts of silt from the formation during pumping; the silt then causes the pretreatment filters to clog. In addition, the concentrate is currently being disposed of into the sewer, however, the City's WWTP is nearing hydraulic capacity and salinity limits, which means the City will have to find an alternative disposal method.

5.3.2 Centralized Groundwater Treatment Plant

Description: 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.

Similar to the single well treatment, the resulting brine concentrate is assumed to be transported via pipeline to a regional evaporation pond for disposal.

For the purposes of this study, it was assumed that four wells would be used at a water treatment plant for a capacity of 6,000 gpm (9,678 acre-feet per year, or 8.64 MGD), and that the TDS concentration in the groundwater, prior to treatment, is 1,500 mg/L. Pretreatment for the groundwater would include filtration for sediment removal and pH adjustment, if necessary. It is anticipated that water will be blended to achieve the target TDS concentration; therefore some water will bypass RO treatment. The chart below estimates what quantities of permeate and concentrate would be using the above described assumptions to achieve the targeted TDS. Volume of concentrate is listed below and is dependent on the water quality that is targeted.

Targeted Water Qualities

Targeted TDS (mg/l)	Bypass Volume (gpm)	Permeate Volume (gpm)	Concentrate Volume (gpm)
400	1200	4080	720
500	1500	3825	675
600	1920	3468	612
700	2400	3060	540

Table 28

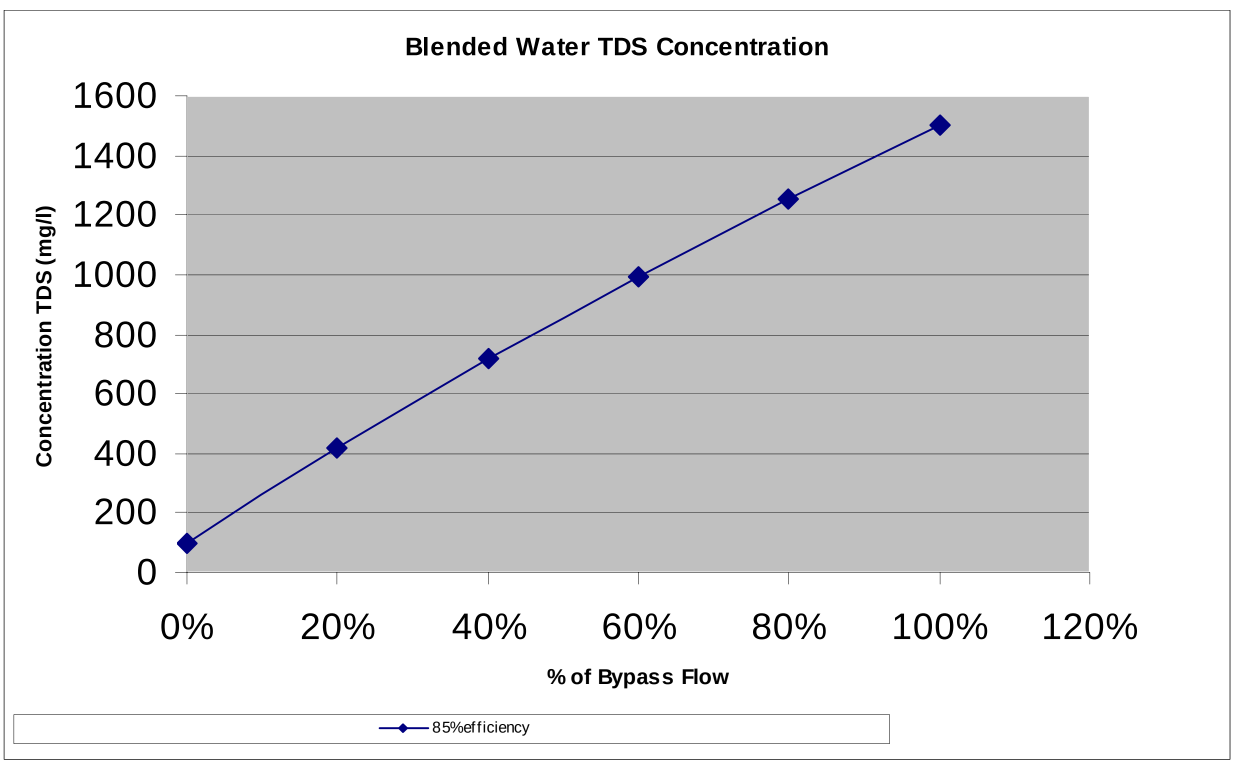


Chart 4

Institutional Considerations
This option would be feasible as long as the water provider has rights to pump within an area of brackish water. Blending plan may require approval through drinking water regulator (state or county), and issues may arise with other water quality constituents that are concentrated in RO process.

The creation of evaporation ponds and pipeline for the disposal of brine concentrate may create the necessity acquisition of easements and possible environmental mitigation. Both of these processes are often lengthy. Additional permits may have to be secured depending on pond liner requirements.

Water Resource Utilization
RO treatment of brackish water is a beneficial to water providers with this resource. The volume of water lost to brine concentration is considerable, especially at lower efficiency rates but this water was not potable.

Technical and Operational Feasibility
RO is a very reliable technology and feasible option, both technically and operationally. The following factors must also be considered prior to implementing this technology: Operation may be more difficult because of membrane sensitivities; Staff may require additional training; operational flexibility is reduced with blending to acquire a specific TDS target.

A brine concentrate pipeline must be made of material resistant to high concentrations of TDS. There is the potential for overloading evaporation basins if they are not properly sized.

Environmental/Public Acceptability
The public will like having better quality water, but may not like the increase in cost associated with acquiring higher quality water.

There are many public issues with evaporation ponds including: Potential for contamination of the area with brine; Unsightliness of large ponds; and wildlife impacts and removal of habitat.

Benefits/Risks of salinity control/reduction option
While the risk of any salinity reduction option is the creation of a brine contaminant stream, the overall benefit of RO wellhead treatment on brackish water is a significant benefit to society because of the beneficial use of a previously unusable source of water.

Economic/Financial Feasibility
The cost of implementing a centralized RO treatment plant is feasible, especially if the water is necessary for a water provider to meet demands. Once again as volumes of concentrate increase, the higher the cost of the alternative because of the amount of land required for evaporation ponds.

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 29

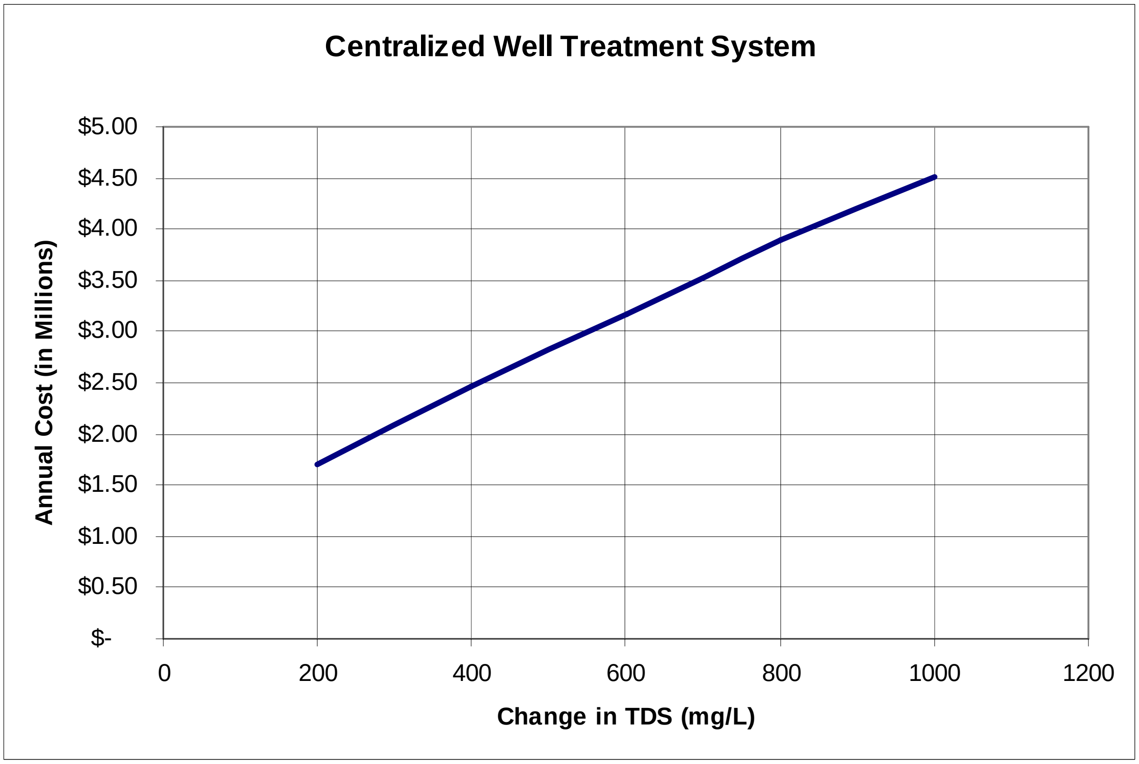


Chart 5

Conclusion: The cost of producing potable water from brackish 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 limits, then the cost of brackish groundwater would be justified.

