Central Arizona Salinity Study

Phase II – Concentrate Management

September 2006

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

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i. Definitions

Acre-foot - The volume of water it takes to cover an acre of land to a depth of one foot or 325,851 gallons.
Blowdown - Concentrated wastewater flow from a cooling tower containing most of the 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, further concentrating the remaining brine.
Concentrate - The unused water, which is high in TDS, generated after water is processed through a reverse osmosis (RO) membrane or other advanced water treatment process. See permeate.
Concentrate Management – The process of disposing in an environmentally sound and economic manner the unused water, which is high in TDS, resulting from advanced water treatment processes
Cooling Tower - Equipment with high surface area which uses evaporation to cool water. The cool water is subsequently used for other cooling purposes.
Crystallizers - Equipment that separates crystalline solids of one or more salts from a solution that contains these salts in dissolved form.
Deep Well Injection - Process where water, concentrate or waste water is pumped under pressure through a properly designed well into a geologic stratum.
Desalination - Process of removing salts from water.
Dewvaporation - A technology recently developed at Arizona State University that is an energy-efficient process which purifies water through evaporation and condensation cycles. At the writing of this report, this technology has not been used beyond bench scale testing.
Effluent - Treated wastewater.
Evaporation Ponds – Ponds used to evaporate water from brine leaving behind the salts.
MGD - Million Gallons per Day. 1 MGD is equivalent to 1120.14 af/yr
Nanofiltration - A type of reverse osmosis membrane system that separates divalent charged ions from monovalent ones sometimes called low pressure RO.
Permeate - Water that is de-mineralized through a reverse osmosis (RO) membrane or other advanced water treatment process which is very low in TDS. See concentrate.
Recharge - Artificially putting water into the aquifer via recharge basins or injection wells. For Arizona, entails the accrual of recharge credits.
Solar Ponds - Bodies of water that are stratified top to bottom by concentration of salt from low to high and can provide passive heating.
Vadose Zone - Designation of the layer of the ground below the surface but above the water table.
WAIV - A developmental technology for separating salt from water that uses flexible fabric moved by ambient wind to evaporate water from a falling film of brine.
Well-head Treatment – Advanced water treatment applied at the location of the well.

ii. Acronyms

ACC – Arizona Corporation Commission
ADWR – Arizona Department of Water Resources
ADEQ – Arizona Department of Environmental Quality
AF/yr – acre foot per year
AWWARF – American Water Works Association Research Foundation
CAP – Central Arizona Project
CASS – Central Arizona Salinity Study
CASI – Central Arizona Salinity Interceptor
EDR – Electrodialysis Reversal
EPA – Environmental Protection Agency
GPD – gallons per day
HERO –Patented *High Efficiency Reverse Osmosis*™ process
kW – Kilowatt
kW/hr – Kilowatt hour
MGD – Million Gallons per Day
mg/L– milligrams per liter
NF – Nanofiltration
O & M – operations and maintenance
pH – potential of hydrogen, or the negative log of the hydrogen ion concentration
POTW – Publicly-Owned Treatment Works
Reclamation – United States Bureau of Reclamation
RO – Reverse Osmosis
SROG –Sub-Regional Operating Group
SRV – Salt River Valley
TDS – Total Dissolved Solids
TSS – Total Suspended Solids
UF - Ultrafiltration
UPW – Ultrapure Water
USGS – United States Geological Survey
VSEP – Vibratory Sheer Enhanced Process
WAC – Weak-acid Cationic
WAIV – Wind-Aided Intensification of eVaporation
WTP – Water Treatment Plant
WWTP – Waste Water Treatment Plant

1.0 EXECUTIVE SUMMARY

In April 2004, the Central Arizona Salinity Study (CASS) Concentrate Management Subcommittee (Subcommittee) began researching, reviewing, and evaluating various concentrate disposal technologies and practices for the purpose of identifying the best method to manage concentrate from desalination processes in Arizona. This document presents and summarizes the work of the Subcommittee. This report:

- Identifies technologies that are currently available or developing in the industry;
- Discusses how the technologies work;
- Presents the various issues resulting from the implementation of each concentrate management strategy;
- Summarizes the general applicability of each technology for small, medium, and large flow rates of concentrate and makes relevant recommendations; and,
- Basic Cost Analysis of each technology

In 2004 when the Subcommittee began its review, few concentrate management options were being used in Arizona and these were generally limited to either sewer disposal or evaporation ponds. Research of new technologies for concentrate management was limited. New ideas for concentrate management were either being used in industry (predominantly the power industry) or were in the early stages of development. Today, several technologies, as well as various combinations of technologies are recognized as potential viable alternatives for further study. These technologies are being evaluated through several national and regional research organizations. This area of research will grow in importance as the population increases, particularly in the arid southwest United States, and the necessity of using poor quality water for the public water supply requires desalination and therefore leads to greater quantities of concentrate being produced.

The Subcommittee has developed consensus on the following:

- Currently, there is no single technology that will meet all concentrate management needs. Large concentrate generators have different problems then small scale concentrate generators.
- Further research is required to better characterize existing technologies, develop new technologies and explore strategic opportunities available to Arizona's water and wastewater industry.
- A concentrate management strategy is necessary for central Arizona if large scale desalination facilities are to be constructed to take full advantage of the benefits of advanced water treatment processes.

2.0 INTRODUCTION

The availability of good quality water resources is approaching full utilization in many communities in central Arizona. These communities are exploring the use of other water resources that, to date, have been regarded as non-potable such as brackish groundwater. The primary deterrent to using brackish groundwater has been in identifying strategies for managing the concentrate generated by advanced water treatment technologies desalting brackish groundwater. Some cities are considering the use of advanced water treatment processes on effluent produced at some wastewater treatment plants for high end uses such as indirect potable recharge and golf course turf irrigation.

The concentrate generated by advanced water treatment technologies is the focus of this report. Concentrate is expensive to manage, considerable amounts of water are lost for beneficial use and large amounts of concentrate if not managed properly could have environment implications.

This report discusses the issues related to concentrate management in central Arizona and assesses the benefits and risks of the technologies that could be used to manage concentrate. Issues related to concentrate management include: the quantity and quality of the concentrate, regulatory and environmental concerns, community awareness, and capital and operating and maintenance costs. The options for managing concentrate were evaluated for technical feasibility, financial feasibility, benefits/risks of technology, environmentally acceptability and institutional considerations. This report also provides a summary of the most viable options available for managing concentrate.

3.0 CONCENTRATE MANAGEMENT IN CENTRAL ARIZONA

Beginning in the early 1990s, the desalination of water and wastewater began to increase significantly. While advanced water treatment has allowed utilities and industries to produce consistently high quality product water, as well as recover previously unusable water sources, the concentrate created can pose a significant disposal issue. More relevant in desert environments, between 5 to 50 percent of the source water is lost as concentrate and represents a significant resource loss.

There are several entities using some form of advanced water treatment in central Arizona. Table 3.1 below summarizes some of the entities in Arizona using advanced water treatment and their current method of disposal.

Table 3.1 Current Concentrate Management Practices in Arizona

Facility	Type of Water Treatment	Water Treatment Capacity (MGD)	Concentrate Disposal type	Comment
City of Chandler	RO	3	Sewer, and evaporation ponds	This facility treats Intel's waste water. The concentrate is then evaporated in ponds.
City of Scottsdale	RO	12	Sewer	Concentrate is discharged to sewer system, which ultimately ends up at the SROG 91st Avenue WWTP.
City of Gila Bend	RO	1.2	Evaporation Ponds	
Lewis Prison	RO	1.5	Evaporation Ponds	Due to inefficient treatment process, concentrate streams are greater than 15% which makes the ponds undersized
Town of Buckeye	Electrodialysis Reversal	0.9	Sewer	Treatment facility is old and only used for peaking purposes.
Yuma	RO	102	La Cienga By-Pass	Concentrate discharged to the Gulf of California. Plant has not operated since 1993.
City of Goodyear	RO	1.5	Sewer	
Industrial Users	RO	Varies	Sewer	Hospitals, bottling industry and microchip industry utilize treated water in their daily operations.

As indicated in Table 3.1, the primary methods of concentrate management in Arizona are sewer disposal and evaporation ponds. These two methods are currently the least expensive and/or easiest methods to dispose of concentrate.

Evaporation ponds work well for small quantities of concentrate in areas with available land, but with larger quantities the cost of land and cost of lining the evaporation ponds becomes prohibitive. Sewer disposal is the least expensive and easiest way to dispose of concentrate but the WWTP receiving the concentrate must be able to handle the increased salt load. Regional WWTP usually can handle the salt load through dilution but smaller satellite reclamation plants sometimes experience high TDS concentrations in the effluent.

4.0 CONCENTRATE MANAGEMENT ISSUES IN ARIZONA

This section presents the issues associated with the planning and implementation of concentrate management technologies.

4.1 Regulatory Issues

The Clean Water Act (CWA) does not specifically address concentrate discharge. As a result, concentrate is addressed through a default classification as industrial waste (AMTA website, Desalting Facts). This results in a more stringent set of regulations, potentially higher permitting costs, and public perception issues. Other regulations not directly geared towards concentrate but which must be considered when faced with a concentrate disposal issue include the National Pollutant Discharge Elimination System (NPDES) permit (or its Arizona equivalent, an Arizona Pollutant Discharge Elimination System [AZPDES] permit), Class 1 Underground Injection Control (UIC) permit, and the Aquifer Protection Permit (APP).

In cases where an industry or water treatment plant chooses to directly discharge concentrate to a waters of the U.S., a NPDES/AZPDES permit is required. Arizona has no such discharges at this time. In order to receive a NPDES or AZPDES permit, the discharge must meet strict water quality standards and it is estimated that it would take 18 to 24 months to receive a permit.

Nationally, 42 percent of concentrate is disposed in sewers (Mickley 2001). Sewer disposal is the most common practice in Arizona. The concentrate is then indirectly discharged into the waters of the United States with the effluent of a WWTP. The WWTP needs a NPDES/AZPDES but TDS is not on the criteria of the permit.

The U.S. Environmental Protection Agency (EPA) has proposed, under the 2004 Effluent Guidelines Plan, a new federal category, under Sections 304(b) and 304(m) of the Clean Water Act. This Act would require a review of discharges from existing drinking water treatment plants. This Act may also require new federal limits on discharges, either through WWTP's as indirect discharges or as a direct discharge to waters of the United States. If a drinking water plant uses advanced water treatment then the concentrate produced by the plant would be subject to these new rules. The schedule for final decision on the proposed Drinking Water Facilities category is August 2007.

Well injection of brine concentrate requires a Class 1 Underground Injection Control (UIC) permit. Because Arizona does not have primary responsibility (primacy) for issuing UIC permits, any applicant considering a UIC permit would need to apply to the EPA. No locations were found in central Arizona that met the criteria for deep well injection.

An APP from the Arizona Department of Environmental Quality (ADEQ) is also required for deep well injection and surface impoundments. Surface impoundments include discharge of concentrate to an evaporation pond. Whether ADEQ will require a single or double-lined pond depends on the quality of concentrate, depth to groundwater, and the potential to harm adjacent land and water users. An APP would also be required for land application methods in which the concentrate would be sprayed, allowed to infiltrate, and/or flow over large areas of land surface.

