Central Arizona Salinity Study

Strategic Alternatives for Brine Management in the Valley of the Sun

January 2010

Thomas K Poulson, PE
Concentrate Management Sub-Committee
Central Arizona Salinity Study
Phoenix, Arizona

Strategic Alternatives for Brine Management in the Valley of the Sun

Abstract:
In the Phoenix metropolitan area advanced water treatment, specifically reverse osmosis (RO), is being used now and increasingly more in the future to supplement potable water supplies. Large amounts of potable water will be produced but also large amounts of waste in the form of brine will be created. If there is not a sustainable method to manage the brine then possibly those future RO facilities will not be constructed.

In the Phoenix metropolitan area the two most common methods of brine management are evaporation ponds and sewer disposal. Neither method is sustainable as larger quantities of brine are generated. Large evaporation ponds are extremely expensive and brine disposal into sewers diminishes the usable hydraulic capacity at the receiving waste water treatment plant and is detrimental to the valuable effluent being produced there.

A logical next step in the planning process would be seek a regional solution and move the brine out of the urban environment to where land is cheaper, power is available and economies of scale can be implemented to seek a common solution. Regional solutions for brine management must be cost effective, energy efficient, environmentally friendly and implementable. This paper examines, at a planning level, six possible alternatives for a regional brine management solution.

A brine management solution for the Phoenix metropolitan area can not be devised using a little bit of economic mathematics, planning exercises and literature research. But it can show what won't work either because it's too expensive or too energy dependent or maybe not implementable. Alternatives such as brine concentrators use way too much energy; regional evaporation ponds are too expensive; and deep well injection needs special geology not found in central Arizona.

A system of brine management techniques linked together such as: chemical precipitation, secondary RO, Vibratory Shear Enhanced Processes (VSEP) and final disposal in a smaller evaporation pond could be an effective Zero Liquid Discharge (ZLD) solution. High technology solutions can recover a good portion of the water from the brine.

The opposite approach is using low technology, such as a wetland to remove contaminants and heavy metals from the brine, blend the brine with effluent and then surface discharging into the Gila River. The brine/effluent mixture would be lower in TDS and be of better quality water than the Gila River. This solution supplies a continuous source of water to the Gila River while other pressures on the River tend to dry it up. While high tech alternatives consume energy this alternative creates habitat to consume green house gasses.

Constructing a pipeline to Yuma to discharge the Valley's brine into the ocean requires cooperation at the local, State, Federal and international level, but it may be the most environmentally friendly solution.

Introduction

Reverse osmosis is a proven technology which can produce potable water from sea water, brackish sources or reclaimed water. Some Arizona communities use RO to produce potable water from brackish water now. In the future, more communities will be using RO to supplement their potable water supplies or to improve the quality of reclaimed water. Brine management is the foil which is keeping some communities from fully utilizing their brackish water sources or reclaimed water.

While the cost of RO produced water has continued to drop in the past decades, brine disposal can easily double the cost of constructing and operating an RO facility. The challenges associated with brine management are exacerbated for inland RO facilities where there is not an ocean for relatively economical brine disposal.

Central Arizona has many RO facilities in the conceptual, planning, design or construction stage. The current economic slow down has pushed some of these projects farther into the future but most of them will eventually be constructed. The Central Arizona Salinity Study (CASS) estimates that, in central Arizona, within the next 25 years nearly 300 million gallons a day (mgd) of potable water will be produced from brackish water sources. However, with that pure clean water comes a by product, a brine, which has very limited use and is difficult to manage.

By the year 2020, the cities of Phoenix, Scottsdale and Goodyear alone may be producing 52 mgd of potable water through RO processes and as a result produce 7.8 mgd of brine. And by the year 2035, these cities may produce over 200 mgd of potable water using RO and 30 mgd of brine. This is an enormous amount of brine to manage. Table 1 shows the RO facilities and size used for this paper. Only the Bullard Water Campus and the Scottsdale Water Campus are operating, the other facilities may or may not be constructed.