When the current water sources are totally allocated then advanced treatment of brackish groundwater will become much more likely to happen.

The biggest drawback is the disposal of the concentrate. Small scale brackish groundwater plants can use evaporative ponds but evaporative ponds get expensive due to large land needs and also the cost of the double liners used to seal the ponds.

The Town of Gila Bend currently treats brackish groundwater from multiple wells by sending the water through one RO facility. The brine concentrate is evaporated in ponds, which work well for the Town because the RO facility is small and land is available and relatively inexpensive.

Appendix B
No Action Alternative Complete Report

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

City of Phoenix
Phoenix, Arizona
Central Arizona Salinity Study

White Paper
On
Future With No Action Alternative

May 2005

Prepared For
City of Phoenix
Water Services Department
Phoenix, Arizona

Prepared By

PBSJ

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Introduction

The primary goals of the Central Arizona Salinity Study (CASS) Phase I were to identify the sources of salinity entering the Central Arizona region, to develop a regional salinity budget to quantify the annual salt loading, assess the potential economic impacts and to recommend the course for Phase II studies. Phase 1 found salinity in the overall water supply has been increasing due to the impacts of drought in the watersheds of the Arizona rivers and the Colorado River, importation and use of Central Arizona Project (CAP) water and due to human activities. The primary goals of Phase II of CASS are to develop and assess alternatives to control or reduce salinity, project the costs and benefits associated with these alternatives and to develop recommendations for implementation. The alternatives in Phase II are all action alternatives because they involve a process or procedure implemented to control or reduce salinity. A Future With No Action Alternative is needed as a baseline to permit assessing the effectiveness of the action alternatives. The purpose of this white paper is to prepare an assessment of the Future With No Action Alternative.

White Paper Summary

CASS Phase I demonstrated approximately 1.3 million tons of minerals, in the form of Total Dissolved Solids (TDS), are imported into the Central Arizona area annually and an additional 0.4 million tons are added by the activities of the residents of the area. In the Phoenix area, approximately 0.5 million tons leave the area but 1 million tons remain. The focus of the Future With No Action Alternative analyses is to identify where these 1 million tons accumulate and to assess potential future impacts. The Future With No Action Alternative assumes no projects will be implemented to control or reduce the TDS in the water sources or the TDS added by the residents.

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, a flow sheet was prepared to track water sources, water use paths, to identify where salinity is increased and to identify where salinity can accumulate. This Salinity Flow Chart is incorporated in the attached Task 100 Memorandum as Figure 1 to provide a foundation to assess future salinity impacts.

The surface water sources in the Phoenix area, include the Salt River, Verde River, Agua Fria River, and Colorado River water imported in the CAP. A review of the historic TDS concentrations verified there is a degree of change in the TDS concentration depending on the conditions in the watersheds; drought, average and surplus or flood conditions. Colorado River TDS measured at Parker Dam averages about 650 milligrams per liter (mg/L) as verified in CASS Phase I. The Federal government has set a TDS limit of 747 mg/L for Colorado River water at Parker Dam. The Agua Fria River is a small quantity water source and changes in TDS concentration will have little impact on the regional TDS. This is because Agua Fria River water is blended with CAP water in Lake Pleasant. The Agua Fria has an average TDS concentration of about 400 mg/L. The Verde River has low TDS concentration, averaging about 270 mg/L. 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 is about 580 mg/L. During flood periods the TDS decreases to about 500 mg/L; however, during drought periods the TDS has increased to 980 mg/L. 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 Salt River TDS is diluted by these other water sources. This analysis indicates the degree of TDS concentrations in surface water sources will probably stay within a defined range and will not 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. Reclaimed water TDS concentration depends on the TDS of the wastewater entering the treatment plants.

Figure 1 in the Task 100 memorandum verifies most residential and commercial/industrial water users who are provided surface water and groundwater will subjected to limited increases in TDS in the future. This is because surface water TDS may vary but will not continue to increase and water providers strive to pump groundwater from aquifer zones with TDS concentrations which are equal to or better than the surface water. A second flow sheet, Salinity Impact Calculation Sheet (Figure 2 in the Task 200 memorandum), was prepared for CASS Phase II to calculate the TDS and salinity impacts on a regional basis. This impact projection sheet shows the regional average TDS of water delivered to residential users is about 568 mg/L. If the Salt River TDS concentration increases to 980 mg/L, the calculation projects residential users receive water with a regional average TDS concentration of 663 mg/L. Residential and commercial/industrial water users add TDS the water they receive. It is projected the interior residential and commercial use increases the TDS concentration by an average of 300 mg/L in the wastewater flow. Exterior water is used for landscaping and most of the water is consumptively used by the vegetation. The plants use the water but the majority of the TDS in the water remains in the soil. This results in the accumulation of TDS minerals, commonly called salts, in the soil. Figure 1 in the Task 100 memorandum verified wastewater is a location where TDS concentrations are increased and the soil horizons are where salts can accumulate. Over a long period of time some of the salts accumulating in the soils beneath residential and commercial/industrial areas may percolate down and impact the TDS concentration in groundwater. However, when the land area currently used for residential and commercial/industrial purposes is compared to the potential salts accumulation in the soils, the potential soil salt accumulation impacts spread over a very large area and may not represent an immediate concern.

Figure 1 in the Task 100 memorandum shows agricultural water uses receive surface water, groundwater and reclaimed water for irrigation. The majority of the irrigation water is consumptively used by the vegetation but unlike residential exterior water users, farmers apply additional water to leach the salts accumulating in the soil. This leaching water carries the salts down below the root zones of the plants and often down into the aquifer units where the leaching water can increase the TDS of the groundwater. Task 100 Figure 1 shows when the groundwater is pumped for irrigation, this cycle of irrigation, leaching and pumping can have long term impacts increasing the groundwater TDS concentration. However, the potential long-term impacts to commercial agriculture may not be significant. Many farmers such as in the Buckeye Irrigation District west of Phoenix use water with high TDS concentrations for irrigation. They need a greater quantity of water for leaching to grow their crops when compared to other areas but they are able to use the poorer quality water. The Salinity Impact Calculation Sheet (Task 200 Figure 2) shows the regional irrigation water TDS is 1,064 mg/L and this includes a groundwater TDS of 2,100 mg/L to acknowledge the use of poor quality groundwater by farmers. If the Colorado River water increases to 747 mg/L, the impact on the regional irrigation water supply changes the TDS to 1,079 mg/L. If the Salt River increases to 980 mg/L the irrigation supply TDS increases to 1,125 mg/L. While this does represent an increase, the 1,125 mg/L represents a lower TDS concentration than some of the reclaimed water used for irrigation. The long term regional impacts associated with agricultural irrigation include TDS increases in groundwater due to the leaching practices. Another factor to consider is the agricultural impacts on groundwater have been decreasing and will continue to decrease as farmland is urbanized.

Reclaimed water is a TDS accumulation point where there may be impacts in the future. Residential and commercial/industrial water users add TDS to the wastewater impacting the quality of the reclaimed water produced at treatment plants. Figure 1 in the Task 100 memorandum shows reclaimed water is used for agricultural irrigation, turf irrigation at facilities such as golf courses and for groundwater recharge. Several of the reclaimed water facilities in the Phoenix are produce reclaimed water with average TDS concentrations ranging from about 900 to 1,100 mg/L. Seasonal water use and water supply impact can result in the production of reclaimed water with TDS concentrations of 1,400 mg/L. As previously stated, this water is used by farmers for agricultural irrigation without significant impacts. The potential problems are associated with turf irrigation and groundwater recharge.

Most golf courses want water with a TDS concentration less than 1,200 mg/L to avoid salinity damage to the turf. When the TDS approaches 1,200 or exceeds this concentration the turf begins to turn yellow and is more susceptible to disease. Water use on golf courses is strictly controlled by the Arizona Department of Water Resources management plan goals, so golf course operators can not simply increase the water application to leach the additional salts below the turf root zone. This means the salts can accumulate in the soil. However, unlike the residential soil salt impacts, the local impacts at golf courses can be significant over time because of the greater quantity of water used and the greater total volume of salts remaining in the soil. The potential future impacts to turf applications associated with no action assessment is as the TDS of water supplies increases the water may no longer meet the intended use. A future scenario associated with this condition is water from other sources may need to be diverted for golf course water use. The increased TDS concentration in reclaimed water then becomes a water resources supply issue rather than just a water quality issue.

Reclaimed water used for groundwater recharge may be impacted if the TDS concentration in reclaimed water continues to increase. In some areas where there is groundwater with high TDS, the impacts of reclaimed water may improve the groundwater. In portions of the Central Arizona area, reclaimed water with concentrations of 1,000 mg/l may not be suitable for groundwater recharge because it will have a negative impact on the groundwater quality. In the Tucson area, Colorado River water has a greater TDS concentration than the groundwater and via recharge it impacts the groundwater quality. If reclaimed water TDS concentrations increase in the future it may not meet the standards established for groundwater recharge. Just as with the direct use on turf, the TDS issue then becomes a water resources issue rather than just a water quality issue.