4.2 Public Awareness Issues

Providing information to the public on issues related to concentrate management is critical to the success of large-scale desalination and concentrate management projects. This will largely be the responsibility of local water providers and governments. Information provided to the public should include a discussion about what the potential consequences would be if advanced water treatment options were rejected based solely on cost factors. The potential consequences would include: 1) the long-term environmental and economic impacts of groundwater pumping and potential associated ground subsidence, 2) the economic impacts of groundwater quality degradation through the continual buildup of salts, and 3) the costs of other potential water sources to meet future demand. Public objections to water losses related to concentrate management will depend on the community's knowledge of quantity and quality of available water resources and/or the community's demand for water.

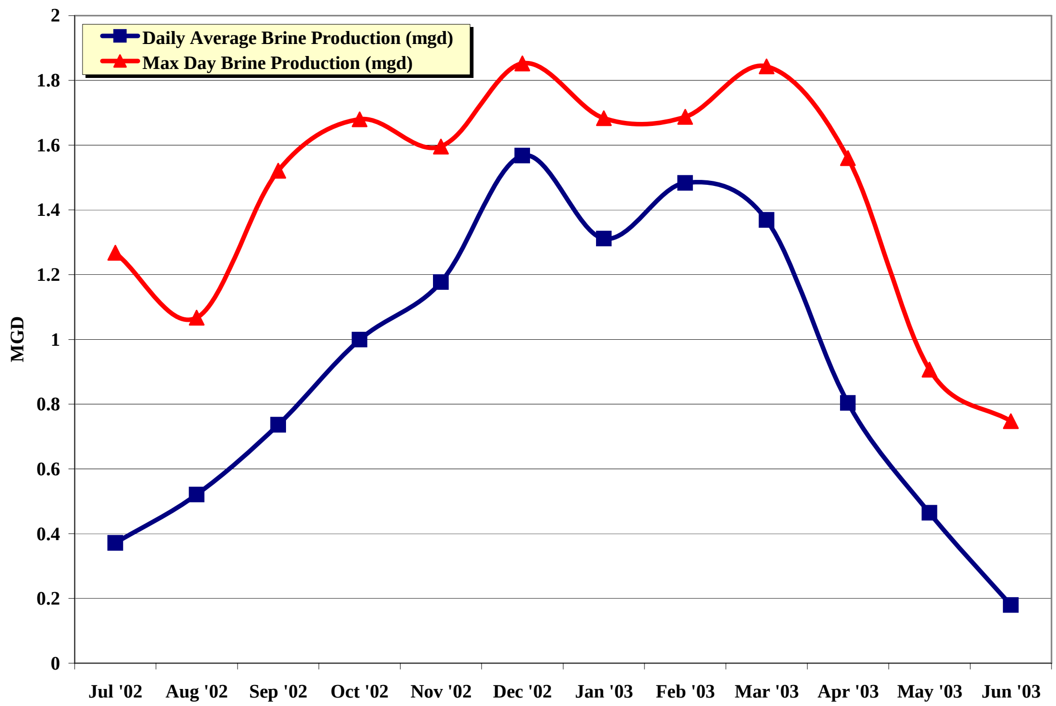
The cost of managing brine concentrate is often a very expensive component of desalinization of water and may require a large capital investment for infrastructure. Most municipalities would typically borrow funds through bonding to construct large capitally intensive infrastructure and water projects. Approval of bonds will depend on the public's understanding of the issues driving the need for desalination. Arizona's private water companies are governed by the Arizona Corporation Commission (ACC). A private water company that needed to implement a desalination program would have to build the desalination and concentrate management facilities before it could request a rate increase from the ACC to recover these costs.

Water providers and governments will also have to address the public's concern on potential environmental impacts of concentrate disposal. For example; evaporation ponds may leak to the groundwater system or they may concentrate hazardous elements such as arsenic or selenium. In addition, evaporation ponds may be unattractive on the landscape. Each concentrate management method has environmental concerns which must be addressed and accurately explained to the public.

4.3 Common Technical Issues

The technical aspects of a concentrate management will vary by technology. The major factor in determining the cost of a concentrate management strategy is the quantity of concentrate which needs to be disposed on a daily basis. Figure 4.1 shows that the concentrate flows vary widely at the Scottsdale Water Campus. They range from a low of 0.15 MGD, to a high of 1.9 MGD (City of Scottsdale Water Campus data, 2002-2003). Actual potential peak day production at this facility is 2.1 MGD. The necessity for treating the total volume and peak day flow rate needs be evaluated carefully because it can limit the type of concentrate management option available. At the present time, the Scottsdale Water Campus disposes of its concentrate into the sewer system. If the receiving WWTP can handle the salinity increase, then sewer disposal is one of the cheapest methods. The 91st Avenue WWTP is a very large regional facility and has been able to absorb the concentrate flows with a manageable salinity increase. On the other hand, the Cave Creek Water Reclamation Plant is a relatively small facility and could not handle the concentrate from a facility like the Scottsdale Water Campus.

Figure 4.1 Scottsdale Water Campus Daily Brine Production



5.0 OPTIONS FOR CONCENTRATE MANAGEMENT

CASS, in efforts to identify the most practical concentrate management options for the region, developed a broad list of alternatives for central Arizona including: Evaporation Options, Transportation Options, Well - Injection Disposal Options, Zero Discharge Options, and Proprietary Volume Reducing Options. These categories were expanded to include more specific concentrate management alternatives. Section 6.0 discusses the management options currently available and some that are being developed. It should be noted that several technologies have emerged since CASS began its Phase 1 work. Undoubtedly, new ideas will be developed in the future.

The selection of a concentrate management option is heavily dependent on the volume of concentrate, quality and geographical location. What may work in California, Texas, or Florida may not be viable in Arizona. This study is specifically looking at methods that are applicable to locations in central Arizona. Even within central Arizona, the effectiveness of various methods may be site-specific. Therefore, the following evaluations address local conditions.

One clear result from this evaluation has been that no single technology serves as a solution for solving concentrate management issues. Some types of technologies may serve in a stand-alone capacity for certain applications; however, as larger concentrate streams are considered, it is clear that a combination of technologies may be required to effectively manage these streams.

5.1 Evaporation Alternatives

Evaporation is an effective option in Arizona's climate for reducing the volume of concentrate and is already used in various locations throughout central Arizona. The problems with this option are primarily related to land availability, land costs and loss of water resource to evaporation.

5.1.1 Evaporation Ponds

Due to the hot, dry climate, evaporation ponds work well in central Arizona. Evaporation ponds can be constructed relatively quickly. Construction entails excavation of basins and construction of berms. Sometime nets are put across the top of the ponds to prevent aquatic fowl from using the ponds. Liners can be constructed of a low-permeability clay layer and/or a single or double synthetic liner (typically composed of high density polyethylene [HDPE]). Optimal depth for ponds is between 1 and 40 inches (Mickley, 2001). Maintenance on evaporation ponds is limited to checking berm integrity and monitoring water quality in monitor wells. An APP from ADEQ is required to operate the facility.

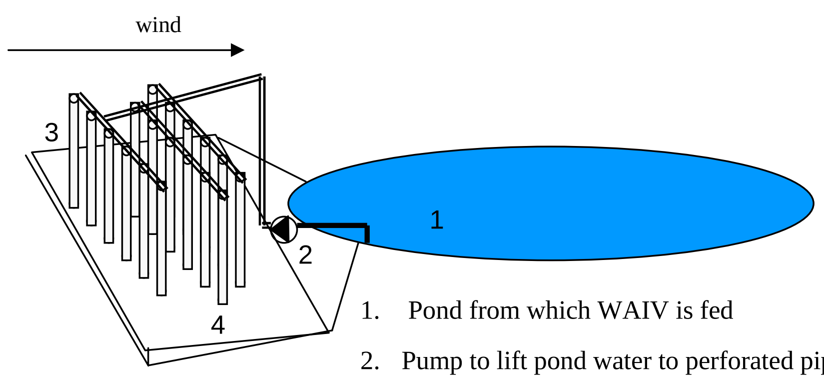
Evaporation ponds work quite well for low amounts of concentrate. The Town of Gila Bend and the City of Chandler both use evaporation ponds to dispose of concentrate from RO facilities. However, larger flows of concentrate can be expensive to dispose through evaporation ponds. The following two examples with the costs calculated using a

Reclamation cost model shows the rapid increase in costs with an increase of concentrate volume. The capital costs for an evaporation pond to dispose of 1 million gallons a day (mgd) of concentrate located in the uninhabited desert would cost approximately $20 million. The capital costs for an evaporation pond to dispose of 5 mgd near the Phoenix metropolitan area would cost approximately $125 million.

5.1.2 Wind Aided Evaporation Process

A relatively new technology, developed in Israel, is referred to as wind aided intensified evaporation (WAIV). WAIV was developed to be used in conjunction with evaporation ponds as a means of reducing the overall surface area of the ponds. The WAIV process uses wind to promote evaporation against a larger surface area than an evaporation pond. The WAIV unit is comprised of a vertical support structure that suspends a series of cloth sheets. Water is pumped from a pond to the top of the WAIV unit where the water trickles down the cloth sheets. As dry air passes over the vertical cloth surfaces, evaporation takes place and the salts are deposited on the cloth sheets. Any excess liquid is drained back to the pond, while the salts deposited are knocked off by the wind action and caught in a trough below the fabric for disposal in a landfill. Studies indicate that the WAIV method intensifies the evaporation process to about 20 times that of regular evaporation ponds (Gilron, et al, 2003). Although this technology is primarily used in Israel, the similar conditions of low humidity and high temperatures make it likely that the technology would be reliable in Arizona.

Figure 5.2 Schematic of a WAIV Unit



Israel Patient Application
130357 and 140158

1. Pond from which WAIV is fed
2. Pump to lift pond water to perforated pipe which distributes water to wetted surfaces
3. Wetted surfaces from which water evaporates
4. Impervious surface (concrete) sloping back to pond to allow excess water to return to pond by gravity

Associated equipment include piping, pumps, electrical equipment, and drains back to the evaporation pond. The evaporation pond would still require excavation, liners, and monitoring wells. Maintenance of the evaporation pond would include inspecting the integrity of the berms and liners, and monitoring the water quality of the groundwater aquifer. Maintenance for the WAIV unit will include lubrication of the pumps, electrical equipment maintenance, cleaning of the WAIV unit (if necessary), and hauling/disposing of crystallized salts.

Reclamation tested this technology and one of the problems discovered was that the nozzles where water was dripped onto the sheets would salt up and clog. This required personnel to clean the nozzles on a regular basis.

5.1.3 Solar Ponds

Solar ponds are a method to store concentrate and produce heat which can be used to generate electricity. The process takes advantage of the heat-storing ability of saline water. The heat created in solar ponds can then be integrated into several technologies including: 1) concentration of brine for recovery of usable water; 2) generating a heat source for RO pre-treatment; 3) generating a heat source for thermal desalination for zero liquid discharge; and/or 4) using the stored solar heat for turbine-generated electricity.

Highly concentrated salt brine makes up the bottom layer of the pond, or lower convective zone (LCZ). The middle layer, called the gradient layer or the middle gradient zone (MGZ), is the convection suppresser, or the insulating layer. The top layer of the pond, or upper convective zone (UCZ), consists of fresh to lightly saline water having a salinity of 0 to 4 percent The MGZ allows the sun to penetrate the water layers, heating and entrapping the bottom layer. Because of the density contrast between the MGZ and the LCZ, the LCZ is heated to temperatures in the range of 60 to 90 degrees Celsius. The stored heat is used to generate electricity through use of special turbine engines.