RO facilities considered in Strategic Alternatives paper (mgd)

Location	2010		2020		2035	
	Size Plant	Concentrate	Size Plant	Concentrate	Size Plant	Concentrate
Bullard Water Campus	3.50	0.53	4.00	0.60	4.00	0.60
Scottsdale Water Campus	24.00	3.60	24.00	3.60	24.00	3.60
Cave Creek RP	0.00	0.00	13.00	1.95	20.00	3.00
Rainbow Valley RO	0.00	0.00	5.00	0.75	60.00	9.00
Western Canal Well Field	0.00	0.00	6.00	0.90	6.00	0.90
Western Canal WTF	0.00	0.00	0.00	0.00	60.00	9.00
Water Market (91st WWTP)	0.00	0.00	0.00	0.00	30.00	4.50
		4.13		7.80		30.60

Table 1

Figure 1 shows the location of the RO Facilities operating and contemplated which would produce the quantity of brine used for this paper.

Reverse Osmosis Facilities used for Strategic Alternatives Analysis

Note: Facilities are in concept, planning, design, construction or operation

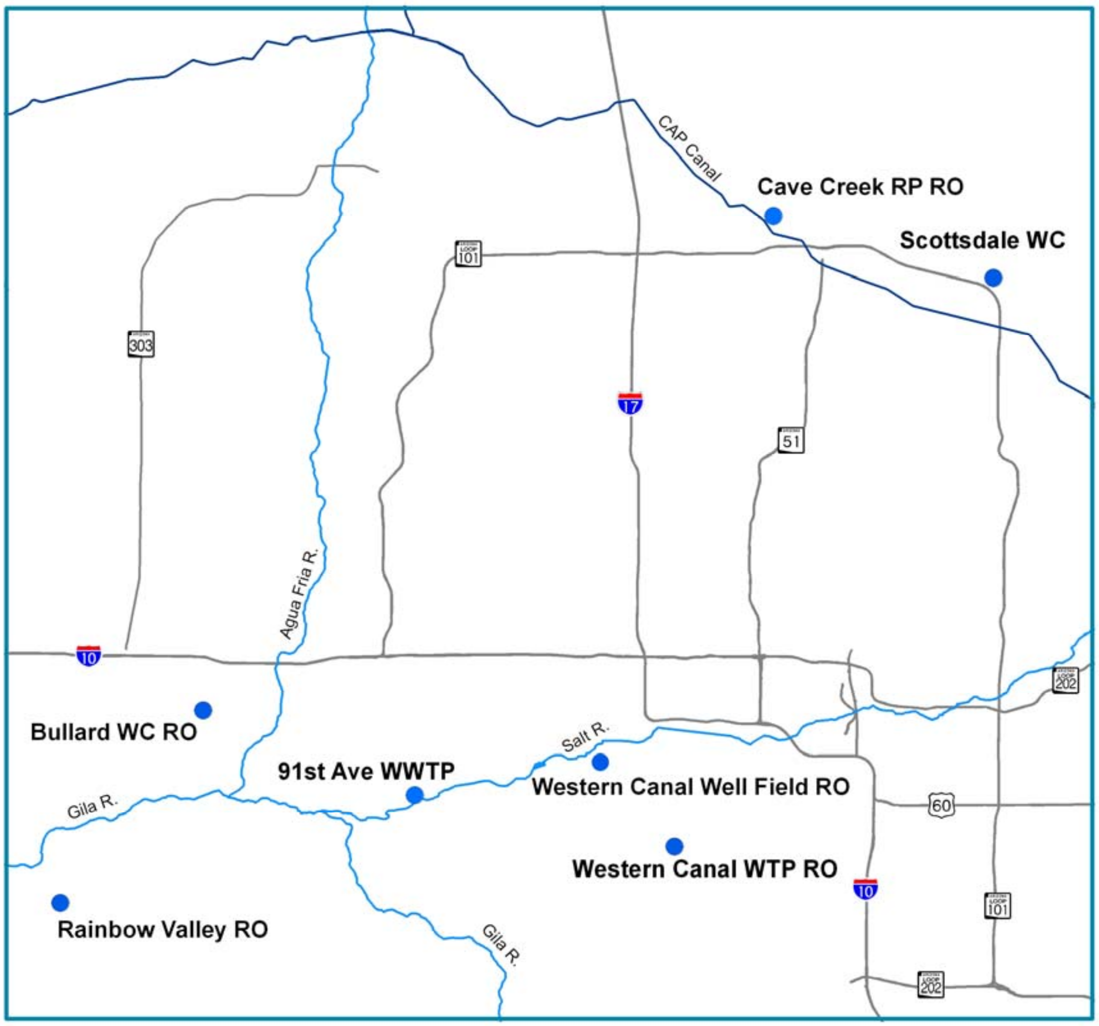

Figure 1

Sewer discharge is the number one method of brine disposal in the Phoenix metropolitan area currently and evaporation ponds are the next most popular method. The quantities of brine which will be produced in the future almost certainly preclude these methods of brine disposal. Ten square miles of valuable real estate would be needed to evaporate 30 mgd of brine and if those quantities of brine were discharged into the sewer the regional wastewater treatment plants would have unacceptable rises in the salinity concentration in the effluent. Clearly, if a portion of the potable water needs are to be met using RO, a sustainable solution to brine management needs to be discovered.