The analyses show the TDS can accumulate as salts in the soils and increase the TDS concentration in reclaimed water and groundwater. Salts in the soil and in reclaimed water will have very little impact on water used for potable supplies, under the current regulatory environment. Regulations may also prevent reclaimed water with high TDS concentrations from being used for groundwater recharge. The accumulation in the soil and in water supplies used for irrigation represents the area where the impacts can be projected.

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 at TDS and in agricultural studies it is referred to as the electroconductivity of the water (ECw) expressed as millimohos per centimeter but can be equated with TDS mg/L concentrations. When considering the impacts of salinity in irrigation water to plants, less than 480 mg/L is not considered to be a problem. Water with a TDS concentration between 480 and 1,920 mg/L represents moderate problems meaning plant growth and crop yield is negatively impacted and the amount of impact is also dependant on the plant sensitivity. Water with a TDS concentration greater than 1,920 mg/L is considered to present severe problems to plants. Most of the surface water used in Central Arizona is in the lower portion of the moderate problem range (Figure 3) in Task 200 memorandum). Groundwater can be in the sever problem range. Most of the reclaimed water produced in the Phoenix area is in the middle portion of the moderate problem range (Figure 4) in the Task 200 memorandum).

Water is only part of the consideration. 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. Using the Phoenix area as an example, most of the soils have an average ECe of 1 to 4 and a maximum of 8. There are some soils with an average ECe of 4 to 8 and a maximum of 60. The following table shows the plant response to soil ECe.

ECe mmhos/cm measurement	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

Soil Salinity Plant Impacts

If the salinity in soil increases, the ECe increases and this will impact the growth of crops, turf and landscaping plants. The degree of potential impact is dependent on the ECe of the soil, the TDS of the irrigation water which impacts the volume of salts accumulating in the soil, the TDS of the irrigation water considering the suitability for irrigation use (ECw) 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 reclaimed water, the impacts may be detected in less than a decade. If no salinity controls are implemented the water may not be suitable for landscape or turf use.

The Future With No Action Alternative analyses verified the water sources most likely to be impacted in the future due to increases in TDS concentrations are reclaimed water and groundwater. The TDS in these water sources may increase to the concentration where they are not suitable for some uses. TDS concentration increases in the water may produce impacts which are easier to quantify and the impacts may be detected in a shorter period of time than the accumulation of salts in the soils. Increasing TDS concentrations may have long term water quality impacts but may also have an impact on the overall quantity of water resources available in Central Arizona if some water supplies are no longer suitable for the intended direct and indirect uses.

Task 100 Impact Identification and Research

Memorandum

Date: May 10, 2005
To: CASS Planning Technical Committee
From: Frank Turek
Re: Central Arizona Salinity Study Phase II
Project No. WS90120017
Future With No Action Alternative White Paper
Task 100 – Impact Identification and Research

- -

The purposes of this memorandum are to:

- Summarize the results of the research completed as a part of Task 100
- Document the potential total dissolved solids concentrations in selected water sources
- Prepare an initial list of potential future impacts

In this memorandum, the term salinity is used to describe the regional condition of the accumulation of dissolved minerals. Total dissolved solids (TDS) is used when references are made to concentration changes in water and soil.

1.0 Research

The principal documents researched as a part of Task 100 were the Central Arizona Salinity Study (CASS) Phase I Final Report and the Technical Appendix reports. Additional information sources reviewed and cited are listed in the 4.0 References Cited section. Information collected by telephone is also cited in the text.

2.0 Salinity in selected water sources

The Scope of Services identified three locations where the TDS in the water sources should be verified. These locations are:

- The average TDS of Central Arizona Project (CAP) water at Lake Havasu as calculated in CASS Phase I
- The Colorado River Basin Salinity Control Forum salinity goal at Lake Havasu
- The Salt River TDS based on drought, normal and surplus flow conditions

2.1 Average TDS in CAP water

The CASS study team reviewed historic TDS concentrations in Lake Havasu and in the CAP and calculated the average TDS concentration. CASS Phase I Final Report (Bur. Rec. 2003) reported the average CAP TDS concentration is 650 milligrams per liter (mg/L).

2.2 Colorado River Salinity Goal at Lake Havasu

The Environmental Protection Agency in 1972 required the development of numeric salinity control standards for the Colorado River. The standards were proposed in 1974 and adopted by all the basin states in 1975. The TDS standard for Lake Havasu, measured at the U.S. Geologic Gaging Station below Parker Dam is 747 mg/L. CAP water TDS concentration is less than this standard. In Water Year 2002, the TDS concentration at the Parker Dam gaging station ranged from a low of 591 mg/L to a high of 613 mg/L and this was a drought year when the TDS concentration is expected to be greater than average.

2.3 Salt River salinity

The salinity of the Salt River varies due to the quantity of flow entering the Salt River and Verde River reservoir system; however, the principal impacts are related to flow in the Salt River. CASS Phase I evaluated the average salinity of the Salt River, measured at Stewart Mountain Dam and calculated an average TDS concentration of 580 mg/L (Bur. Rec., 2003). Steward Mountain Dam is a location upstream of where the Verde River joins the Salt River and is upstream of Granite Reef Diversion dam where CAP water is added to the combined flow of the Salt and Verde Rivers.

Dr. Gregg Elliot at SRP was contacted to verify the average TDS concentration of the Salt River at Stewart Mountain Dam in a high flow year and drought year. Dr. Elliott reported the TDS was about 500 mg/L in 1993 which was a high flow year and was about 980 mg/L in 2002 which was a drought year.

3.0 Potential Future Salinity Impacts

3.1 Water Use and Salinity Flow Chart

The initial step in the identification of potential future salinity impacts was to develop a flow sheet to track water sources, water use paths, identify where salinity is increased and identify where salinity can accumulate. Figure 1 is a graphic representation of this information.

Surface water sources include the Salt, Verde, Agua Fria, Gila and Colorado Rivers. Surface water sources will have changes in the TDS concentration due to seasonal flow fluctuations, blending, flood conditions and the impacts of drought. However, the long term salinity of surface water sources will be relatively constant.

Groundwater TDS concentrations vary throughout the Central Arizona area. TDS concentration of groundwater can be in the range of 250 mg/L to more than 3,000 mg/L. This is a much greater variation than occurs in surface water. The groundwater TDS concentration differences are due to the hydrogeologic conditions in the area and the impacts of land uses. This is explained in greater detail in the section 3.6 Groundwater Recharge.

3.2 Residential Water Use

Residential water use is divided into exterior and interior uses and is supplied by surface water and groundwater as shown on Figure 1. The proportion of surface water and groundwater supplied to a residential area does vary; however, both water sources are appropriate for potable water use. Reclaimed water is not delivered for residential use.

3.2.1 Exterior Residential Water Use

Most of the exterior residential water use is for landscape irrigation including turf and evapotranspiration concentrates TDS in the soils at or near the surface. Commercial agriculture irrigation includes a volume of water for leaching to flush the TDS down through the root zone and, in many cases, to the groundwater table. Residential irrigation uses less water and does not include a planned volume for leaching. Therefore, the TDS will accumulate in the soil. As the TDS concentration in the soil increases, the turf can yellow. Rainstorms can provide a dilution of TDS in the soil and leach the TDS to a depth below the root zone but usually there is not sufficient rainwater infiltration to cause the TDS to percolate to the groundwater table. Rainstorms can result in a reversal of the yellowing trend and produce green turf. During a drought and between rainstorms, many homeowners may increase the irrigation application and apply fertilizers in an attempt to get the turf to turn green again. Fertilizers add salinity to the soils and can increase soil salinity problem. In CASS Phase I, it was projected fertilizers used on lawns add 245 pounds of salinity per acre of lawn per year (CASS Phase I Appendix R, 2003). Some homeowners may use more water for irrigation and have increasing water bills. Regionally, the water use impacts of increasing irrigation to compensate for soil salinity may be offset due by conservation as other homeowners replace turf with xeriscape vegetation.

Figure 1 shows exterior residential water use results in salinity accumulating in the soil and soil represents a terminal salinity storage location. Soil salinity is a regional condition as the urbanized areas expand and turf irrigation continues. Residential exterior water use will not produce local high concentrations of salinity but the long term, regional impact will result in significant tonnage of salinity accumulating over wide areas. As urbanization continues throughout Central Arizona, salinity will continue to accumulate in the soil expanding the potential area of impacts.

The future with no action assumes there will be no control or reduction of TDS in water used for exterior residential purposes and salinity will continue to accumulate in the soil. The exterior residential water use impacts associated with salinity buildup in the soils are:

- Soils will become a reservoir or sink for accumulating TDS
- Landscape water use may increase due to increased water needs to flush salinity below the root zone

- Individual homeowner costs may result due to increased water use and fertilizer use

3.2.2 Interior Residential Water Use

Interior water use is where there are increases the salinity in the wastewater discharges from the homes as shown on Figure 1. There is an estimated TDS increase of 300 mg/L associated with interior residential water use (Bur. Rec., 2003). A part of this increase is due to the use of residential water treatment units. Many homeowners have installed water treatment units and many homebuilders now include water treatment units when the home is constructed. In areas where there are a high number of home water treatment units, the TDS increase may be as great as 400 mg/L (Kelso, oral communication, 2004).