Experimental solar ponds have been in operation in locations throughout the world for several years. The solar pond in El Paso, Texas was initiated in 1983 and began operation in 1985. This research location has subsequently closed and is no longer in operation. There was some success in demonstrating the theory but the size of the pond was not large enough to drive the special turbine engine for long periods of time.

Central Arizona averages 211 days of sunshine and 85 mostly sunny days per year. This abundance of solar heat could be very conducive in producing thermal energy from solar ponds. For small solar ponds, a circular configuration is the best. Larger ponds can be either square or rectangular. Formulas are available for determining the volume and area of a solar pond in order to generate the necessary kilowatts. The best construction is wall slopes of 1:3 with a depth of approximately 10-1/2 feet . The pond liner system is usually constructed with low permeability clay overlain by a synthetic liner.

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Concentrated brine from the LCZ will dissipate into upper zones with time, requiring the addition of more salts to the LCZ. Pond clarity and pH levels are important for maximum solar radiation which requires monitoring and maintenance. A low

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groundwater table is best because the LCZ of the solar ponds require insulation to hold the heat.

Solar ponds have some concentrate volume-reducing properties but they are not a concentrate management process.

5.1.4 Land Application

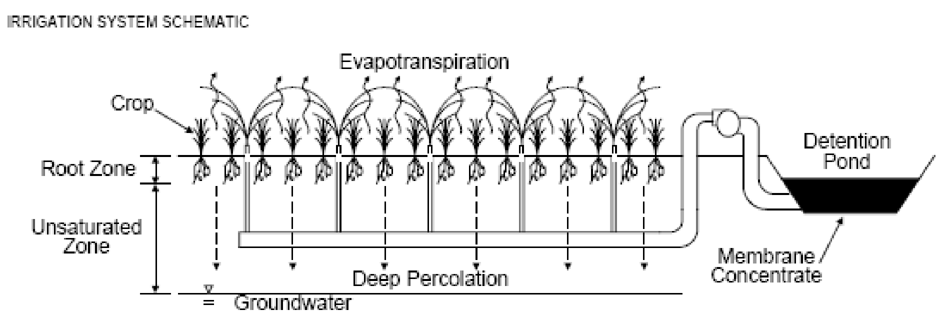
Land application methods for concentrate management include spray irrigation, rapid infiltration and overland flow application. Spray irrigation involves using concentrate from membrane systems for irrigation of salt tolerant grasses or other salt tolerant vegetation. Plants take in the water they require and the remaining portion of the water will percolate into the subsurface. Contamination of the aquifer may become an issue if liners and drainage systems are not incorporated.

The technology of spray irrigation has been utilized successfully for irrigation of crops and turf. But using membrane concentrate as source water can cause problems because the salts tend to precipitate and clog irrigation nozzles. Spray irrigation utilizing concentrate would have to be limited to salt tolerant crops and turf.

Spray irrigation systems can be built relatively quickly. It will require excavation for installation of piping for water delivery and drainage. Maintenance of the irrigation system will require periodic inspections and maintenance, i.e. replacement of lines and sprinkler head nozzles.

Figure 5.4 shows a typical unlined spray irrigation system using membrane concentrate as the water source.

Figure 5.4 Concentrate Management By Spray Irrigation



5.2 Transportation

This section evaluates concentrate management options that transport concentrate away from its point of origin to another location for ultimate treatment or disposal.

5.2.1 Sewer Disposal

Sewer disposal is the most common method of disposal of concentrate in the U.S and along with surface water disposal the easiest and least expensive method of concentrate management. The costs associated with implementing this option are constructing a pipeline to the sewer. The WWTP must have enough hydraulic capacity to handle the additional flows from the concentrate. In addition, the salinity into the plant can not reach levels that compromises the plants treatment processes or compliance with its NPDES permit.

In the Phoenix metropolitan area there are many point sources of high salinity discharges into the sewer system. These include municipal and industrial desalination facilities and blowdown from cooling towers. The regional wastewater treatment facilities, such as the 23rd Avenue WWTP and the 91st Avenue WWTP, are better able to handle concentrate because of the large volume of other flows into the plants. These plants have seen a rise in TDS, although it has not affected the usability of the effluent at this point. Smaller satellite reclamation plants do not see as much dilution of TDS concentration due to the lower overall flows being received by the plants. Several reclamation facilities in the Phoenix metropolitan area are receiving elevated TDS inflows. The effluent coming from these reclamation facilities has caused concern among golf course managers who use the effluent for irrigation.

In the future, it may not be practical to construct desalinization facilities which discharge large amounts of concentrate into the sewer system. On a case by case basis, decision makers will have to decide if their facilities can handle the additional salt load from concentrate without adverse impacts on the end uses of the effluent. This can increase the cost of constructing a desalinization facility by requiring an alternative method for managing concentrate, other than sewer discharge.

5.2.2 Central Arizona Salinity Interceptor (CASI)

In 1996, Reclamation and the City of Tucson initiated a study on desalinating CAP water delivered to the Tucson metropolitan area. This appraisal level study examined the various advanced water treatment alternatives and various methods of disposing of the resulting concentrate. Three sizes of RO facility were examined; 50 mgd, 100 mgd and 150 mgd. Extensive and thorough capital and O&M costs were produced for each size of facility. Depending on the size of desalinization facility built the amount of concentrate produced varied from 8.8 mgd to 26.5 mgd.

Eleven different concentrate management alternatives were analyzed. Seven alternatives were discarded after initial research and four alternatives were investigated further. They were: Deep well injection, supply water for a local mine to process ore, blend concentrate with effluent from local WWTP, and a concentrate transmission pipe line to the Sea of Cortez. It was concluded that the pipeline to the Sea of Cortez, called the Central Arizona Salinity Interceptor (CASI), was the most cost effective way to dispose of the concentrate.

Two pipelines were identified for CASI. One was a direct route from Tucson to Puerto Penasco with a length of about 162 miles. The other route went northwest to the Phoenix metropolitan area, where additional concentrate from future Phoenix metropolitan area projects would be added, then headed southwest to Yuma for a over all length of 245 miles.

Estimated costs for the pipelines range from $356,000,000 to $883,000,000 depending on quantity of concentrate and route selected. (The costs are in 1998 dollars.) The biggest drawback for this project besides the enormous costs is the loss of water which accompanies the disposal of the salt. The Arizona Department of Water Resources opposed the project because of the significant water losses associated with transporting concentrate out of state. Ultimately, the desalinization of CAP water and CASI did not adequately reflect the evolving goals of the City of Tucson's long range water plans.

5.2.3 Painted Rock Dam

A potential concentrate management option developed by members of CASS is to transport concentrate to Painted Rock Reservoir and use it as a large evaporation basin. Painted Rock Dam is located about 20 miles northwest of Gila Bend and about 45 miles southwest of Phoenix, Arizona. The United States Army Corps of Engineers (USACE) owns and operates the dam. Constructed in 1921, it is the last dam located along the Gila River and is designed to control and prevent flooding downstream in the Yuma irrigation districts. The only time water passes through Painted Rock Dam is during a major flood event. Flood waters are contained in the Painted Rock Reservoir (53,200 acres) and then released in a controlled manner. The design flood inflow of Painted Rock Dam is 300,000 cubic feet per second (cfs); design flood outflow is 22,500 cfs.

A brine line could be constructed to transport the concentrate to near the base of the dam. Large shallow evaporation ponds would be constructed in the dry reservoir bed and the concentrate would be allowed to evaporate. When the next flood event occurred, the salts in the evaporation ponds, would be re-mobilized and carried down the Gila River to the Colorado River then out to the Sea of Cortez. The TDS concentration of the flood waters would be fairly low, depending on how much salt had been deposited and the size of the flood event. The impact to downstream farmers would be negligible because during flood events they would not be using or diverting river water for irrigation purposes.

This disposal option would be simple to construct and operate. The size and frequency of flood events would be a concern and are not predictable. A clay layer with or with out a single geomembrane liner would protect the groundwater from salt intrusion. A double-lined geomembrane pond would be more protective of groundwater, but considerably more expensive.

The area of the Painted Rock Reservoir is large enough to potentially handle all the concentrate produced by the Phoenix metropolitan area and possibly the Tucson area for the foreseeable future.

The option of using the Painted Rock Reservoir as a large-scale evaporation pond is less expensive then the CASI pipeline, and would return the salts to the sea consistent with the natural water cycle.

It is possible that environmental groups and farmers downstream of Painted Rock Reservoir may oppose this method of concentrate disposal because of the perceived impacts to the environment.

5.2.4 Palo Verde Nuclear Generating Station Discharge

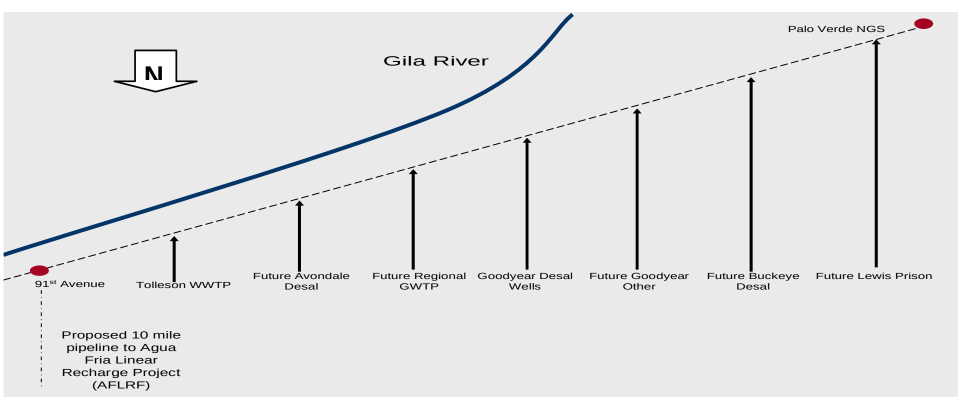
Currently the 91st Avenue WWTP sends reclaimed water to the Palo Verde Nuclear Generating Station (Palo Verde) for cooling water purposes. The reclaimed water line that interconnects these facilities extends along the southwest portion of the Salt River Valley and through the cities of Avondale, Goodyear and the Town of Buckeye.

Each of these municipal water providers are considering desalting brackish groundwater as a means for meeting their future water demands. A plausible option would be to dispose of concentrate into the Palo Verde reclaimed/cooling water line. This could either be done by collecting concentrate through the use of a concentrate collection system that would then tie into the reclaimed water line to Palo Verde, or making individual connections on a site-by-site basis to the reclaimed/cooling water line.

The concentrate from municipal membrane water/wastewater treatment processes would be mixed with the reclaimed water from the 91st Avenue WWTP and delivered to Palo Verde. Palo Verde softens the incoming water before using it for cooling water and then discharges the cooling tower blowdown to onsite evaporation ponds.

If this option was to be implemented such issues as additional chemical costs for water softening, reliability, construction requirements, maintenance requirements, capacity, timeliness, assured supply, safety and cost would have to be thoroughly evaluated.

Figure 5.5 Concentrate Intercept Concept



5.3 Injection

Injection refers to the action of pumping concentrate into the ground utilizing wells. There are geological and legal restrictions on how injecting concentrate into the ground.

5.3.1 Class I Injection Wells (or Deep Well Injection)

Deep well injection involves pumping concentrate into a relatively deep geologic formation (typically 1,000 to 8,000 feet) that has the ability to contain, isolate, and prevent movement of the concentrate into a potable water aquifer. Pumps are used in above ground facilities to inject the concentrate into a receiving geological formation.