Methods
Six regional brine management alternatives were developed through brain storming sessions during CASS meetings. These alternatives were examined for cost, energy consumption, environmental acceptability and intangibles.

The main tool used to compare the alternatives was cost, both capital and operational. Some of the design/cost analysis tools (models) developed in the CASS Phase II report were used to calculate the costs. All the costs for each of the alternatives were developed using the same methods and tools so "apples can be compared to apples." The costs were calculated at a "planning level" and are accurate enough for comparison of the alternatives.

Energy consumption of the alternatives was also examined. Only the major energy consumption components of the alternatives were analyzed; such things as large pumps, brine concentrators, RO units, etc. were accounted for in the calculations. Energy consumption could be higher by possible 5-15% for incidental energy use such as lighting, air conditioning, small pumps, etc. which were not accounted for in the calculations. Although, for comparison purposes, it would seem they all would have about the same incidental energy use.

Another, criterion used was: How well does the alternative remove the salts from the local environment and/or return the salts to the ocean where they belong? This is a very narrow view of the environment but it does focus the discussion on the salts and removing the salts permanently from the local water cycle. Other issues of environmental concern are addressed in the discussion portion of this paper if they were relevant.

Each of the alternatives has unique factors which could make them very exciting or possibly make them very difficult to implement. These factors, by definition, are not easy to compare but by discussing some of the unique factors of each alternative they shed light on the overall benefit or problems of a given alternative.

This white paper uses the confluence of the Gila and Agua Fria Rivers as the beginning point for the cost calculations for all the Alternatives. The additional costs of getting the brine from where it is produced to that location have been calculated. Appendix B captures the costs of transporting the brine from the various advanced water treatment facilities to the collection point where the cost calculations for the alternatives begin.

<u>Alternative 1 - Pipe line to Yuma</u>
Most (70%) of the salt accumulating in the Phoenix metropolitan area comes from the Salt River and the Colorado River via the CAP. The salts were bound for the ocean before the water was diverted for agricultural and municipal uses. With the water, come the salts. The best solution, environmentally, would be to have the salts continue their journey to the ocean. The pipeline to Yuma alternative is a solution which transports the salts out of the local environment. A pipeline from the Phoenix metropolitan area to

Yuma would be approximately 174 miles in length and would be down gradient almost the entire length. This is a low technology simple solution.

Once the brine was delivered to Yuma, a couple of environmentally beneficial options are possible. One option would be to release it down the Santa Clara Slough to the Cienega de Santa Clara. The Ciénega de Santa Clara is an open water wetland that covers more than 40,000 acres. The Ciénega is by far the largest wetland in the Colorado River delta, and functions as an essential component of the ecosystem. This option would insure a constant source of water to the Cienega.

A second option would be to build a pipeline to the dying Salton Sea and use the relatively low TDS brine (4000-8000 mg/L) to “freshen up” the highly saline Salton Sea (40,000 mg/L). The Salton Sea is one of the few remaining stopovers for migrating birds in southern California. Millions of dollars have been spent trying to figure out how to save the Salton Sea, the pipeline to Yuma with this option could be the solution.

Alternative 2 - Pipe line to Evaporative Ponds in Desert

Evaporation ponds are a low tech, low energy, proven solution to brine management. The biggest drawback for the technology is the cost of land in an urban environment. Not only does one pay for high land prices but there are future tax revenues that are lost if this land could otherwise be developed into commercial, industrial or residential uses.

This strategy bypasses that problem by constructing a pipeline to transport brine out of the Phoenix metropolitan area south to a series of very large evaporation ponds east of Gila Bend. The evaporation ponds would be constructed in open desert areas where land prices are much lower and where development would not take place for many years.

Alternative 3 - Brine Concentrator/Evaporation Ponds

This strategy envisions building a pipeline, approximately 28 miles in length, from the Phoenix metropolitan area to near the Palo Verde Nuclear Power Plant. Enough land would be secured to construct a brine concentrator facility and evaporation pond.