Demineralization water treatment units, such as reverse osmosis (RO) units, remove TDS from the water. Most residential RO units produce about one to nine gallons of concentrate for each gallon of treated water (Plumberspage, 2004) and some units can waste 90 gallons of concentrate to produce 5 gallons of purified water (North Dakota State University, 1992). The concentrate is a concentrate including the minerals removed from the treated water produced by the unit. Fortunately, most residential RO units are small and the quantity of water consumed and concentrate produced is limited. RO units do not increase the overall TDS load in the wastewater but they can increase the concentration. The TDS load is not increased because the RO units do not add minerals during the treatment process. RO units produce concentrate water when water is consumed, primarily during times corresponding with when people are awake. This is also when the wastewater flows in the sewers are high and can dilute the small TDS concentration increases. Wastewater treatment plants (WWTP) and water reclamation plants (WRP) are usually not impacted by the use of RO units because the overall salinity load to the plant is not changed.

Many homes contain water softeners increase the TDS load and concentration. Ion exchange units substitute sodium or potassium ions for calcium and magnesium ions in the water. The TDS in the softened water is for all practical purposes the same as the input water. However, the ion substitution results in an increase in the TDS load because the calcium ions are discharged to the sewer when the softeners are regenerated. This increases the overall TDS load to the WWTPs and can impact the quality of the reclaimed water produced by the WWTPs as discussed in section 3.5 Reclaimed Water. Ion exchange water softeners can have a significant impact on the TDS concentration in wastewater because most units are set to regenerate at night and the regeneration delivers a concentrated stream of high TDS water to the sewer. Because this regeneration occurs at night when the wastewater flows are low, the impact of ion exchange regeneration discharges can have a significant impact on the concentration of the wastewater entering WWTPs. The overall load to the sewer system would be the same if the regeneration occurs during the day or night but there is a difference in the concentration due to the potential dilution in the sewers.

Figure 1 shows the wastewater from interior residential water use flows to WWTPs and WRPs for treatment and production of reclaimed water for reuse.

The future with no action assumes there will be no reduction of the TDS in the water supply for interior residential use. The interior residential water use potential salinity impacts are:

- Slightly increased water consumption associated with the operation of residential water treatment units
- Increased TDS in the residential wastewater
- Potentially greater sewer treatment bills due to the salinity impacts at WWTPs and WRPs

3.3 Commercial and Industrial Use

Commercial and industrial sites can be provided with surface water, groundwater and reclaimed water as illustrated on Figure 1. This use category also includes residential uses such as schools, public buildings and hospitals.

3.3.1 Process Water

Surface water, groundwater and reclaimed water are all included in the process water supply. In some commercial operations, such as the food industry, only surface water and groundwater is appropriate for use. In other operations, the use of all three water sources is appropriate.

Some of the process water is consumptively used but the remainder is usually discharged to the sewer where it flows to WWTPs and WRPs for treatment as shown on Figure 1. Many of the commercial and industrial process water uses increase the TDS load and concentration. Industrial processes can add minerals to the water increasing the load. Some industries purify the water using demineralization and this increases the TDS due to the concentrate stream discharge.

Process water is also used in cooling towers (for purposes other than air conditioning) and this concentrates the TDS. Industrial cooling tower uses increases the concentration of TDS discharged to the sewer but not the load.

Surface water and groundwater from the potable water system will not have significant impacts on the use for process water. Potable water must meet specific standards and public acceptance criteria. The TDS concentration may vary throughout the year but should remain within acceptable water quality and palatability standards. Groundwater pumped directly from wells to the commercial and industrial site and reclaimed water may be subjected to regional salinity increase impacts. Seasonal variations in the salinity in water sources, treatment costs and the disposal of TDS concentrate have a significant impact on the cost of process water and the feasibility for an industry to locate in an area served by water with high salinity (TNT, 2003).

If the salinity of the groundwater from local wells and reclaimed water increases to a concentration where it is no longer suitable for the intended process water purposes, then the commercial and industrial water user may need to use water from the potable water system to meet their demand. This will increase the water demand placed on the water provider and could result in increased water costs as water providers develop additional water sources to meet the increasing demands. The other option is to provide additional treatment to reduce the TDS in the process water.

Process water use can increase the TDS load and concentration in the final water which is discharged to the sewers where the impacts are seen at the WWTPs and WRPs.

The future with no action assumes there will be no control or reduction in the TDS in surface water, groundwater or reclaimed water supplies delivered for commercial and industrial process water. Commercial and industrial process water potential salinity impacts are:

- Increased water treatment costs
- Reduced suitability of water sources for process water use
- Potentially greater sewer treatment bills due to the salinity impacts at WWTPs and WRPs

3.3.2 Exterior Commercial and Industrial Use

Exterior commercial and industrial water use focuses on irrigation using surface water, groundwater and reclaimed water supplies as shown on Figure 1. The salinity of commercial and industrial irrigation mirrors the impacts associated with residential exterior water use, the accumulation of TDS in the soil.

Salinity accumulation will continue as the urbanized areas with commercial and industrial landscape irrigation expands. Commercial and industrial exterior water use will not produce local high concentrations of salinity. Soil TDS is a terminal salinity storage location. The long term, regional impact will result in the accumulation of salinity over wide areas on an annual basis.

The future with no action assumes there will be no control or reduction in TDS in water used for exterior commercial and industrial purposes and salinity will continue to accumulate in the soil. The exterior commercial and industrial water use potential impacts associated with increasing salinity buildup in the soils are:

- Soils will become a reservoir or sink for accumulating TDS
- Landscape water use may increase due to increased water needs to flush salinity below the root zone
- Additional costs may result due to increased water use and fertilizer use

3.3.3 Commercial and Industrial Environmental Use

The commercial and industrial environmental use includes the water used for cooling and for other public uses. Figure 1 shows the water sources include surface water and groundwater from the potable water system. Cooling tower water concentrates the salinity and discharges to the sewer, in most cases. Rest room water and other uses similar to interior residential water use, results in discharges to the sewers. Many commercial and industrial sites use local water treatment systems to enhance the palatability of the water. Just as with the residential units, these on-site water treatment units increase the salinity concentration and load in the wastewater.

The future with no action assumes there will be no control or reduction of the TDS in the water supply for commercial and environmental use. The commercial and industrial water use potential salinity impacts are:

- Slightly increased water consumption associated with the operation of on-site water treatment units
- Increased TDS in the wastewater discharge
- Potentially greater sewer treatment bills due to the salinity impacts at WWTPs and WRPs

3.4 Irrigation Use

Figure 1 shows surface water, groundwater and reclaimed water are used for irrigation and irrigation is divided into three general categories:

- Commercial agriculture
- Golf course irrigation
- General turf irrigation

3.4.1 Commercial agriculture

Commercial farming can tolerate a wide range of salinity in irrigation water depending on the salinity tolerance of the crop and the soil conditions. Most farmers include a quantity of water in their irrigation supply for flushing the TDS accumulating in the soil below the root zone of the plants. This is called leaching water and TDS is concentrated in the leaching water. It was calculated in CASS Phase I, an irrigation water source with a TDS of 700 mg/L could result in a leaching water TDS concentration of 4,200 mg/L (CASS Phase I, Appendix P, 2003). Figure 1 shows this leaching water will eventually percolate down to the water table and will impact groundwater. This condition has been well documented throughout Central Arizona in agricultural areas. TDS is not the only chemical component impacting groundwater, fertilizers, pesticides and other agricultural chemicals have been transported to the water table with the leaching water.

In the past, commercial agriculture was far more extensive than it is currently. In the future as urbanization continues, additional land will be converted from farming to other land uses. This means the quantity of leaching water percolating to the aquifer will be reduced. However, commercial agriculture has been on-going in Central Arizona since about the 1860s and the leaching water has impacted the groundwater. In some locations, the full impact of leaching water has not yet occurred because the leaching water percolates slowly to the water table. There may be a volume of leaching water still moving down and this leaching water will continue to percolate even after the farmland is urbanized.

Salinity associated with commercial agriculture can result in an accumulation of TDS in the soil but due to leaching, the majority of the TDS will impact the groundwater. The accumulation of TDS in the groundwater is not a terminal accumulation point because continued groundwater pumping recycles the TDS as shown in Figure 1.

The future with no action assumes there will be no control or reduction of the TDS in the surface water, groundwater and reclaimed water supplies for commercial agriculture. The commercial agriculture use potential salinity impacts are:

- Increasing TDS in the groundwater supply beneath commercial agriculture areas
- Changing the cropping pattern to use more salinity tolerant crops if the groundwater quality degrades. This could increase farming costs and decrease the per acre profit as crops are changed.