Deep well injection is under strict regulatory control in Arizona and requires an Aquifer Protection Permit (APP) through the Arizona Department of Environmental Quality (ADEQ). Under the Code of Federal Regulations, Title 40, (40 CFR) Chapter I, Part 144 and 146 (deep well injection rules), an injection well used for brine disposal would be classified as a Class I well. A Class I injection well must be sited such that injection occurs into a highly saline water-bearing zone (having at least 10,000 mg/L TDS) and the water-bearing zone must be separated from any overlying drinking water aquifers by hydrologically impermeable formation(s) that prevent upward migration of the injected concentrate. The receiving formation must have sufficient permeability so that the injected flow will not excessively raise the pressure and fracture the confining zone or the injection zone. If the groundwater in the receiving formation contains less than 10,000 mg/L TDS, it may qualify as an "exempted" aquifer. The USEPA defines an exempted aquifer as an aquifer that does not currently serve as a source of drinking water and it cannot now and will not in the future serve as a source of drinking water; *or*
as an aquifer having the total dissolved solids (TDS) content of the ground water of more than 3,000 mg/l and less than 10,000 mg/l, and the aquifer is not reasonably expected to supply a public water supply.

Injection wells must be constructed according to applicable state and federal environmental regulations. Concentrate is highly corrosive and, therefore, operational materials must be able to resist corrosion to avoid reduced equipment life cycle. The most common problem with deep well injection is plugging of the receiving formation or well. Significant suspended solids may be present when concentrate is mixed with membrane pre-filter backwash. This may require the concentrate to be pretreated to prevent plugging of the receiving formation. Depending on specific characteristics of the receiving aquifer and the concentrate, pH adjustment may be necessary to minimize scale formation.

Most of the Class I non-hazardous injection wells are located in either Florida or Texas. Florida has limestone formations which are conducive to deep well injection. Texas has sandstone formations between shale formations, which also work very well for deep well injection.

At the Paradox Valley Unit in Colorado, normal operations are 14 to 14.5 million gallon of brine per month or 128,000 tons of salt per year. (Test Well 1 for the Paradox Valley

Unit was completed at a depth of 15,932 feet below ground surface.) Disposal capacity is limited to pipe casing size and porosity, or take rates, of the geologic target zone.

One example of deep well injection in Arizona is the proposed El Paso Natural Gas Company brine injection into the part of the West Salt River Valley aquifer system known as the Luke Salt Body, approximately 17 miles west-northwest of Phoenix. The Luke Salt Body is a massive salt deposit, estimated to contain between 15 and 30 cubic miles of halite sodium chloride (Eaton et al. 1972). The top of the salt dome has been documented at 790 to 880 feet below ground surface; the base is estimated by gravity data to be approximately 6,900 feet below ground surface (Eaton et al. 1972). The proposed El Paso Natural Gas project sought to obtain an APP to inject a limited amount of brine concentrate into the "basement" or bedrock rock beneath the Luke Salt Dome.

The depth of the proposed injection well was 8,307 feet below ground surface. The total amount of brine that was proposed to be injected was 432,000 barrels, or 18.1 million gallons, or 55.7 acre-feet, over a period of 60 days. The concentrate would come from a cavity that was to function as a natural gas storage facility created in the Luke Salt Body. Ultimately, the natural gas storage project was canceled due to political pressure, and therefore, it is unknown if the injection well portion of the project will be continued.

The suitability of the Luke Salt Dome for deep well injection/disposal is very limited. TDS concentration in the groundwater in the basement rock is above 100,000 mg/L, which meets one of the criteria for constructing and permitting a Class I injection well; the Luke Salt Body would be considered the confining layer. However, the problem lies in the basement rock, which consists of Tertiary volcanic, granitoid, and metamorphic rocks, to continuously receive a steady input of concentrate. All of the basement rock types have low permeability and are not what is considered an ideal receiving formation. The only reason El Paso Natural Gas Company considered the Luke Salt Body was because the project required disposing of only a finite, relatively small amount of concentrate.

One potential site for deep well injection may lie immediately west of the Luke Salt Dome. The receiving aquifer, if close enough to the salt dome, would still meet the 10,000 mg/L of TDS requirement. At this particular location, the subsurface is composed of interbedded water-bearing alluvial materials (sand, gravel, silt) and several impermeable clay layers. The clay layers could act as confining units. Questions that need to be answered development of a deep well injection site at this location include: (1) how extensive is the 10,000 mg/L TDS aquifer, (2) could the concentrate migrate laterally and contaminate potable water wells in the area, (3) are the clay layers continuous and uninterrupted to prevent migration of the concentrate upwards, and (4) what is the volume of concentrate that could be injected into the receiving formation.

Comment: Do you want to add an approximate number of miles west?

Other then the two above examples no other suitable locations for deep well injection are known in central Arizona at this time. The basin and range geology does not lend itself to hydrological impenetrable geological strata.

5.3.2 Injection Into Salt Dome Caverns

The Luke Salt Body, as discussed in Section 5.3.1, is a massive salt deposit located in the West Salt River Valley. The Morton Salt Company (Morton Salt) extracts salt from the Luke Salt Body by solution mining using fresh water pumped through a well casing into the salt deposit to dissolve the salt. The water then becomes saturated and the resulting salty brine is pumped to the surface into large, lined ponds. The water is evaporated leaving the salt (halite) as a usable product. As the salt is dissolved and pumped out (mined) of the salt dome, a cavern is formed. It is these caverns that could potentially be used to dispose of concentrate from the Phoenix metropolitan area.

AmeriGas currently uses the salt caverns created by Morton Salt for storing natural gas (Neal, 1996). Subsurface salt bodies are ideal for gas storage because they are essentially impermeable, making it impossible for the gas to escape and because gas can be compressed under pressure to fit within the confined space of the caverns. However, when considering the salt caverns for concentrate disposal, it needs to be understood that the volume of a cavern can hold only a limited volume of liquid (concentrate) because water is not compressible. The size of the cavern, and hence, the limit of concentrate able to be disposed, depends on how much salt is removed.

Morton Salt extracts slightly over 100,000 tons of salt annually from the Luke Salt Body. Based on a density of salt (sodium chloride) of 0.031 tons per cubic foot, this would result in approximately 3.2 million cubic feet of storage space created annually. This available space would hold approximately 24 million gallons of liquid annually, or about 66,000 gallons per day (gpd). This equates to the storage capability to store concentrate from a 0.44 mgd RO plant that creates a 15 percent concentrate stream.

This method could work for very concentrated product from a relatively small RO facility; however, personnel from Morton Salt have stated concerns with possible hazardous ions in the concentrate contaminating their source of salt. Because of these concerns and the limited storage volume for concentrate this option does not seem very promising.

5.3.3 Artificial Recharge Into Poor Quality Aquifers

In Arizona artificial recharge is a water management tool used to store CAP water and effluent, so that this water can be recovered in times of drought. This program is administered by the Arizona Department of Water Resources (ADWR). There are almost 80 recharge facilities, currently permitted to recharge CAP, surface water, and/or effluent in Arizona. Currently, Arizona statutes currently only permit the recharge of CAP water, effluent, and/or decreed and appropriative surface water; recharge of brine water is not allowed.

5.4 Zero Liquid Discharge (ZLD) Systems

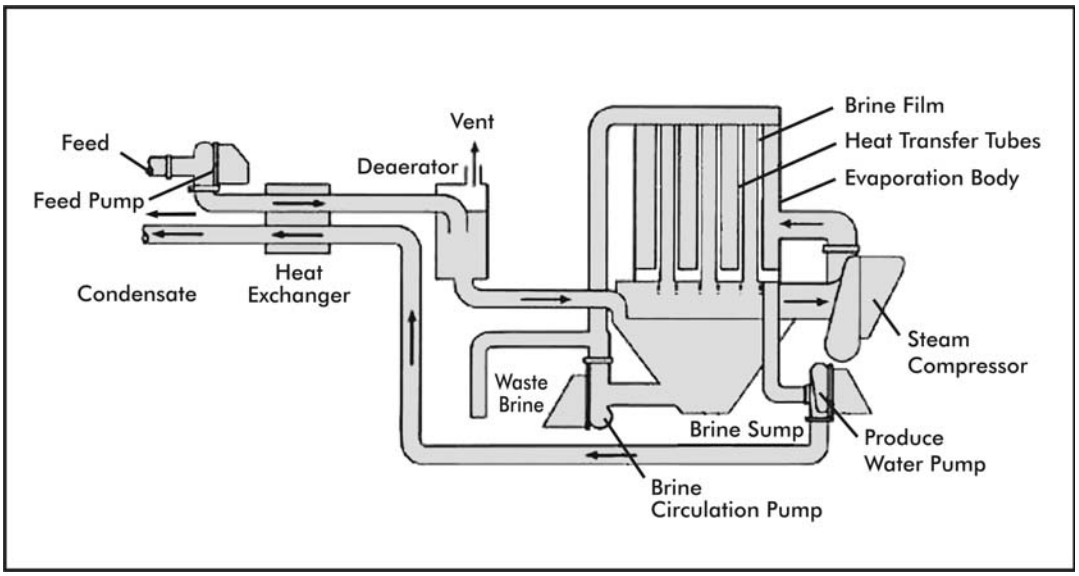
This section discusses zero liquid discharge systems that are designed to treat, recycle, and reuse all process wastewater (liquid) from an operation leaving only the solids (salts) in the concentrate. Several of the ZLD methods that currently exist are discussed in the next sections.

5.4.1 Brine Concentrators

Brine concentrators are used to convert highly saturated industrial wastewaters into distilled water for reuse. A brine concentrator is similar to a conventional evaporator, except that the vapor released from the boiling solution is compressed using a compressor. Compression raises the pressure and saturation temperature of the vapor so that it may be returned to the evaporator body to be used as heating steam. The latent heat of the vapor is used to evaporate more water instead of being rejected to cooling water.

Scaling of heat transfer tubes within the brine concentrator can be an issue and is prevented by the seeded slurry process. Calcium sulfate and silica precipitates build up on calcium sulfate seed crystals in the recirculation brine instead of scaling on the heat transfer surfaces. With the seeded slurry process, concentration of up to 30 percent can be reached without scaling.
Recovered water from the brine concentrator typically has a TDS concentration of less than 10 mg/L. The stream from the concentrator ranges between 2 to 10 percent of the feed water with TDS concentrations as high as 250,000 mg/L.

Figure5.6 Schematic of a Brine Concentrator



Brine concentrators are typically used to process cooling water and concentrate reject from industrial RO plants. The largest brine concentrators can treat about 700 (Mickley, 2001) gallons per minute (gpm), or 1.15 MGD of wastewater. However, most are smaller, typically treating around 300 gpm of wastewater. If needed, brine concentrators can be placed in parallel process lines to treat larger amounts of concentrate. The limiting factor for this process is the cost of power to operate them. Electrical energy consumption can range from 60 to 100 kilowatts per hour (kW/hr) per 1,000 gallons of feed water. Using $.06 per kW/hr as an estimate, the cost ranges from $3,600 to $6,000 per day to process 1 MGD of brine.

The corrosive nature of many wastewater brines require brine concentrators be constructed of high quality materials, such as titanium evaporator tubes and stainless steel vessels.