While the previous two strategies discard the water with the salts, the brine concentrator/evaporation ponds alternative allows the recovery of additional water from the brine. The brine concentrator extracts water using thermal energy. The remaining brine would be evaporated in a pond. Approximately, 94% of the water would be recovered from the brine using brine concentrators leaving 6% of the brine to be evaporated. The size of an evaporation pond can be reduced by a factor of 16 by processing the brine through the brine concentrator.

But brine concentrators use enormous amounts of energy and are most commonly found at power plants processing blow down water and using “inside the wire” electrical costs. Being near the nuclear power plant, possibly an agreement could be arranged where lower electrical rates are secured in exchange for a steady supply of high quality water extracted from the brine. This is a symbiotic relationship where the nuclear power plant gets much needed good quality water for its cooling towers and the owners of the brine get subsidized power to operate the brine concentrators at a lower cost. This would be a win-win situation.

Alternative 4 - Softening/2nd RO/VSEP/Evaporation pond

This strategy would extract additional water from the brine and leave a small portion of the brine to be processed in an evaporation pond.   A pipeline, approximately 28 miles in length, would be constructed from the Phoenix metropolitan area to near the Palo Verde Nuclear Power station to transport the brine to that location. At that location land would be purchased and a water softening facility, a RO facility, and a Vibratory Shear Enhanced Processing (VSEP) facility and evaporation ponds would be constructed. The softening facility would first soften the brine by removing calcium, magnesium and other select ions through chemical reactions. This softened brine would then be processed through a Reverse Osmosis facility to extract additional water from the brine. The brine from the RO would then be processed by the VSEP which would extract even more water and further concentrate the brine. The final fraction of extremely concentrated brine would then be evaporated in a pond.

Similar to the brine concentrator strategy, an agreement could be arranged with the Palo Verde Nuclear Power Plant where lower electrical rates are secured in exchange for a steady supply of high quality water extracted from the brine. This is also a symbiotic relationship where the nuclear power plant gets much needed good quality water for cooling and the owners of the brine gets subsidized power to operate the Softening/2nd RO/VSEP facility.

Alternative 5 - Wetlands with Surface Discharge to Gila River

This strategy is a very low tech approach to brine management. Brine would be treated through a series of wetlands specifically designed to remove heavy metals and other hazardous ions from the brine. The brine would then be blended with effluent or other waters in mixing ponds to reduce the TDS to the same level or lower then the Gila River (approximately 3200 mg/L TDS in the lower reaches). From the mixing ponds the brine/effluent blend would be surface discharged to the Gila River.

This strategy has many benefits to society and the environment. First none of the brine is wasted, it is used to support and/or create wetlands environment. Second, a minimal amount of energy is expended managing the brine.   Third, this strategy supplies water to the Gila River when other factors are putting pressure to dry up the River. Finally, this strategy is relatively inexpensive compared to other strategies.

Alternative 6 - Pipeline to Deep Well Injection Site

Injection wells are a proven technology for brine management. They are being used mainly in Texas and Florida. With the right geology they are cost effective, environmentally sound and have a small footprint.   This strategy envisions a pipeline to a location where a deep well would be constructed. The brine would then be pumped underground into a geological formation which is isolated from drinking water aquifers.

Figure 2 shows the Alternative's approximate locations and relative pipeline lengths.