3.4.2 Golf Course Irrigation

Golf course irrigation is a commercial irrigation water use regulated by the Arizona Department of Water Resources (ADWR). These regulations encourage the use of reclaimed water but as shown on Figure 1, surface water, groundwater and reclaimed water are all used for irrigation. The hybrid turf grass species are not very salinity tolerant. Research has shown when the TDS concentration exceed 650 mg/L the grow-in after winter over seeding was slowed and when the TDS exceeds 1,000 mg/L the effectiveness of fertilizers is reduced (CASS Phase I, Appendix L, 2003).

The principal salinity impact is tied to reclaimed water and groundwater used for turf irrigation. The addition of TDS to the sewer system increases the TDS concentration in the reclaimed water provided to golf courses. Groundwater pumped from aquifer units with high TDS concentrations will also impact golf course operations. The hybrid turf grasses become stressed and turn yellow and the salinity accumulates in the soil.

Golf course managers can apply for a leaching allotment to supplement their irrigation supply and ADWR can approve the allotment after reviewing information on the soil conditions and the TDS of the irrigation water. The leaching allotment is usually sufficient to flush the TDS from the root zone of the turf but is not sufficient to flush the TDS to the groundwater table. This means golf courses can result in the long term accumulation of TDS in the soil horizons.

The future with no action assumes there will be no control or reduction in TDS in water used for golf course irrigation and salinity will continue to accumulate in the soil. The golf course water use potential impacts associated with increasing salinity buildup in the soils are:

- Soils will become a reservoir or sink for accumulating TDS
- Water use may increase due to an allotment of leaching water for turf irrigation
- Additional golf course operation costs may result due to increased water use and fertilizer use

3.4.3 General Turf Irrigation

General turf irrigation includes uses for parks, cemeteries and school fields. Irrigation water quantities for this irrigation are also regulated by ADWR. Surface water, groundwater and reclaimed water can all be used for general turf irrigation and the principal salinity impact is the accumulation of TDS in the soil as shown on Figure 1. Bermuda grass normally used for general turf applications has a greater salinity tolerance than the hybrid grasses used on the greens and tees at golf courses. However, the water allocation for leaching is limited and TDS will accumulate in the soils rather than percolating to the groundwater table. The soils represent a terminal point where TDS accumulates. General turf irrigation will not produce local high concentrations of salinity.

The future with no action assumes there will be no control or reduction in TDS in water used for general turf irrigation and salinity will continue to accumulate in the soil. The general turf water use potential impacts associated with increasing salinity buildup in the soils are:

- Soils will become a reservoir or sink for accumulating TDS
- Water use may increase due to an allotment of leaching water for turf irrigation

3.5 Reclaimed Water

Discharges from residential areas and from commercial and industrial uses are conveyed through the sewer system to WWTPs and WRPs where the water is treated and reclaimed water produced. Reclaimed water can be used directly for irrigation and for commercial and industrial purposes as shown on Figure 1 or it can be used indirectly via groundwater recharge and later recovery. Most of the reclaimed water produced in Central Arizona can be used without additional treatment to reduce the salinity. However, there is a concern as salinity increases in the discharges to the sewers; the salinity of the reclaimed water may increase to a concentration where it no longer is appropriate for some direct or indirect uses. Advanced water treatment may be required to reduce the salinity of the reclaimed water.

Figure 1 shows high salinity reclaimed water going through additional treatment to reduce the TDS. The product water can be used for the same reclaimed water direct and indirect uses. The concentrate streams can go to disposal or, in some cases, is discharged to the sewer where it eventually gets back to WWTPs and WRPs, further impacting the TDS of reclaimed water.

An alternative to recover additional quantities of reclaimed water is to provide additional demineralization treatment to remove TDS from the concentrate stream. The product water from this additional treatment can be used for reclaimed water direct and indirect purposes and the concentrate stream will go to disposal. Disposal represents a terminal point where salinity can accumulate in landfills, evaporation ponds and potentially, can be beneficially used by selected industries.

The future with no action assumes there will be no control or reduction in TDS in wastewater used to produce reclaimed water and salinity will continue to increase in the reclaimed water supply. The potential impacts associated with increasing salinity in the reclaimed water supply are:

- Reclaimed water may not meet the quality requirements for direct use
- Reclaimed water may not be appropriate for groundwater recharge in some locations
- Additional water sources may be needed to replace the reclaimed water
- Water rates may increase as water provides develop additional water sources to meet the increasing demands
- Potentially greater sewer treatment bills due to the salinity impacts at WWTPs and WRPs

3.6 Groundwater Recharge

Figure 1 shows both surface water and reclaimed water are used for groundwater recharge. While the TDS of the surface water is relatively constant, reclaimed water TDS can vary and this may have an impact on the average quality of the groundwater in the zone of hydrologic impact. In Central Arizona, the TDS of the groundwater varies from about 200 mg/L to an extreme of about 40,000 mg/L. In some locations the quality of the recharged reclaimed water may have a negative impact on the average groundwater quality and in other locations the recharge may enhance the groundwater quality.

Figure 1 shows in some cases pumped groundwater, consisting of groundwater in storage and both natural and artificial recharge, is suitable for delivery in the public water system and can be used for commercial and industrial uses as well as for irrigation. If the groundwater quality is poor, treatment may be needed to enhance the quality so it meets standards and public acceptance. Some poor quality groundwater may not meet public acceptance criteria but can be directly used for irrigation.

Treatment to reduce the TDS of poor quality groundwater produces product water which can be added to the overall groundwater supply and used for the same purposes as good quality groundwater as shown on Figure 1. The concentrate is either discharged to the sewer where it can exacerbate the reclaimed water salinity problem or sent to disposal facilities. Discharging the concentrate to the sewer moves the TDS problem from the groundwater reservoir to the reclaimed water system. Disposal is a terminal accumulation point for salinity.

In some cases, it will be feasible to provide additional demineralization treatment of the concentrate stream to recover additional water. The product water can be added to the overall groundwater supply and used for the same purposes as good quality groundwater. The concentrate will go to disposal.

The future with no action assumes there will be no control or reduction in TDS in reclaimed water used for groundwater recharge and salinity may increase in the groundwater in some areas. The potential impacts associated with increasing salinity in the groundwater supply due to recharge are:

- Increasing salinity in the aquifers
- Groundwater quality degrading until it can not be used for the intended purposes
- Prohibition of using some reclaimed water for groundwater recharge
- Increasing cost to those who want to treat high TDS groundwater for specific uses such as potable water or irrigation

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PBS&J

Task 200 Assessment of Impacts

Memorandum

Date: May 13, 2005
To: CASS Planning Technical Committee
From: Frank Turek
Re: Central Arizona Salinity Study Phase II
Project No. WS90120017
Future With No Action Alternative White Paper
Task 200 – Assessment of Impacts

- -

The purposes of this memorandum are to:

- Summarize the results of the research completed as a part of Task 200.
- Develop a list of TDS concentration limits associated with water uses.
- Project the impacts associated with salinity increases in the soil horizons.
- Identify the magnitude of changes which may occur in the surface water, groundwater and reclaimed water supplies.
- Compare the salinity tolerance limits associated with the uses to the projected water supplies to project when the supply may not be suitable to meet the intended uses.

In this memorandum, the term salinity is used to describe the regional condition of the accumulation of dissolved minerals. Total dissolved solids (TDS) is used when references are made to concentration changes in the salinity of water sources. Soil salinity changes are described in terms of loading such as tons of accumulation and the electrical conductivity of the soil extract (ECe).

1.0 Research

The principal documents researched as a part of Task 200 were the Central Arizona Salinity Study (CASS) Phase I Final Report and the Technical Appendix reports. Additional information sources are listed in the 10.0 References Cited section. Information collected by telephone is also cited in the text.

2.0 Water Use and Salinity Flow Chart

As a part of the identification of potential future salinity impacts, a flow sheet to track water sources, water use paths, to identify where salinity is increased and to identify where salinity can accumulate was prepared in Task 100. This Salinity Flow Chart is incorporated as Figure 1 to provide a foundation to assess future salinity impacts.

3.0 Salinity Load Flow Chart

As a companion to Figure 1 a Salinity Load Flow Chart is included as Figure 2 in this Task 200 memorandum. The Salinity Load Flow Chart was prepared in conjunction with the CASS Phase II Planning Technical Committee efforts. Figure 2 is a graphic representation of the average year salinity conditions in the Phoenix Active Management Area (Phoenix AMA) and shows the salinity loading impacts in water sources, water uses and where salinity is accumulating. The Phoenix AMA Salinity Load Flow Chart is used in this memorandum because the Phoenix AMA has the most complex water sources mixture and salinity discharges. The Salinity Load Flow Chart is based on the salinity balance developed in CASS and the information presented in Figure 1 Salinity Flow Chart.

The Salinity Load Flow Chart is a two part modeling spreadsheet. The first worksheet is the data input section to the model. This allows the quantity and TDS associated with the water sources to be adjusted to project future conditions. It also allows for adjustment of the water use data. A copy of the data input worksheet is included as Figure 3. The model input information is used in the Salinity Load Flow Chart worksheet to calculate TDS concentration changes and the salinity loading, accumulation and discharge impacts. These changes impact the water sources, water supplies and water uses.

The Salinity Load Flow Chart is used in the Task 200 memorandum to project the future impacts associated which may occur in the future if no action is undertaken to control or reduce the salinity.