Brine concentrators are reliable and are not dependent on weather or geographical conditions, but they are very expensive to operate. Brine concentrators are not extremely difficult to operate but do require 2 to 4 man hours of trained personnel per 8 hour shift. In addition, they require laboratory support. It is advantageous to have the operators conduct the basic testing, such as TDS and suspended solids. Maintenance of the units over a year is usually limited to one or two chemical cleanings of the evaporator tubes.

Brine concentrators produce pure water and a very concentrated brine which could then be sent to an evaporation pond or a crystallizer.

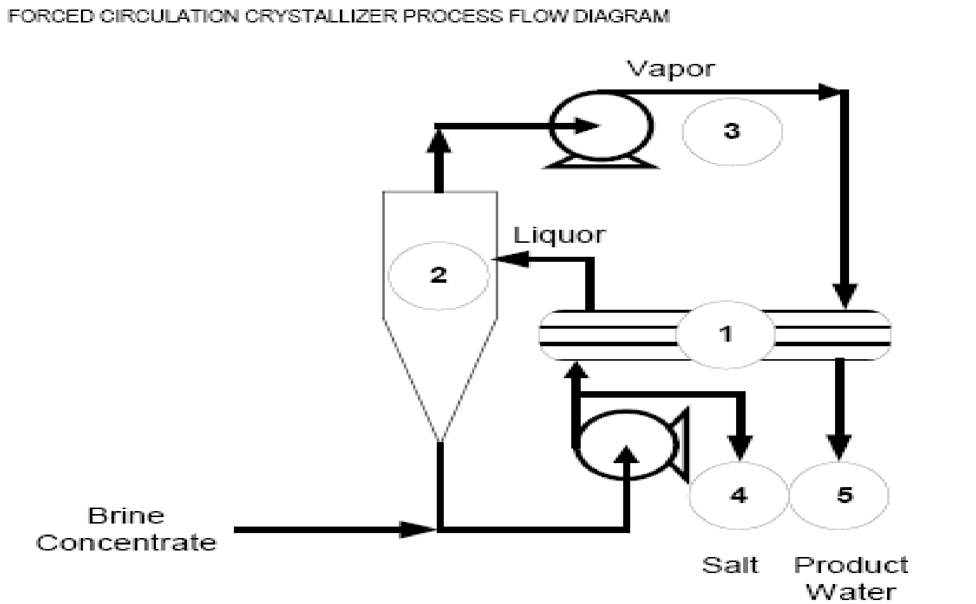
5.4.2 Crystallizers

Crystallizers are mechanical equipment designed to make solid crystals out of concentrated solutions using heat and pressure. Crystallizers have been used successfully for many years for industrial, single-component applications, where only one compound is isolated as a solid from a concentrated brine liquid stream. More recently, the technology has been used to reduce the concentrate from a desalination plant brine concentrator by creating a slurry. In all applications, a mixture of salts in the concentrate stream will reduce the efficiency and the ability of a crystallizer to drop out solids. Industrial applications generally have problems when the liquid concentrate contains low percentages of other liquid compounds that change the thermodynamics of the crystallization process. For example, copper sulfate pentahydrate crystals will not form when the source solution contains appreciable amounts of peroxide from copper etching operations.

In Arizona, power plants with ZLD systems have installed brine concentrators, crystallizers, and centrifuges to eliminate evaporation ponds for cooling tower blowdown. Municipal wastewater that is fed into these ZLD systems has caused problems due to soluble nitrates and organic fines. In addition, the distillate contains total organic carbon (TOC) and ammonia, reducing the reuse potential of solids.

The capacity of most crystallizers ranges from 2 to 50 gpm. Smaller systems are steam-driven. When co-located at a power plant, the limitation of power use for larger sizes is eliminated. The composition of the wastewater feed determines the non-routine maintenance of the system. Routine maintenance is typically done to clean/purge the crystallizer body and discharge port/piping.

Figure 5.7 Schematic Diagram of a Crystallizer



5.4.3 Freeze Crystallization

Freeze crystallization processes remove purified water from solution as frozen crystals. When water that contains impurities, such as salts, is slowly frozen, relatively pure ice crystals will form on the surface and the salts will be concentrated in the remaining unfrozen solution, or brine. Freeze crystallization has been tried since the mid-1950s to separate the salt from sea water in an effort to find a low-energy method of desalination but was never implemented on large scale (Wiegand and Berg, 1980). The initial work used cold ambient temperatures (29 degree Fahrenheit) to freeze sea water that was sprayed into holding ponds. The salt separated from the water reducing the salinity (TDS) from 30,000 mg/l to 10 mg/l.

Freeze crystallization has been used by the industrial sector to recover specific heavy metals from wastewater from such operations as metal finishing, pickling operations, munitions, pharmaceutical, and chemical. The power necessary to reach freezing temperatures make this technology impractical in central Arizona.

5.5 Proprietary Volume-Reducing Technologies

New concentrate management alternatives are developing on a continual basis. Proprietary volume-reducing technologies for the purposes of this paper are technologies that are patented processes which can reduce the volume of concentrate by innovative methods of desalinization.

5.5.1 DewVaporation

DewVaporation is a relatively new technology developed at Arizona State University. DewVaporation is a process that uses air as a carrier-gas to evaporate saline water leaving the salts behind and then condenses the vapor to form pure water. This process operates at atmospheric pressure. Although the technology is still being developed, there are a number of pilot projects currently being conducted. Below is a general summary of how the technology works.

The DewVaporation system consists of a tower with two areas separated by a heat transfer wall (see Figure 5.8). One area is the evaporation side and the other area is the dew formation side. In the example shown in Figure 5.8, the process begins by introducing air into the bottom of the evaporation chamber at a temperature around 70 degrees Fahrenheit. At the same time, saline water is added to the top of the evaporation chamber so the water flows down the heat transfer wall. A fan blows the air up the chamber and evaporates some of the water. At the top of the evaporation tower, the air is further heated by an external source . This raises the temperature to 190.2 degrees Fahrenheit. This heated air moves down the dew formation side of the tower. Since the air on the dew formation side of the heat transfer wall is warmer than that on the evaporation side, heat is lost from the dew formation side to the evaporation side. This heat transfer causes the water on the evaporation side to warm up and allows for easier evaporation of the saline water. In addition, the loss of heat on the dew formation side causes water to condense and form pure water, which is collected at the bottom of the dew formation side of the tower.

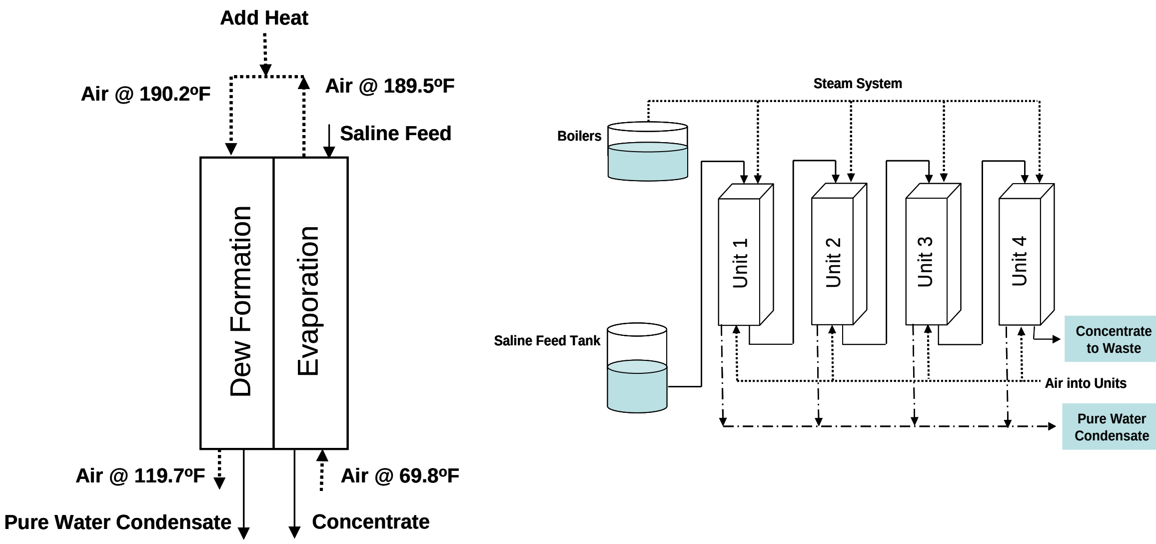
For a group of towers in series, the concentrate from one tower becomes the feed for the next tower. This allows for further concentrating of the liquid and recovering of additional pure water condensate. Theoretically, the concentrated stream can be taken to a crystallized state for landfill application.

At this time, DewVaporation has only been demonstrated for small applications of 100 gpd to 5,000 gpd. Research is being done to prove the technology can maintain 95 percent recovery of the saline feed water. The technology is still being tested and there have been improvements on the tower design and operation of heat sources.

The towers are a patented technology. Other components include a heat source (i.e. boiler, solar panels, etc.), feed pumps for saline solution, piping, holding tanks, and electrical equipment. The majority of the maintenance requirements are related to maintaining the moving parts of pumps, boilers, and electrical equipment.

Figure 5.8 Schematic Diagram of the DewVaporation Process

Individual Unit: *Units in Series:*

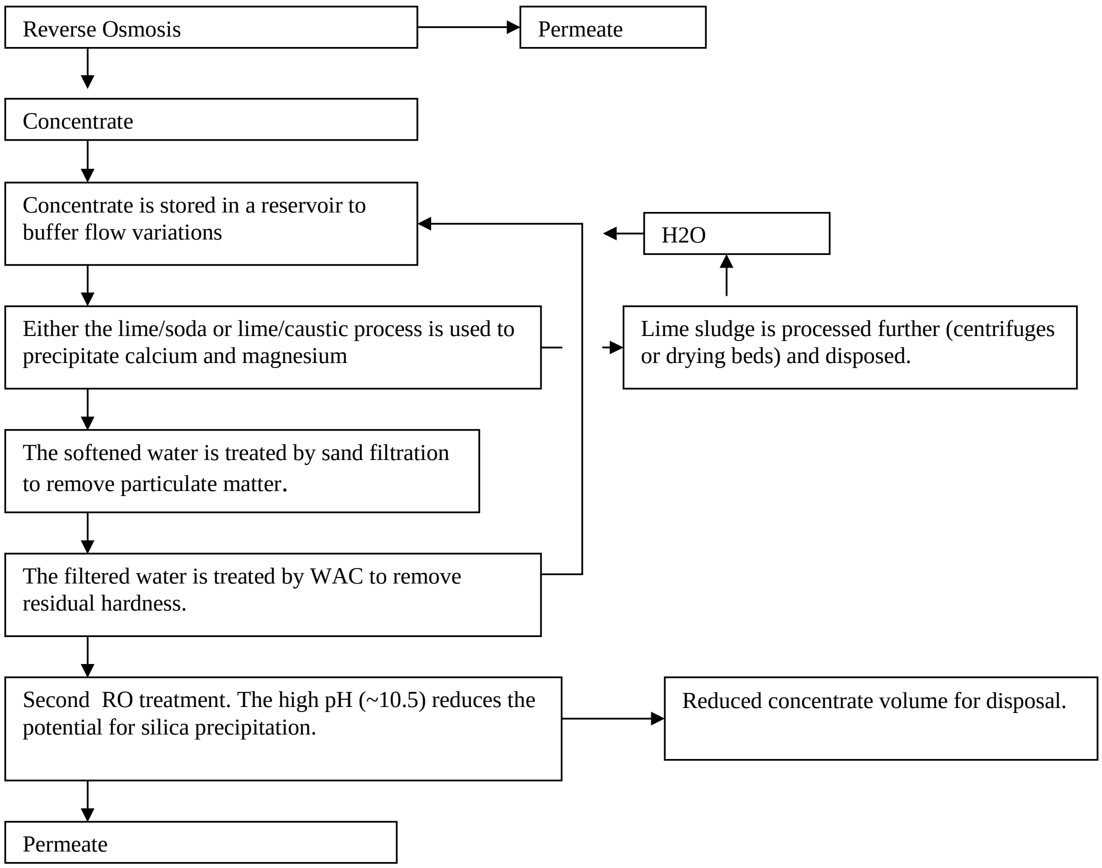


5.5.2 High Efficiency Reverse Osmosis (HERO™)

The internationally patented HERO™ process was originally developed for use in the semiconductor industry. HERO™ was developed to overcome two significant impediments to high-recovery RO: removal of hardness (calcium and magnesium) and silica.