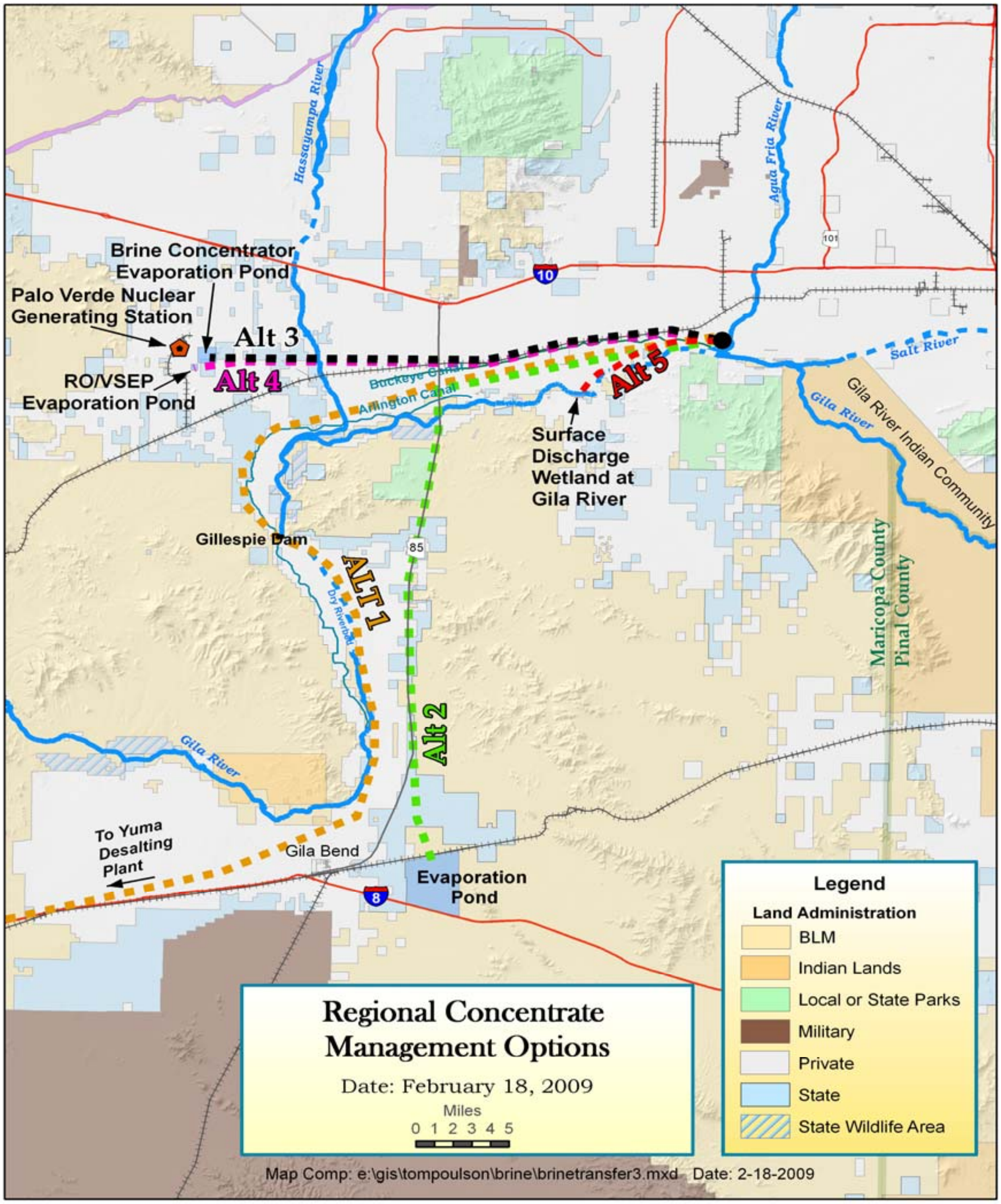

Figure 2

Alternative 1 - Pipeline to Yuma
Alternative 2 - Pipeline to Evaporative Ponds in Desert
Alternative 3 - Brine Concentrator/Evaporation pond
Alternative 4 - Softening/2nd RO/VSEP/Evaporation pond
Alternative 5 - Wetlands with Surface Discharge to Gila River
Alternative 6 - Pipeline to Deep Well Injection Site (not shown)

A deep injection well requires, among other things, that the receiving aquifer be above 10,000 mg/L TDS and that the receiving aquifer be isolated by geological formations from other drinking water aquifers. As of the writing of this report, no location in central Arizona has been identified where the geology meets the criteria for a deep injection well. An early investigation by a local consulting firm states that a location south of the Sierra Estrella Mountains may possibly have the geological characteristics needed for a deep injection well. An exploratory drill hole would be needed to confirm the site's suitability.

Since no suitable site has been located in central Arizona, an arbitrary pipeline of 50 miles was selected and the pumps and pressures were modeled after a deep well injection site in the Brazos River Basin, Texas to carry out the economics of the alternative.

Each alternative was evaluated at two sizes, 10 mgd representing the year 2020 brine production and 30 mgd representing the 2035 brine production. Costs and energy consumption were calculated for each alternative at both sizes. The project life for all alternatives was considered to be 50 years. The interest rate used was 4.875% which is Reclamation's construction interest rate for 2008. This information and the detailed cost estimates are in Appendix A.

Results

Table 2 shows the capital costs, O&M costs and annualized costs for the 10 mgd sized alternatives. Evaporation ponds have by far the most expensive upfront capital costs; while the brine concentrator alternative consumes tremendous energy and thus has high O&M costs. On an annualized basis, these two alternatives would be the most expensive to implement. The other four alternatives group together in a lower cost bracket.