4.0 Salinity in Water Sources

There are three primary sources of water in Central Arizona; surface water, groundwater and reclaimed water which includes both secondary and tertiary treated municipal effluent. Each source meets the demands of several uses and some sources are not suitable for specific uses. An example is reclaimed water is not generally provided for residential use. In Tucson, some residential customers receive reclaimed water for non-potable use. The numbers are currently small but will increase significantly over time. Groundwater with a high TDS concentration is also not provided for residential use. Prior to assessing future salinity impacts it is necessary to project the TDS concentrations and salinity loading associated with the water sources. A purpose of Task 200 is to identify the magnitude of changes which may occur in the surface water, groundwater and reclaimed water supplies. The following subsections identify and quantify the TDS and salinity load changes.

4.1 Surface Water

Surface water is used in public water supply systems to meet residential, commercial and industrial demands, for agricultural, turf and golf course irrigation and for artificial recharge of groundwater. This is shown on Figures 1 and 2. The surface water sources available for use in Central Arizona include:

- Colorado River via the Central Arizona Project (CAP) which is used in the Phoenix AMA, Pinal AMA and Tucson AMA.
- Agua Fria River water is blended with CAP water in Lake Pleasant and thus, physically is used in the same Central Arizona areas as is CAP water but all water rights associated with the Agua Fria River are dedicated for use in the Phoenix AMA.
- Salt River water is used in the Phoenix AMA
- Verde River water is used in the Phoenix AMA.

Surface water sources will vary in the TDS concentration due to seasonal flow fluctuations, blending, flood conditions and the impacts of drought. However, the long term salinity of surface water sources will be relatively constant.

4.1.1 Colorado River Water (CAP)

The average TDS concentration established by the Federal government for Colorado River at Parker Dam and thus the CAP is 650 milligrams per liter (mg/L) (CASS, 2003). This concentration is less than the limit of 747 mg/L established in 1972 for the Colorado River at Parker as a part of the numeric salinity control standards. The Salinity Load Flow Chart calculated the CAP imports 1,322,764 tons of salts into the Central Arizona area annually, including 661,382 tons into the Phoenix AMA, based on an average salinity of 650 mg/L. If the TDS increased to the numeric standard limit of 747 mg/L, the Central Arizona salinity load increases to 1,520,161 tons representing 197,397 additional tons of salinity loading into Central Arizona. The salinity load in the Phoenix AMA is 760,080 tons representing and an increased salinity load of 98,698 tons.

The average annual salinity load associated with the CAP entering into the Pinal was calculated in CASS Phase I to equal 298,400 tons. In the Tucson AMA the projected CAP salt load is 65,000 tons in 2000 but due to increasing CAP use over time, the load will increase to 191,000 tons by 2015 (CASS,2003). In the Tucson and Pinal AMAs, CAP water is the only surface water source available. This is why the focus of this memorandum is the Phoenix AMA; it has a greater number of water sources.

4.1.2 Agua Fria River Water

The Agua Fria River represents a small quantity of water, about 50,000 acre-feet per year, entering the Phoenix AMA. Due to the nature of the tributary watershed, the TDS concentration is not expected to vary significantly. The primary salinity impact will be small changes in the salinity load associated with inflow quantity changes. The Agua Fria flow and salinity load impacts on the combined Agua Fria River and Colorado River are also insignificant. This was confirmed using the Salt Loading Flow Chart. If the Agua Fria flow decreased from 0.05 million acre-feet to 0.01 million acre-feet, the combined TDS of the water sources increases from 634 mg/L to 647 mg/L. This is not a significant change.

4.1.3 Salt River Water

The salinity of the Salt River varies based on the quantity of flow entering the Salt River reservoir system due to the salt springs located in the headwaters. As the total Salt River flow decreases, the salt springs inflow constitutes a greater proportion of the total flow and thus there is a corresponding increase in the TDS. CASS evaluated the median salinity of the Salt River, measured at Stewart Mountain Dam, and calculated a median TDS concentration of 580 mg/L (Bur. Rec., 2003). Stewart Mountain Dam is a location upstream of where the Verde River joins the Salt River and is upstream of Granite Reef Diversion dam where CAP water is added to the combined flow of the Salt and Verde Rivers and is diverted by Salt River Project (SRP).

Dr. Gregg Elliot at SRP was contacted to verify the TDS concentration of the Salt River at Stewart Mountain Dam in a high flow year and drought year. Dr. Elliott reported the TDS was about 500 mg/L in 1993 which was a high flow year and was about 980 mg/L in 2002 which was a drought year.

The salinity load is a function of the TDS concentration and the quantity of flow. The United States Geological Survey (USGS) water data website was researched to verify the quantity of flow gaged in 1992 and 2002 at the gage below Stewart Mountain Dam on the Salt River. In 1993 the mean flow was 4,501 cubic feet per second (cfs) which is equal to an annual flow of 3,260,000 acre-feet. In 2002 the mean flow was 416 cfs which is equal to an annual flow of 300,000 acre-feet per year.

The following table presents the TDS and salinity loads associated with median, flood and drought conditions in the Salt River.

TDS in mg/L	Flow Condition	Flow in Acre-feet	Salinity Load in Tons	Deviation from Average
580	Median	540,000	424,912	---
500	Flood	3,260,000	2,211,389	1,786,477 tons increase
980	Drought	300,000	398,864	26,048 tons decrease

This analysis confirms the salinity load into the Phoenix AMA area during drought is less than during median flow periods. Even though the TDS concentration is much greater during a drought the limited quantity of flow results in less tons of salinity load. During floods the opposite is true. The greater volume of flow results in a greater salinity load entering the Phoenix AMA. However, during periods of flood a majority of the Salt River flow passes through the

Phoenix AMA and carries this additional salt load downstream and out of the area. The volume of flood water and associated salinity load varies greatly depending on the amount of available storage in the Salt River system reservoirs, the duration of flood flow and the volume of flood flow. The salinity load associated with the median and drought conditions is more significant than the flood conditions because the salinity load associated with median and drought flows remains in the Phoenix AMA.

4.1.4 Verde River Water

The Verde River is much like the Agua Fria River when evaluating salt loading. The watershed is stable and does not contain salt springs like the Salt River. The median TDS concentration of the Verde River is 270 mg/L. The principal impact to the Phoenix AMA water supply will be when the flow is reduced or increased and there is a corresponding change in the total salinity load.

4.1.5 Combined Salt and Verde Rivers

The Verde River joins the Salt River upstream of the SRP Granite Reef Diversion Dam. The combined flow is then delivered via a series of canals to water users on the north and south sides of the Salt River. Because the TDS concentration of the Salt River can vary, the following is a projection of the TDS concentration and salinity load of the combined flows at the Granite Reef Diversion Dam.

Salt River TDS	Salt River Flow Condition	Salt & Verde Rivers TDS	Salinity Load in Tons	Deviation from Average
580	Median	502	523,814	---
500	Flood	508	2,269,591	1,745,777 tons increase
980	Drought	678	497,766	26,048 tons decrease

This analysis verifies the combined salinity load of the Salt River and Verde River at Granite Reef Dam does not vary significantly when comparing median and drought flow conditions in the Salt River. The greatest variation is in the TDS concentration. The average TDS concentration difference between the median and flood conditions is not significant but the salinity load is much greater. The load in median and drought conditions is more significant because the salinity load remains in the Phoenix AMA while most of the salinity load during flood periods passes through the AMA.

4.1.6 Surface Water Sources Long Term Salinity Impacts

A purpose of this study is to project the potential long term regional salinity impacts. The TDS concentration of the surface water sources can and often does vary annually. However, long term projections of salt loading can be calculated associated with variations in surface water TDS. The

Salinity Load Flow Chart was used to calculate the theoretical annual salinity load remaining in the Phoenix AMA assuming the TDS remained constant during the 10-year and 25-year projection periods. The 10-year time period was selected because the flood conditions in the Salt River system circa 1980 was almost a 10-year period and the current drought is defined as a 7 to 9 year period (depending on the information source). The 25-year period was selected as a long term projection based on input from the CASS Planning Technical Committee. The purpose of the following table is to present the magnitude of the potential impacts and to identify which surface water source has the greatest impact on salinity loading in the Phoenix AMA.

Water Source	TDS Concentration	Annual Salinity Load Remaining in Phoenix AMA	10-year Salinity Load Remaining in Phoenix AMA*	25-year Salinity Load Remaining in Phoenix AMA*
CAP Average TDS	650 mg/L	1,212,330 tons	12,123,300 tons	30,308,250 tons
CAP Salinity Standard TDS	747 mg/L	1,311,028 tons	13,110,280 tons	32,775,700 tons
Salt River Median	580 mg/L	1,212,330 tons	12,123,300 tons	30,308,250 tons
Salt River Flood	500 mg/L	2,998,807 tons	29,988,070 tons	74,970,175 tons
Salt River Drought	980 mg/L	1,186,282 tons	11,862,820 tons	29,657,050 tons
CAP Salinity Standard TDS and Salt River Drought	747 mg/L CAP and 980 mg/L Salt River	1,284,980 tons	12,849,800 tons	32,124,500 tons

* Shown for comparison only.