The HERO™ process uses standard RO and chemical processes. The first step is RO desalinization. The permeate is recovered and used but instead of disposing of the concentrate, it is lime-softened to remove the majority of hardness. The addition of lime raises the pH of the water. The lime sludge is then removed and further processed returning any recovered water to be reused. The concentrate is then filtered through a sand filter to remove particulate matter and treated by weak-acid cationic (WAC) exchange to remove residual hardness not removed by the lime softening. The concentrate maintains the high pH produced during the lime-softening process, which prevents silica precipitation during a the subsequent RO treatment of the concentrate. The final step is another RO desalinization process where the permeate is recovered for reuse and the much reduced, much higher TDS concentrate is disposed.

Figure 5.9 Flow Chart of the HERO™ Process



5.5.3 Vibratory Sheer Enhanced Process (VSEP) Membrane System

The vibratory sheer enhanced process, or VSEP, is an ultrafiltration (UF) membrane system that was developed by New Logic Research, Inc. in California. VSEP uses high shear waves on the face of a flat membrane element which produces a high tolerance for colloidal silica, total suspended solids (TSS), and scale-forming components. The shear rate of 150,000 inverse seconds is produced tangentially to the membrane element by torsional oscillation. An alternating current (AC) motor agitates the membrane stack in a resonant spring mass system. The membranes move at an amplitude of 5 to10 degrees and a frequency in the range of 60 hertz (Hz). The membrane stack is lighter and moves with high amplitude. The other mass, the heavier Seismic Mass, moves with smaller amplitude proportional to the ratio of the two masses. This allows the system to resonate without need for vibration isolation pads. Nearly 99 percent of the total energy is converted to shear at the membrane surface, or nine times that achieved with cross-flow systems. The feed slurry in a VSEP system can be extremely viscous (up to 70 percent solids) and still be successfully processed.

Data on this technology indicate treatment capacity usually less then 1 MGD. VSEP is a proven technology within the industrial sector, but has yet to be utilized in the municipal sector. The footprint size could potentially benefit smaller reclamation facilities which have limited space for expansion.

5.5.4 Separation Process Technologies

Geo-Processors Pty Ltd (Geo-Processors) has developed innovative saline water treatment systems for the selective removal of valuable salt products, known as SAL-PROC™ and ROSP (reverse osmosis integrated with SAL-PROC™). In most cases, the technology is applicable as a dual-purpose ZLD and product recovery process. By selectively removing salts, concentrate waste is minimized. Depending on the chemical characteristics of the saline water, the process may involve one or more steps of chemical reaction and evapo-cooling, supplemented by mineral and chemical processing steps. This technology has been piloted in Australia at several locations and the technology could be applied to municipal water supply, agricultural drainage management, salinity control, and various industrial wastewater minimizations.

Saline Effluent to Products CONversion, or SEPCON, facilities are the centerpiece of Geo-Processor's technology innovation. These treatment plants use either SP or ROSP processes to recover valuable products and minimize discharge, and can be fabricated in various sizes and configurations, either fixed or portable, to meet site-specific requirements. Both fixed and portable units have been piloted, with extensive public demonstrations. The trials have ranged from fixed pilot plants with a design capacity of 57 to 350 gpm throughput volume to a trailer-mounted module for multi-site test work.

Saline waters vary in their chemical composition and therefore, produce different product streams. The Separation Process (SP) works by using common chemistry practices and depending on the source water, potentially marketable by-products are produced by the treatment process. Some of these salt products include gypsum, magnesium hydroxide, precipitated calcium carbonate, sodium chloride, and sodium and potassium sulfate in crystalline, slurry, and liquid forms. These compounds are useable or saleable products and are routinely used to offset treatment costs. See Table 5.1.

Figures 5.10 and 5.11 illustrate the ROSP process routes that may be applied to seawater-type effluents for the recovery of various product streams and to achieve ZLD outcomes. As shown in Figure 5.11, sodium chloride salt is only one of the four product streams. Independent product quality tests and market studies have confirmed the suitability of these products for diverse industrial, agricultural, and environmental applications.

Table 5.1 Potential Products Produced by RO or ROSP Treatment Processes

Product from Fresh or Irrigation-quality water	**Agricultural and Other applications**
Gypsum-magnesium hydroxide	Soil conditioners, pH adjustment, and building materials
Magnesium hydroxide	Wastewater treatment, pH buffering and adjustment, and metal production
Fine-grained gypsum	Soil conditioner, fertilization agent, and building materials
Precipitated calcium carbonate	Fine-grained filler and coating agent for paint, plastics, and paper
Sodium chloride (NaCl)	Chemical and industrial grades, food, and livestock
Sodium sulfate (Na_2SO_4)	Basic industrial chemical, detergents, surfactants, and hair care products
Potassium sulfate (KSO_4)	Fertilizer

Most common process is a reducing RO concentrate through the SP process to recover salt and chemical products and minimize effluent discharge, as shown in Figure 5.10. Various process options are possible and depending on water quality, production volumes, and operational requirements, two or more process options may be possible for a single site.

The process equipment for typical operations can be found in the chemical process industry and water/wastewater treatment plants.

Figure 5.10 Flow Chart of ROSP Process

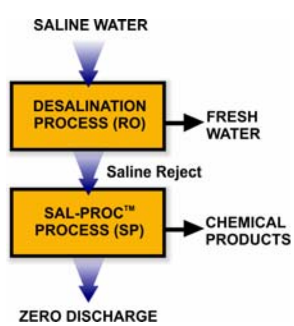
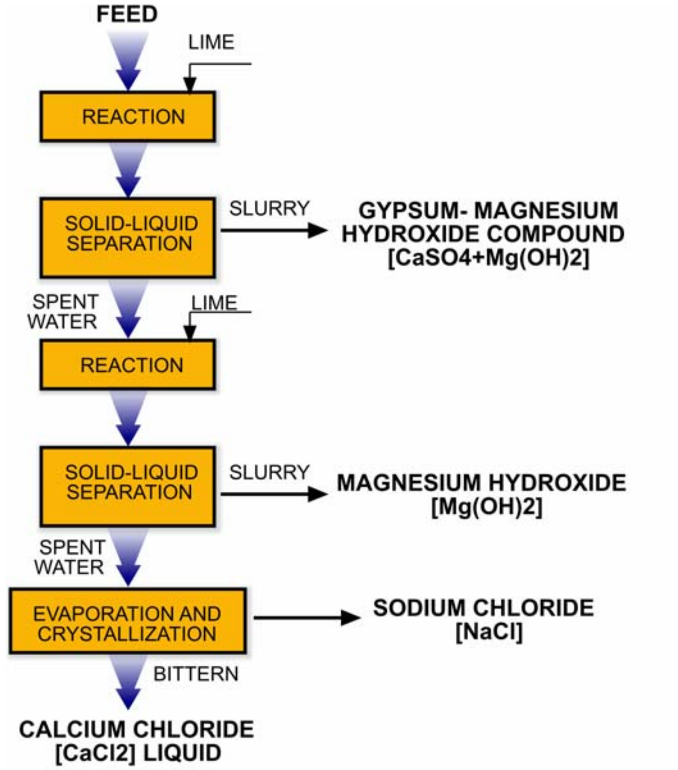


Figure 5.11 Flow Chart of a ZLD Process Route for the Treatment of Seawater-Type Saline Impaired Waters



6.0 EVALUATION AND COST ANALYSIS OF ALTERNATIVES

As part of the evaluation process, the CASS Concentrate Management Subcommittee developed four major categories that were used as screening criteria for determining which concentrate management alternatives are practical for use in central Arizona. The criteria were; Institutional Considerations, Technical and Operational Feasibility, Environmental/Public Acceptability, and Economic/Financial Feasibility. Table 6.1 lists the evaluation criteria. Under each of the major criteria are relevant considerations which are used as definitions for the evaluators.

Table 6.1
Concentrate Management Evaluation Criteria

Institutional Considerations	
	Conformance with federal environmental regulations
	International and Tribal Issues
	Conforms with land uses
	Conformance with state environmental regulations
Technical and Operational Feasibility	
	Project features technically feasible
	Operational flexibility
	Site Access
	Adaptability to changing conditions
	Operational flexibility to changing TDS targets
	Operational flexibility in addressing emerging contaminants
	Treatment compatibility with existing systems
	Reliability of technology
	Capacity of Treatment Considerations
	Efficiency of managing concentrate
	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
	Institutional sensitivity
Economic/Financial Feasibility	
	Land costs
	Project features financially feasible

The members of the Subcommittee applied the criteria against each alternative and determined which alternatives were practicable or not practicable for use in central Arizona. Table 6.2 summarizes the results of that work. The following alternatives were deemed to be practicable: Evaporation ponds, WAIV, Sewer Disposal, Deep Well Injection, Brine Concentrators, DewVaporation, Sal-Proc (Selective Removal), and High Efficiency Reverse Osmosis (HERO).

Table 6.2 SUMMARY OF CONCENTRATE MANAGEMENT ALTERNATIVES

	Concentrate Management Alternatives	**Cost Analysis**	**Reason for No Further Study**
Evaporation Options	Evaporation Ponds	Yes	
	Wind Aided Intensified eVaporation (WAIV)	Yes	
	Solar Ponds	No	Process component, not a solution
	Land Application	No	Limited by plants, land and potential for environmental harm
Transportation Options	Sewer Disposal	Yes	
	Central Arizona Salinity Interceptor (CASI)	No	Cost study previously done by BOR.
	Painted Rock Dam Storage	No	Storage offers no environmental protection and shifts problem to different area.
	Palo Verde Discharge	No	Requires regional efforts not identified in this study
Well - Injection Disposal Options	Deep Well Injection	Yes	
	Storage in salt dome caverns	No	Inadequate storage volume
	Recharge into Poor Quality Aquifer	No	Currently not allowable under Arizona law.
Zero Discharge Options	Brine Concentrators	Yes	
	Crystallizers	No	Process component, not a solution
	Freeze Crystallization	No	Not practical in Arizona.
	Lime Softening	No	Process component, not a solution
Proprietary Volume Reducing Technologies	DewVaporation	Yes	
	Sal-Proc (Selective Removal)	Yes	
	HERO	Yes	
	V-SEP	No	Process component, not a solution

For the alternatives which were determined to be practical by the subcommittee, the major capital and O&M costs were identified. These costs were further broken down to site specific costs and general costs. A series of simple cost models were developed as a tool to estimate the relative costs of each alternative. These cost models are contained on the CD and examples are contained in the Appendix of this report. These models use general capital and operational costs, but not site specific costs.