Alternative Comparison 10 mgd (millions of dollars)

10 MGD	Pipeline to Yuma	Evaporation Pond	Brine Concentrator	Soften/ RO/ VSEP	Wetlands Surface Discharge	Injection Well
Capital	$266.11	$651.69	$272.71	$286.56	$150.22	$ 114.46
O&M	$ 0.62	$ 3.50	$ 29.75	$ 6.90	$ 1.75	$ 11.31
Annualized	$ 14.92	$ 40.26	$ 44.40	$ 22.30	$ 10.37	$ 17.46

Table 2

Table 3 shows the annual energy consumed, the cost of that energy and the amount of water recovered by the 10 mgd alternatives. Water recovered from the brine is an attractive feature of the Softening/RO/VSEP and the Brine Concentrator alternatives. But the brine concentrator energy costs are prohibitive.

Alternative Comparison - Annual Energy & Water Recovered

10 MGD	Pipeline to Yuma ****	Evaporation Pond	Brine Concentrator	Soften/RO VSEP	Wetlands Surface Discharge	Injection Well
Energy* (kilowatt-hours)	minimal	1,146,000	310,250,000	68,135,000	minimal	143,769,000
Energy Cost**	minimal	$88,000	$23,889,000	$662,000	minimal	$11,070,000
Water Recovered*** (af)	0	0	10,528	9,238	0	0

Table 3

Notes: * Kilowatt-hours of energy required (annual)
** $.077 per kilowatt-hour
*** Acre-feet of water recovered from the brine by this alternative (annual)
**** Does not include the pipeline to Salton Sea Option which would require energy for pumping

Table 4 shows the capital costs, O&M costs and annualized costs for the 30 mgd sized alternatives. The results are similar to the 10 mgd sized alternatives. If anything the brine concentrator alternative moved farther out of competition because of energy costs. The Wetlands Surface Discharge alternative remained the lowest cost alternative.

Alternative Comparison 30 mgd (millions of dollars)

30 MGD	Pipeline to Yuma	Evaporation Pond	Brine Concentrator	Soften/ 2nd RO/ VSEP	Wetlands Surface Discharge	Injection Well
Capital	$580.25	$1,837.74	$724.78	$718.94	$399.75	$204.98
O&M	$ 1.41	$ 10.22	$ 88.69	$ 20.01	$ 5.14	$ 33.60
Annualized	$ 32.58	$ 114.22	$125.63	$ 58.66	$ 26.62	$ 44.62

Table 4

Table 5 shows the annual energy consumed, the cost of that energy and the amount of water recovered by the 30 mgd alternatives.

Alternative Comparison - Annual Energy & Water Recovered

30 MGD	Pipeline to Yuma****	Evaporation Pond	Brine Concentrator	Soften/RO VSEP	Wetlands Surface Discharge	Injection Well
Energy* (kilowatt-hours)	minimal	3,438,000	930,750,000	204,405,000	minimal	431,307,000
Energy Cost**	minimal	$265,000	$71,668,000	$1,985,000	minimal	$33,210,000
Water Recovered*** (af)	0	0	31,583	27,719	0	0

Table 5

Notes: * Kilowatt-hours of energy required (annual)
** $.077 per kilowatt-hour
*** Acre-feet of water recovered from the brine by this alternative (annual)
**** Does not include the pipeline to Salton Sea Option which would require pumping

Table 6 compares the alternatives on two environmental issues: Does the alternative remove the salts from the local environment? Does the alternative use the brine in a beneficial manner?

Alternative Comparison of Environmental Aspects

	Pipeline to Yuma	Evaporation Pond	Brine Concentrator	Soften/ RO/ VSEP	Wetlands Surface Discharge	Injection Well
Remove Salts from Local Environment	Yes	Yes	Yes	Yes	No	Yes
Beneficial use of Brine	Yes	No	Yes	Yes	Yes	No

Table 6

Discussion

<u>Alternative 1 - Pipeline to Yuma</u>

The Pipeline to Yuma was first proposed in 1999 during the Tucson RO study. It even has a name, CASI or the Central Arizona Salinity Interceptor. A pipeline all the way to Yuma, sounds outrageous to new comers dealing with inland brine management, but it compares very well financially with the other alternatives. This alternative lands in the midrange of costs, and most of the costs are tied up in the 178 mile pipeline that would be built. Since it is down gradient to Yuma, the energy consumption would be minimal. Maintenance costs would be low because of the limited need for high technology apparatus to operate and maintain.