If the conditions on the Colorado River resulted in an increase in TDS to the numeric standard, the calculation projects an additional 1 million tons of salinity would remain in the Phoenix AMA after 10 years. This calculation is based on a constant CAP delivery with no changes in flow volume. However, drought conditions on the Salt River system can increase the TDS concentration and reduce the flow volume thus reducing the projected salinity load. Based on the drought condition in the Salt River system there is a net decrease of about 260,480 tons in the Phoenix AMA salinity load over the 10 year period. This data verifies the CAP TDS impacts have a more significant salinity load impact on the Phoenix AMA than does the drought impacts related to the Salt River system.

This data also projects the salinity loading impacts associated with flood conditions on the Salt River. These calculations are included for reference because unlike a drought, flood conditions would not be expected to last for 10 years or more.

The projections for the 25-year period follow the same trends as the 10-year projections. The difference is in the amount of total changes.

4.2 Groundwater

Groundwater is used in public water supply systems to meet residential, commercial and industrial demands and also for agricultural, turf and golf course irrigation (Figure 1). Groundwater TDS concentrations vary throughout the Central Arizona area and can be in the range of 250 mg/L to more than 3,000 mg/L. This is a much greater variation than occurs in surface water. In this memorandum the TDS and salinity loads are expressed based on regional conditions rather than site specific conditions.

Groundwater quality in Central Arizona basins is impacted by the quality of natural recharge, groundwater inflow from other groundwater basins, local geologic conditions, artificial recharge and agricultural leaching,

The quantity of natural recharge in Central Arizona is limited and in all the Central Arizona basins such as in the Phoenix, Pinal and Tucson AMAs, groundwater pumping greatly exceeds the quantity of natural recharge. While the rainfall generating the runoff which may recharge the aquifer units is usually of very high quality, the quality of the natural recharge will vary depending on the geologic formations the runoff crosses. In the majority of the locations, natural recharge water is high quality water. Due to the quantity of natural recharge, any TDS and salinity load changes associated with natural recharge will be small and occur over long periods of time.

Groundwater inflow from adjacent basins can impact water quality. The projected average salinity load entering the Tucson AMA from the Santa Cruz AMA and other sub-basins in the Tucson AMA is about 5,000 tons per year. The average load entering the Pinal AMA from the Tucson AMA and the other sub-basins in the Pinal AMA is about 68,300 tons per year (CASS, 2003). The average load entering the Phoenix AMA from the Pinal AMA and other sub-basins is 36,902 tons per year. As with natural recharge, any TDS and salinity loading changes will be small and will occur over long periods of time.

Local geologic features such as the Luke Salt Dome in the western portion of the Phoenix AMA can influence local groundwater quality. Wells adjacent to the salt dome have reported TDS concentrations of 40,000 mg/L. These local impacts are diluted as the groundwater moves and blends with other groundwater in the aquifer units.

Regional groundwater quality impacts associated with agricultural leaching and artificial recharge will be assessed in following sections of the Task 200 memorandum where the impacts will be calculated using the Salinity Load Flow Chart.

Groundwater is used for different purposes based on the quality. Groundwater used in the Phoenix AMA in the public water supply system was projected to have an average TDS concentration of 740 mg/l while the groundwater used for agricultural irrigation was calculated to have an average TDS concentration of 2,100 mg/L (CASS, 2003). Crops can tolerate a greater TDS concentration than the general public will accept as a part of the drinking water supply. In the Tucson AMA, groundwater used in the public water supply system averages 265 mg/L while the groundwater used for agricultural supply averages 450 mg/L.

Groundwater pumping does not increase the TDS in the aquifer or the salinity load but rather is a redistribution of the salinity load. Figure 1 shows groundwater pumping takes the salinity load from the aquifer and through the public water system which distributes groundwater to uses where the salinity load is added to the soil, the reclaimed water supply, or is placed back in the aquifer through the artificial recharge of reclaimed water. In other cases the groundwater salinity is recycled back to the aquifer due to agricultural leaching.

4.3 Reclaimed Water

Reclaimed water is used to meet some commercial and industrial demands, for the irrigation of agricultural crops, turf and golf courses and for artificial recharge. Wastewater discharges from residential, commercial and industrial uses are conveyed through the sewer system to wastewater treatment plants (WWTP) and water reclamation plants (WRP) where the water is treated and reclaimed water produced (Figure 1). The average reclaimed water TDS concentration calculated for the reclaimed water in the Phoenix AMA was 890 mg/L and for the Tucson AMA was 525 mg/L (CASS, 2003).

The interrelationship of the water sources and water uses to the regional reclaimed water supply is shown on Figure 2. A change in the TDS concentration of CAP or Salt River water will have wide spread impacts throughout the regional water supply impacting water uses and eventually the reclaimed water quality. The following table projects the impacts to the regional reclaimed water supply if the CAP TDS increased to the numeric standard of 747 mg/L and the Salt River TDS variations associated with median, flood and drought conditions. The TDS concentration associated with flood conditions in the Salt River system is more important than the associated salinity loading because a portion of the flood water with the reduced TDS concentration is diverted for use and will impact the regional reclaimed water TDS concentration. The table also projects the reclaimed water TDS impacts should the CAP TDS be at the numeric standard and the Salt River is in drought condition.

Water Source	TDS Concentration	Regional TDS Reclaimed Water
CAP Average TDS	650 mg/L	859 mg/L
CAP Salinity Standard TDS	747 mg/L	897 mg/L
Salt River Median	580 mg/L	859 mg/L
Salt River Flood	500 mg/L	829 mg/L
Salt River Drought	980 mg/L	926 mg/L
CAP Salinity Standard TDS and Salt River Drought	747 mg/L CAP and 980 mg/L Salt River	970 mg/L

The TDS concentration and salinity load associated with reclaimed water varies due to the proportion of the water sources used in the public water supply system tributary to the WWTP and WRP and TDS increases associated with the uses. Staff at several WWTPs and WRPs were contacted to verify the average TDS concentration in the reclaimed water produced at their facilities. These facilities were selected to provide a range of TDS concentrations based on the initial sources of water contributing wastewater to the plants.

WWTP or WRP	Principal Water Sources	Average TDS Concentration	Maximum TDS Concentration
Fountain Hills Sanitary District	CAP	900 mg/L	1,300 mg/L
23rd Avenue WWTP	CAP, SRP & groundwater	1,022 mg/L	1,380 mg/L in 2004
91st Avenue WWTP	CAP, SRP & groundwater	1,040 mg/L	1,400 mg/L in 2004
Cave Creek WRP	CAP & groundwater	1,143 mg/L	1,250 mg/L in 2004

The data for 23rd Avenue, 91st Avenue and Cave Creek are based on 24-hour composite samples rather than one sample collected at a specific time.

5.0 Future Salinity Impacts

The projected future salinity impacts are related to the retention of salinity within the Central Arizona area and how the retention of salinity may influence the water supplies and the potential uses of these supplies. Figure 1 maps the path of water and associated salinity showing uses where the salinity potentially increases and where salinity can accumulate.

Surface water supplies may have seasonal and annual changes in TDS concentrations but these are caused by conditions outside of the Central Arizona area. The primary salinity load impact is caused by importing of surface water and the associated salinity load into the Central Arizona area. In the Phoenix AMA, Figure 2 projects surface water imports about 77 percent of the salinity load while 33 percent is added as a part of the use of the water.

Reclaimed water and a portion of the pumped groundwater recycle the salinity and do not represent accumulation points. Interior residential, commercial and industrial water use can concentrate the salinity load contained in the source water and these uses can increase the TDS concentration through the addition of additional compounds to the wastewater stream. The reclaimed water and associated salinity load is recycled when the water is used for irrigation, artificial groundwater recharge and some commercial or industrial uses (Figure 1). A portion of the pumped groundwater is used for residential, commercial and industrial interior uses and follows the same path as surface water through the reclaimed water system. When reclaimed water is used for artificial groundwater recharge, some of the salinity load initially associated with groundwater is returned to the aquifer where it can be pumped again and further recycled.

Figure 1 shows there are several salinity accumulation points including the soil horizon, aquifers and some industrial uses. Non-agricultural irrigation of turf and landscaping usually does not include a water allotment for leaching to flush the salinity through the soil to below the root zones. In this case salinity will accumulate in the soils.

Aquifers are also accumulation points. Agricultural irrigation does include water allotments for leaching and the salinity associated with the irrigation water is flushed down to the groundwater. The result is increasing TDS concentrations in the aquifer units and in the pumped groundwater.

In some cases the accumulation of salinity removes the TDS from the Central Arizona system. Reclaimed water provided to the Palo Verde Nuclear Power Plant is used for cooling water and eventually discharged to evaporation ponds where the minerals precipitated out of solution due to the increased concentration.

The future impacts associated with the recycling and accumulation of salinity in soils are assessed in the following sections.

6.0 Salinity Limits and Tolerances

A goal of this white paper is to assess potential future impacts associated with TDS concentration increases and salinity accumulation. The initial step in these assessments is to define the TDS limits associated with specific uses.