Costs for concentrate disposal vary depending on location, volume and the alternative selected. In an attempt to compare technologies equally, the cost components of each alternative were identified. Within the review of each alternative, these cost components were classified as being a general cost or a site specific cost. Site specific costs have been identified, but not included as part of the costing calculations because the degree of variation is significant depending on where the alternative is used. Data for the models were compiled from manufacturers' quotes, other concentrate management studies and assumptions developed by CASS based on technical expertise. The cost components are defined as follows:

Capital Costs – Costs associated with constructing a tangible operating facility:

- Equipment – cost associated the actual physical apparatus
- Instrumentation and controls – devices used to control and monitor flow, pressure, water levels, temperature, etc.
- Electrical Power Distribution/Supply – costs associated with getting power to the concentrate management facility
- Structural piping-costs for the structures (buildings, tanks, supports, etc.) to support the specific technology
- Mechanical infrastructure – costs associated with conveying brine to the equipment (pumps and piping)
- Patent Cost – the cost for paying for a licensed technology
- Site Development – The cost for developing the land to accommodate new facility
- Land Cost – cost to purchase land required for the facility.
- Right-of-Way – cost to acquire the right to pass over property owned by another party.

Operating and Maintenance Costs – Costs associated with operating equipment at the facilities:

- Maintenance/Labor Costs – Staffing costs required for operation and maintenance of the equipment
- Specialized Operator Costs – Staffing costs associated with specialized skills required to maintain the technology
- Power/Operating Costs –Costs required to operate the equipment
- Hauling and Disposal Costs – Costs to transport and dispose of solid wastes (i.e salt crystals or salt slurry)
- Waste/Water Quality Testing – Costs associated testing water quality prior to disposal and for monitoring potential hazard levels in the water
- Chemicals – The cost of the chemicals required for the treatment process

Factors Influencing Costs – Items of consideration that may increase or decrease the value of the alternative

- Capacity – Volume of concentrate to be treated in the treatment alternative
- Construction Materials – Due to high TDS concentrations, special material may be required. (i.e. high grade Stainless Steel versus Carbon Steel)
- Value in Water Recovered or Lost – Some alternatives capture water that would otherwise be lost as waste.
- Value of Saleable Chemical Products – Costs associated with selling a final product that results from the treatment process
- Type of Heat Source - Costs associated with using a particular type of heat during the treatment process

The Subcommittee also evaluated the alternatives under different flow regimes. For this evaluation, the hypothetical quantities of concentrate to be disposed on a daily basis are: 0.25 MGD, 1 MGD, 3 MGD and 5 MGD. Each alternative was rated on how well they could dispose of the various quantities of concentrate. The results of this evaluation were put into tables with simple High (H), Medium (M), or Low (L) ratings for suitability for each alternative.

6.1.1 Evaporation Ponds

Evaporation ponds are a well developed technology for disposing of concentrate. The costs associated with evaporation pond construction are mostly driven by the cost of land and the cost of liners that are needed to protect the aquifers beneath the ponds. Table 6.3 identifies the major cost components of this concentrate management alternative.

Table 6.3 EVAPORATION PONDS

CAPITAL COSTS		*OPERATING AND MAINTENANCE COSTS*		*Factors Influencing Costs*
General	*Site Specific*	*General*	*Site Specific*	
Area/Depth of the Pond	Cost of Land	Maintenance/Labor Costs	Hauling and Disposal Costs for Industrial Waste	Evaporation Rate (Winter vs. Summer Conditions)
Height of the dike	Soil Conditions			Quantity of Water
Liner Thickness				Value of Water Lost
Cost for Excavation/Site Development				
Pumps and Piping				

The evaporation rate of the region plays an important role in the size of an evaporation pond, which is influenced by the average rainfall per year. For the Phoenix/Tucson area, evaporation ponds work well because of the hot, dry climate. The evaporation rate will vary seasonally. For example, summer evaporation rates are significantly higher than winter evaporation rates and during rainy seasons the net evaporation rate is reduced. Evaporation ponds must be sized to account for seasonal variations.

Additional capital investment costs may include the costs for environmental protection of the potable aquifer. Other environmental regulations require a double liner and/or an impervious liner of clay or synthetic membranes to protect surrounding potable water aquifers and will significantly impact the cost of the ponds. Groundwater monitoring well(s) may also be required for the site to protect/detect leakage from the evaporation ponds. Construction of fencing and the building of roadways is also part of the initial capital investment for an evaporation pond facility and are in part dependant on the capacity/size of the ponds.

Operating and maintenance costs for this technology are relatively low. Periodic dredging of the pond and disposing of the accumulated salts is necessary.

Several communities/entities in Arizona are using evaporation ponds for disposal of concentrate. Evaporation ponds work well for small-scale projects (0.25 MGD or less) especially if located in areas with inexpensive land. Large evaporation ponds located in urban areas where land is expensive do not make economic sense. Table 6.4 is a summary of the Subcommittee's evaluation of evaporation ponds. Some of the more subtle deficiencies with evaporation ponds are loss of the physical water and the loss of the use of the land which could be used for higher purposes.

Table 6.4 Evaporation Ponds Summary Evaluation

Evaporation Ponds	0.25 MGD	1 MGD	3 MGD	5 MGD
Institutional Considerations	H	H	H	H
Technical and Operational Feasibility	H	H	H	H
Environmental/Public Acceptability	H	M	L	L
Economic/Financial Feasibility	H	M	L	L

6.1.2 Wind-Aided Intensified eVaporation (WAIV)

Wind Aided Intensified eVaporation (WAIV) is a relatively new technology that is used in conjunction with Evaporation Ponds to reduce the overall surface area of the ponds. Table 6.5 below summarizes some of the cost components associated with the WAIV technology.

Table 6.5 WAIV – WIND AIDED INTENSIFIED EVAPORATION

CAPITAL COSTS		*OPERATING AND MAINTENANCE COSTS*		*Factors Influencing Costs*
General	*Site Specific*	*General*	*Site Specific*	
Area/Depth of the Pond	Cost of Land	Maintenance/Labor Costs	Hauling and Disposal Costs for Industrial Waste	Evaporation Rate
Height of the dike			Power/Operating Costs	Quantity of Water
Liner Thickness				Value of Water Lost
Cost for Excavation/Site Development				
Pumps and Piping				

WAIV technology is primarily being used in Israel and a cost model was not developed due to insufficient costing information. WAIV technology utilizes evaporation ponds for storage; but has the ability to evaporate water faster than the traditional evaporation pond because the netting allows for increased evaporation. Therefore, size of the evaporation pond can be reduced, which in turn, reduces the capital costs associated with purchasing land. Although land costs may be reduced, there are additional capital costs associated with this technology, which include piping, pumps, material used to collect the salts, and associated electrical equipment required. Additional operation and maintenance costs include hauling and disposal costs and a trained operator for the facility.

Because WAIV technology is currently being pilot tested a complete evaluation could not be completed. One problem noted was that the nozzles which drip concentrate onto the netting would tend to "salt" up. The hot and dry climate of the Phoenix and Tucson area are ideal conditions for WAIV. Further study is required to understand if WAIV is a cost effective alternative for central Arizona.

Table 6.6 WAIV Summary Evaluation

WAIV	0.25 MGD	1 MGD	3 MGD	5 MGD
Institutional Considerations	H	H	H	H
Technical and Operational Feasibility	*	*	*	*
Environmental/Public Acceptability	H	H	H	H
Economic/Financial Feasibility	*	*	*	*

6.1.3 Sewer Disposal

Sewer disposal of concentrate is currently being used in several cities in central Arizona. Sewer disposal is the least expensive and least technical method of disposing concentrate, but its limitations must be considered. A high volume of concentrate delivered to the sewer can impact the receiving wastewater treatment plant either hydraulically or operationally or both. Smaller WWTP's are more susceptible to high flows of concentrate, while the larger regional WWTP's can usually accept the additional hydraulic flow and the TDS load.

The cost of the WWTP expansion, if necessary to hydraulically accommodate the additional flow, needs to be included in the costs estimate to see the true cost of sewer disposal of concentrate. Expanding a WWTP to accommodate the additional flow is costly.

Table 6.7 below illustrates the major cost components of the sewer disposal option.

Table 6.7 SEWER DISPOSAL

SEWER DISPOSAL				
CAPITAL COSTS		*OPERATING AND MAINTENANCE COSTS*		*Factors Influencing Costs*
General	*Site Specific*	*General*	*Site Specific*	
Pipe Costs, including trenching, pipe and installation	Distance between the desalting plant and City's sewer system		Sewer Disposal Rates	Value of Water Recovered (if the wastewater treatment plant effluent is not degraded by TDS concentrations)
	Cost of WWTP Upgrades to accommodate flow			Alternative Treatment for high TDS flow (if TDS concentration is too high, the wastewater treatment may not accept the flow)
				Loss of Water Resource (if TDS concentrations are too high, the WWTP effluent may not be reused)
				Type of Pipe

The sewer disposal alternative may not be feasible if TDS levels inhibit the WWTP process. WWTP process inhibition can occur when TDS concentrations begin to reach 3,000 mg/L. Other environmental concerns could be toxicity test failure because of ion imbalances or if TDS concentration is listed on the National Pollutant Disposal Elimination System (NPDES) permits.

Another disadvantage of the sewer disposal option is that it has potential to degrade the value of the WWTP effluent for reuse. If the TDS concentration is too high, it maybe unusable for particular uses (i.e. golf course turf irrigation).

Table 6.8 Sewer Disposal Summary Evaluation

Sewer Disposal	0.25 MGD	1 MGD	3 MGD	5 MGD
Institutional Considerations	H	M	L	L
Technical and Operational Feasibility	H	H	H	H
Environmental/Public Acceptability	H	M	L	L
Economic/Financial Feasibility	H	H	H	H

6.1.4 Deep Well Injection

Deep well injection is a commonly used disposal method for "produced water" from oil fields and has also been used to dispose of brine concentrate generated from RO facilities. Deep well injection takes highly concentrated brine and puts it into the ground isolated from any potable aquifer. It is dependent on the geology of the area and may not be feasible in areas where the depth to bedrock is shallow. Table 6.9 identifies the major cost components of the deep well injection alternative.

Table 6.9 DEEP WELL INJECTION

DEEP WELL INJECTION				
CAPITAL COSTS		*OPERATING AND MAINTENANCE COSTS*		*Factors Influencing Costs*
General	*Site Specific*	*General*	*Site Specific*	
Pumping Equipment	Electrical Power Distribution/ Supply	Maintenance/Labor Costs	Power/Operating Costs	Geologically Feasible Areas
Instrumentation and Control	Size of Well (Diameter, Depth and Construction)			Capacity – Can't quantify flow acceptance capacity until well is drilled and outfitted.
Piping and Mechanical Infrastructure	Permitting			Well construction costs are highly dependant on depth
Well construction costs (see discussion below)				

Deep well injection is a viable concentrate management alternative in some states when a suitable geologic formation is available for disposal. Currently, no suitable formations for deep well injection in south/central Arizona have been identified.

Comment: Has anyone ever looked for one? Its not only the lack of available "suitable aquifers" it's the permitting issues and public perception.