This alternative has some unique opportunities to improve the environment while solving Arizona's brine problem. First, it removes the salts from the local environment. There are two options beneficial to the environment once the brine reaches Yuma. The brine could be used to support habitat at either the Ciénega de Santa Clara or the Salton Sea.

From Yuma, if the brine was diverted to the Ciénega de Santa Clara, the additional costs would be minimal. Possibly, the slough would have to be rebuilt or expanded. Those costs were not examined.

From Yuma, if the brine was sent to the Salton Sea there, there would be significant additional costs. These costs would be for the pipeline and a pumping facility. The capital and O&M costs of a pipeline to the Salton Sea for the 10 mgd option are about $9.5 million annualized and for the 30 mgd they are about $15.7 million annualized. The aforementioned additional costs might be borne by California stakeholders interested in using the brine for restoration of the Salton Sea.

There are issues which would need to be addressed in getting this alternative in place. The first issue would be either to convince Mexico or California to accept the brine and believe it would be beneficial for them to do so. This could be problematic because by regulation RO brine is considered "industrial waste" which has negative environmental connotations. The brine may contain constituents (arsenic, selenium, etc.) above the legal limit for discharge which would make it unusable for the Salton Sea or the Ciénega de Santa Clara.

Dealing with Mexico would require the Federal Government to be involved. International negotiations with Mexico would take time and Mexico may want compensation for accepting “industrial waste” from the U.S.A. On the other hand, Mexico may see the value in a continuous supply of water for their Ciénega de Santa Clara.

Negotiating with Mexico may be easier then negotiating with California considering the acrimonious water conflicts between California and Arizona in the past. The Salton Sea would be receiving water which would be four times better quality but California Environmental Protection Agency (Cal/EPA) would have to approve discharging the brine into the Salton Sea. That may or may not prove difficult depending on how they view the discharge. Cal/EPA would have to decide if the brine is to be treated as a regulated industrial waste or a beneficial water which would improve the Salton Sea.

Alternative 2 - Pipeline to Evaporation Pond in Desert

This option tends to be on the high end of the costs. The capital costs for this alternative are the highest of the alternatives considered. The capital costs explode for this option as the size of the evaporation ponds increase. Dr. Mike Mickley’s research indicates that, “construction costs for evaporation ponds have little economy of scale and typically become excessive for all but the smallest plants.”[1] Capital costs for the 30 mgd option are $1,838 million, which is more than double the next highest alternative.

The high capital costs are somewhat off set by the low O&M costs. Maintaining evaporation ponds is relatively easy and it does not take specialized skills to operate this alternative. An evaporation pond is a simple reliable technology that works very well in central Arizona. On the down side, the brine is not used in a beneficial manner as no water is recovered from the brine but only evaporated away.

Environmentally, this project removes the salts from the local environment and places them in a pond approximately 45 miles to the south. At the end of the lifetime of the ponds the salts would be sequestered in place or moved to a land fill. But, there would be approximately 11 square miles of ponds for the 30 mgd alternative. If selenium or other toxic metals were concentrated in the evaporation ponds, there is some concern that these ponds would be hazardous to water fowl which would be attracted to them.

Alternative 3 - Brine Concentrator/Evaporation Ponds

Brine concentrators are a proven technology and are used at power plants which must employ ZLD techniques. They require specialized and highly trained personnel to operate and maintain them.

This is the most expensive alternative examined. Capital costs for the construction of the brine concentrators are high. Also, high energy usage and therefore costs add to the overall cost of this alternative. The annual cost for this alternative is nearly twice the cost of the next highest alternative examined.

Energy consumption is the major problem with this alternative. Brine concentrator energy consumption can range from 60 to100 kilowatts per hour per 1,000 gallons of brine. Using $.077 per kW/hr, the cost ranges from $4,600 to $7,700 per day to process 1 mgd of brine. Although, some of the cost could be defrayed by trading the high quality water recovered from the brine for a special deal on energy costs.

This alternative removes the salts from the local environment and will ultimately sequester them either in a land fill or in the closed and sealed evaporation pond. But, new electrical energy sources are already needed to meet the projected population growth in central Arizona without this project. Environmentalist groups may oppose the project because of the amount of energy required. This alternative is not attractive either financially or energy wise.