6.1 Vegetation Salinity Tolerances

The TDS concentration limits associated with vegetation vary because food, forage and landscaping plants have different salinity tolerances. The terms used to express plant tolerance are sensitive, moderately sensitive, moderately tolerant and tolerant. These are general terms. Water is classified based on the TDS concentration and the Sodium Adsorption Ratio, calculated using the ratio of sodium, calcium and magnesium concentrations in the water. This white paper will assess the salinity hazard of water based on the TDS concentration.

The TDS concentration is expressed as mg/L or as millimhos per centimeter (mmhos/cm). TDS is also identified in calculations as the electroconductivity of the water (ECw). The following is a general classification of water based on the TDS concentration (Bouwer, 1978).

Potential Plant Toxicity	TDS in mg/L	TDS in mmhos/cm
None	Less than 480	Less than 0.75
Moderate	480 to 1920	0.75 to 3.0
Severe	Greater than 1920	Greater than 3.0

The relationship of the TDS of the surface water, groundwater and reclaimed water sources to the potential plant toxicity is presented on Figure 3. This data shows the Agua Fria and Verde River are in the no problem range while the groundwater used for irrigation can be in the severe problem range. The remainder of the water sources available in Central Arizona are in the moderate problem range.

Table 4 compares the reclaimed water salinity presented in Section 4.3 to the potential plant toxicity. This information shows the reclaimed water is in the moderate problem range. The average daily TDS concentrations would have to increase significantly to pose a severe problem.

The suitability of a water source for irrigation is based in part on the TDS concentration of the water and also the salinity of the soil. Water with a higher TDS concentration may not be appropriate for irrigation in poorly drained or saline soils without making an allowance for leaching to flush the salinity below the root zone. Soil salinity is classified based on the mmhos/cm measured in the soil saturated extract solution measured in a laboratory. The soil salinity is the electroconductivity of the soil saturated extract (ECe). The following is a general classification of ECe and plant response (Kotuby-Amacher, et. al., 1997).

ECe mmhos/cm measurement	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

The plant response does not mean when the tolerance ECe is exceeded the plant will die. The impacts of ECe and ECw increases results in plant stress and in the case of commercial agriculture, a reduction in yield per acre. For example, alfalfa is a common forage crop grown in Central Arizona. It has a tolerance ECe of 2.0. When the ECe increases to 3.4 mmhos/cm there is a 10 percent yield reduction. When the ECe is 5.4 mmhos/cm the reduction is 25 percent and at 8.8 mmhos/cm, the reduction is 50 percent.

Table 6-1 presents the soil associations in the Phoenix AMA area and the ECe classifications. The soil data is from Soil Conservation Service reports. This table verifies most of the soils are in the mostly negligible to growth of sensitive plants may be restricted plant response categories when the soils are assessed on a regional basis. However, the local soil conditions reflecting the maximum typical ECe includes the full range of plant responses.

The formulae and other ECe and ECw calculations are outlined in the CASS Phase I Technical Appendix A white paper. The following references provide additional background information to assess the impacts of increasing TDS concentration in the water supplies and increasing salinity in the soil. These references can be researched on the internet.

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6.2 Commercial and Industrial Requirements

Increases in the TDS concentrations in water sources can influence the suitability of the water to meet the commercial and industrial use requirements. In the CASS Phase I appendices there are several white papers outlining the water quality needs for commercial and industrial uses. Figure 1 shows the commercial and industrial uses can receive surface water, groundwater and reclaimed water. If the commercial or industrial user is provided potable water, then the potential for future TDS concentration increases to impact their operations is very slight. If the water user is provided groundwater or reclaimed water, then there may be impacts if the TDS concentration increases in these water sources in the future.

The Future With No Action Alternative analyses has shown there may be impacts to the suitability of reclaimed water for agricultural uses if the TDS increases to the concentration where there may be impacts on plant growth. This is also true for the turf related commercial operations such as golf courses. Industrial operations where the groundwater or reclaimed water is used for cooling or other industrial purposes may have increased costs to reduce the TDS concentration. These cost increases could also include chemical to control scale formation and increased water costs if cooling water salinity prevents multiple passes through the cooling towers. This is also outlined in the CASS Phase I appendices.

6.3 Potable Water Uses

Many communities use a TDS target of 500 mg/L for potable water; however as the data shows several surface water sources and groundwater can and often does exceed this goal. In Tucson, the TDS goal is lower than the 500 mg/L. There is no maximum contaminant level (MCL) established for TDS only a secondary standard of 500 mg/L. The Future With No Action

Alternative analyses show the water source that may be subjected to long-term TDS increases in the future is groundwater. If the TDS concentration in groundwater increases to the amount where it impacts the palatability of the groundwater, water providers will have to treat the groundwater, blend the groundwater with a water sources with a lesser TDS concentration or stop pumping from that well.

The public may desire water with a lower TDS concentration than is in the water delivered to their homes. This desire to reduce the TDS, especially the scale forming minerals such as calcium, is what drives the water softener market. Potable standards established by Federal and State agencies are different from palatable needs of the public. The water provided by municipal and investor owned water utilities must meet the potable standards but the public may desire water treatment to enhance the quality palatability. The then becomes a needs verses wants issue for treatment.

If the TDS reduction technologies are being considered because there is a goal to reduce the TDS concentration because it is wanted rather than needed, then water resources losses associated with the treatment concentrate reject may be a significant impact. The concentrate reject water is difficult and expensive to recover and represents a reduction in the overall water resources. The loss of water may require development of new or expanded water supplies, may require additional pumping of groundwater from aquifers and may increase the demand on existing water supplies to make up for the shortfall.

6.4 Groundwater Recharge

Figure 1 shows groundwater can be recharged naturally by precipitation and stream flow infiltration and also due to infiltration and leaching associated with exterior irrigation and farming and due to artificial recharge. Groundwater salinity can be impacted by leaching and artificial recharge. As described in Section 4.2, the TDS concentration in groundwater varies throughout Central Arizona. In almost all instances, leaching water will increase the TDS concentration in groundwater. Artificial recharge using surface water or reclaimed water may have either a negative or positive impact on the groundwater quality depending on the TDS concentration of the groundwater and the recharge water. In locations such as the southwest portion of the Phoenix area, the groundwater contains very high TDS concentrations and surface water or reclaimed water recharge will improve the overall groundwater quality. In locations such as Tucson where the groundwater has a very low TDS concentration, recharge using CAP water and reclaimed water will increase the overall TDS concentration of the groundwater. Most of the Central Arizona areas will be somewhere between these extremes and site specific conditions will dictate if groundwater recharge will improve or degrade groundwater quality.

There are no TDS MCL standards for groundwater only a secondary standard of 500 mg/L. Arizona can regulate the recharge of water sources which map produce a degradation of groundwater quality as a part of the Aquifer Protection Permit program. The Future With No Action Alternative analyses indicates recharging surface water may have an impact on some groundwater sources like in Tucson but generally surface water sources will not continue to have TDS concentration increases in the future. Reclaimed water may be subject to increasing TDS concentrations in the future and this may result in the ability to use reclaimed water as a source for groundwater recharge. If the TDS concentration in reclaimed water prevents use for groundwater recharge, this could impact the long term water budget and water supply in the future because other water sources may need to be diverted or developed to replace reclaimed water for recharge.

7.0 Summary

The Future With No Action Alternative analyses determined:

- The TDS concentration in surface water may vary depending on drought, flood or normal conditions in the watershed but the overall TDS concentration will remain within a concentration range defined for each surface water source.
- TDS minerals will accumulate over time in the soil as a result of exterior water use and agricultural irrigation. This soil salinity increase will impact the ECe of the soil and impact the growth pattern of vegetation and may require additional irrigation water use to compensate for the increased ECe. The impacts of soil salinity increases and the timing of the impacts are site specific based on the soil types, current ECe and TDS of water used for irrigation.
- TDS concentration increases in water used for irrigation may impact the suitability for use on certain crops. The degree of impact will depend on the salt tolerance of the crop, the ECw of the water and the ECe of the so
- il. The amount of impact and the timing of when impacts may occur are site specific considerations.
- TDS concentration increases in water used for groundwater recharge may result in an overall degradation of groundwater quality in many areas of Central Arizona. In some instances, reclaimed water may not meet acceptable limits for use as a recharge water source. This is also a site specific issue because reclaimed water quality is influence by the quality of the water used and discharged to the sewers and the residential, commercial and industrial interior water uses which add TDS minerals to the water prior to discharging to the sewers.
- In some cases, the TDS of water may not need treatment to control or reduce the TDS concentration but the treatment is initiated because it is what the public wants to increase the palatability of the water.
- In the future, increases in the TDS concentration in groundwater and reclaimed water may result in the water not meeting the quality required for some specific uses. In these cases, if treatment to reduce or control the TDS concentration is not applied the water may not be suitable for the intended use. In such a case, either the use must be discontinued or an alternative water source must be secured. This means the TDS concentration is not only a water quality issue but also become a water resources issue because the overall water supply available for a region in Central Arizona may be reduced.

11.0 References Cited

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