Table 6.10 Deep Well Injection Summary Evaluation

Deep Well Injection	0.25 MGD	1 MGD	3 MGD	5 MGD
Institutional Considerations	M	M	M	M
Technical and Operational Feasibility	L	L	L	L
Environmental/Public Acceptability	H	H	H	H
Economic/Financial Feasibility	L	L	L	L

6.1.5 Brine Concentrators

Brine concentrators are a technology used to pull more of the water out of brine thereby reducing the volume of brine that needs to be disposed and also increasing the amount of water available for reuse. Primarily they are used in power plants where abundant cheap energy is available. The biggest costs involved with operating brine concentrators is energy. Table 6.11 identifies the cost components of brine concentrators.

Table 6.11 BRINE CONCENTRATORS

BRINE CONCENTRATORS				
CAPITAL COSTS		*OPERATING AND MAINTENANCE COSTS*		*Factors Influencing Costs*
General	*Site Specific*	*General*	*Site Specific*	
Equipment	Electrical Power Distribution/ Supply	Maintenance Labor Costs	Power/Operating Costs	Capacity
Instrumentation and Control	Structural, piping and mechanical infrastructure	Specialized Operator Costs	Hauling and Disposal Costs for Industrial Waste	Materials of Construction
			Constituent Testing Costs on Disposed Salts/Concentrate	Value of Recovered Water

Brine concentrators are currently being used at several power generating stations in Arizona. This disposal alternative rates high for Institutional Considerations because the process is relatively simple to permit and implement. It also rates high for Environmental/Public Acceptability because it recovers water from the concentrate for reuse and reduces the concentrate disposal volumes. The Technical and Operational Feasibility of this alternative was rated at medium because it requires highly specialized operators and requires construction with special materials because of scaling issues. Brine concentrators require huge energy inputs for operation. The cost of energy and equipment for running a brine concentrator rates low for Economic/Financial Feasibility and may also rate lower if not built where cheap electricity is available.

Table 6.12 Brine Concentrators Summary Evaluation

Brine Concentrators	0.25 MGD	1 MGD	3 MGD	5 MGD
Institutional Considerations	H	H	H	H
Technical and Operational Feasibility	M	M	M	M
Environmental/Public Acceptability	H	H	H	H
Economic/Financial Feasibility	L	L	L	L

6.1.6 DewVaporation

DewVaporation is a developing concentrate management technology that is being piloted at the 23rd Avenue Wastewater Treatment Plant in Phoenix, Arizona. Further research is being conducted by Dr. James Beckman at Arizona State University. Table 6.13 identifies the cost components of the DewVaporation system.

Table 6.13 DEW-VAPORATION

CAPITAL COSTS		*OPERATING AND MAINTENANCE COSTS*		*Factors Influencing Costs*
General	*Site Specific*	*General*	*Site Specific*	
Equipment	Electrical Power Distribution/ Supply	Maintenance/Labor Costs	Power/Operating Costs	Type of Heat Source
Instrumentation and Control			Heat Source	Capacity
Piping and Mechanical Infrastructure			Hauling and Disposal Costs for Industrial Waste	Value of Water Recovered

Dr. James Beckman of Arizona State University has provided some costing for two units of different capacity. According to Dr. Beckman, the capital costs for a 1,000 gallon per day plant will range from approximately $1,000 to $2,000 and the cost for a 1 million gallon per day plant will range from $720,000 to $1,100,000. Capital costs are influenced by the number of towers required, the number of pumps and fans required, the amount of piping needed, size of holding tanks needed, and the level of electrical and control components desired.

Estimates of the operations and maintenance costs were also provided by Dr. Beckman. For the 1000 gallon per day plant he estimates that the costs may range from $1.50 to $4.00 per 1000 gallons and for the 1 million gallon per day facility, the costs may range from $0.91 to $3.44 per 1000 gallons. The operating cost largely depends on the heat source and the number and size of pumps and fans.   Hauling and disposal costs for the liquid waste or dry salt cake waste also need to be considered when using this alternative.

Since the DewVaporation technology is currently being pilot tested, the Technical and Operational Feasibility criteria of this alternative could not be evaluated. The Institutional Considerations rated high because this alternative would probably not require significant permitting efforts. The Environmental/Public Acceptability of this alternative also ranks high because this alternative attempts to reduce the size of evaporation ponds.

Comment: There was no mention in Section 6.5.1 of needing an evaporation pond with this technology….according to Section 6.5.1 it consists of a tower.

Table 6.14 DewVaporation Summary Evaluation

Dewvaporation	0.25 MGD	1 MGD	3 MGD	5 MGD
Institutional Considerations	H	H	H	H
Technical and Operational Feasibility	*	*	*	*
Environmental/Public Acceptability	H	H	H	H
Economic/Financial Feasibility	H	M	L	L

6.1.7 SAL-PROC

Sal-Proc is a unique and proprietary treatment option that extracts dissolved minerals from concentrate and produces valuable products that can be used in other industries. This technology is owned by Geo-Processors. Table 6.15 identifies the major cost components of the Sal-Proc system.

Table 6.15 SAL-PROC

CAPITAL COSTS		*OPERATING AND MAINTENANCE COSTS*		*Factors Influencing Costs*
General	*Site Specific*	*General*	*Site Specific*	
Equipment	Electrical Power Distribution/ Supply	Maintenance/Labor Costs	Power/Operating Costs	Value of Water Recovered
Instrumentation and Control		Chemical Usage		Potential Value of saleable chemical products
Mechanical Infrastructure (Pumps, Pipes, Mixers, Tanks)				Water Quality
Patents				Process Routes

Sal-Proc is a unique technology with respect to cost-benefit analysis. This is because the capital costs and operating costs can potentially be recovered (or substantially off-set) by the value of the saleable products produced by the treatment process. Potential revenue obtained from this process differentiates this technology from other technologies from a cost comparison standpoint.

The costs for this technology vary depending on the desired objectives. These objectives may include sustainable management of saline impaired waters, operational improvement, smaller footprint for physical operation, recovery of products, or a combination thereof. There are many different process routes which may be used depending on the minerals/salts in the concentrate, how concentrated those minerals/salts are, and the value of the products that can be recovered.

Because the SAL-PROC technology can be used as zero liquid discharge system, a rating of high was given for Institutional Considerations and Environmental/Public Acceptability. Minimal, if any, permitting efforts are required, therefore Institutional Considerations were rated high for all concentrate volumes. The Environmental/Public Acceptability is also high for this alternative because the SAL-PROC technology turns waste into valued products. The water quality of the concentrate is a major factor on the technical feasibility of this alternative. Therefore, a rating for Technical and Operational Feasibility would vary on location and source water to be treated. The Economic/Financial Feasibility of the SAL-PROC™ technology potentially improves as concentrate flow increases because of the increase in product recovery associated with an increase in concentrate flow.

Table 6.16 SAL-PROC Summary Evaluation

SAL-PROC	0.25 MGD	1 MGD	3 MGD	5 MGD
Institutional Considerations	H	H	H	H
Technical and Operational Feasibility	*	*	*	*
Environmental/Public Acceptability	H	H	H	H
Economic/Financial Feasibility	L	M	H	H

6.1.8 High Efficiency Reverse Osmosis (HERO)™

High Efficiency Reverse Osmosis (HERO)™ is a proprietary system developed by Aqua-Tech that uses chemical processes to pre-treat concentrate before it is processed through a second RO unit. It is a developing technology that has only been used for small-scale flows. Table 6.17 lists the major costs and the factors that influence the costs.

Table 6.17 HERO™ – HIGH EFFICIENCY REVERSE OSMOSIS

CAPITAL COSTS		*OPERATING AND MAINTENANCE COSTS*		*Factors Influencing Costs*
General	*Site Specific*	*General*	*Site Specific*	
Equipment	Electrical Power Distribution/ Supply	Maintenance/Labor Costs	Power/Operating Costs	Capacity
Instrumentation and Control	Patents	Chemicals	Hauling and Disposal Costs for Industrial Waste	Value of Water Recovered
Piping and Mechanical Infrastructure				

The subcommittee rated the HERO™ process high for Institutional Considerations because the technical processes used are common permitting processes of existing water treatment plants and should be relatively easy to obtain. Environmental/Public Acceptability also rates highly because this alternative recovers the water resources. Technical and Operational Feasibility rates low because although the individual processes within the HERO™ have been industry-tested, there is limited experience with the combining process trains for concentrate treatment. This alternative also requires highly specialized personnel to operate the system.

Comment: The HERO system doesn't use "common permitting processes". The subject or object need to be revised in this sentence to agree.

Table 6.18 HERO™ Summary Evaluation

HERO	0.25 MGD	1 MGD	3 MGD	5 MGD
Institutional Considerations	H	H	H	H
Technical and Operational Feasibility	L	M	M	M
Environmental/Public Acceptability	H	H	H	H
Economic/Financial Feasibility	L	L	M	M

7.0 Conclusions

Table 7.1 summarizes the concentrate management alternatives studied by the Subcommittee. The evaluation and rating exercise conducted by the Subcommittee indicates that traditional strategies, such as evaporation ponds and sewer disposal, will continue to meet the needs of smaller concentrate generators. Technologies to handle large flows of concentrate are in the development stage, a significant amount of testing is still required to prove they solve the concentrate disposal problem. Until a concentrate management alternative is available to deal with large flows, large-scale desalination facilities may be limited.

Table 7.1 Concentrate Management Alternative Ranking at Varying Flows

Concentrate Management Alternative	0.25 MGD	1 MGD	3 MGD	5 MGD
Evaporation Ponds	H	M-H	L	L
WAIV[1]	*	*	*	*
Sewer Disposal	H	M-H	L	L
Deep Well Injection	L	L	L	L
Brine Concentrators	L	L	L	L
DewVaporation[2]	H	M-H	L	L
Sal-Proc[3]	L	M	H	H
HERO[4]	L	L	M-H	M-H

[1]Insufficient data to evaluate alternative fully.

[2]Ranking based on all criteria except Technical and Operational Feasibility
[3]Alternative is heavily dependent on water quality. Ranking based on all criteria except Technical and Operational Feasibility

[4]Alternative heavily dependent on water quality.

The Concentrate Management Subcommittee recommends continued research on developing technologies which could help in resolving concentrate management issues.

The subcommittee also recommends that a regional solution to managing concentrate is in the best interest of Arizona. Salt accumulation in the Phoenix metropolitan area is over one million tons a year. While this accumulation of salts is not an immediate threat to the sustainability of the live style of Arizonians, in the long term it is necessary to remove the accumulating salts from the water cycle. The best way to do that is to have economical and environmentally sound methods of concentrate disposal. Presently, in central Arizona this is not being done. Many places where salts are being removed from the water cycle, like the RO facilities at the Scottsdale Water Campus, the City of Goodyear's well head treatment site, or the many beverage bottling plants, the salts are removed from the product water and then put right back into the water cycle by disposing of the concentrate into the sewer system. The salts are transported to a WWTP where they eventually end up in the groundwater when the effluent is recharged, released to a river or used for irrigation. Further work is necessary to find regional solutions to permanently remove the salts from the water cycle. Removing the salts from the water cycle can lead to Arizona having long term sustainability.

Salinity and concentrate management studies, similar to CASS, are being conducted throughout the United States, including California and Texas. Arizona will benefit by its continued involvement in regional, national and international salinity forums to listen and discuss lessons learned through these other studies.

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