<u>Alternative 4 - Softening/2nd RO/VSEP/Evaporation pond</u>

This alternative is surprising because even with all the high technology processes in this alternative, it still falls right in the mid-range of the annualized costs. The big plus for this alternative is the recovery of the additional water from the brine. Approximately, 82% of the water would be recovered from the brine sent to the facility with this alternative. This recovery is achieved with a 65% recovery by the secondary RO and then another 50% recovery with the VSEP.

Environmentally, this alternative removes the salts from the local environment. The salts would be isolated either at a lined land fill or sealed in the lined evaporation ponds when the ponds useful life is at an end.

This alternative would require numerous highly skilled and trained operators to handle the equipment and operation at the different facilities.

The VSEP technology has only been used on small industrial water streams at the writing of this paper. It has never been used for a large scale municipal application. There is concern about the amount of maintenance (costs) required to keep a very large VSEP facility operating.   The VSEP technology is proprietary and the company which owns the rights is not large. All replacement membranes must be purchased through that company.   Currently, Reclamation and others are testing a small VSEP unit in Tucson, AZ.

The Palo Verde Nuclear Power Plant has the largest lime softening facility in the United States and seems to be able to handle all the complexities of the process. This alternative would have a softening facility similar in size and scope. The process produces a sludge which creates another management issue. The easiest method, but not the least expensive, would be to truck the sludge to a land fill. Another option would be to purchase additional land and create a local landfill for the sludge on site.

Alternative 5 - Wetlands with Surface Discharge to Gila River

The lowest annualized costs, and therefore, the least expensive alternative is the "Wetlands with Surface Discharge to the Gila River." Upfront capital costs were second lowest and O&M costs are reasonable. One of the reasons capital costs were low is because the site was the closest to the brine collection point, reducing pipeline costs significantly. The wetlands take up significantly less land than evaporation ponds reducing land acquisition costs. O&M costs are midrange, low energy consumption and the lack of high technology machinery drive O&M down but the replacement of the wetlands as they become saturated with heavy metals drives the O&M up. Financially, this alternative is quite attractive but it also has the most risk. A pilot project is under way to test if this alternative is feasible.

This alternative removes the heavy metals and other ions from the brine and from the environment. The contaminants which are monitored by Arizona Department of Environmental Quality (ADEQ) are contained in the wetlands and ultimately end up in a landfill, but the vast majority of the salts are not removed by the wetlands. The brine will be high in TDS when it leaves the wetlands. Blending with effluent or other water source will lower the TDS to match the Gila River's TDS. The salts will travel with the brine/effluent blend into the Gila River. From this point, the Gila River water is used two more times by the farms using the Arlington Canal and Paloma Irrigation and Drainage District. As these agricultural entities use the water, the salts would end up first in the root zone and then eventually be leached down into the aquifer. The receiving aquifers to the southwest of the Phoenix metropolitan area are already high in TDS.

This alternative has many benefits. The biggest benefit is to the environment along the Gila River southwest of Phoenix. Pressures on the Gila River in this area are making it likely that the River will "dry up" within the next 50 years. First, the farmers, whose irrigation practices contribute much of the water to the Gila River, are selling their land to developers. When all the farming is gone, the large amounts of water being delivered to this area of the Valley will be extremely slowed. Secondly, the City of Phoenix will continue to put effluent into the River but only enough to supply Tres Rios Wetlands (28,000 ac-ft/annually). According to the Agua Fria Linear Recharge Draft Environmental Impact Statement (DEIS), the rest of the 91st Ave. WWTP effluent will be diverted to the Agua Fria Recharge Project or other uses. Finally, the Luke cone of depression to the north will influence the direction of the groundwater flow. Traditionally, the groundwater flowed out of the Valley to the southwest. According to groundwater modeling, in the future, the natural flow of groundwater will change from flowing in the natural southwest direction and move in a northern direction towards the Luke cone of depression[8]. All these pressures will act on the Gila River in this area and will affect the amount of water in the River. This alternative would supply a continuous source of water for the Gila River and its habitat.

This alternative is very green, in that it does not use much energy, it contributes water to enhance the environment and it uses the concentrate in a beneficial manner. But there is a major concern, the brine/effluent blend may not be able to pass the whole effluent toxicity (WET) test because of high chlorides. If this is the case then rule R18-11-106

Net Ecological Benefit would have to be invoked. The implementation of this rule would take close cooperation with ADEQ. A wetlands pilot project is under way testing the concept, the capabilities of removing toxic ions and if the brine/effluent blend can pass the WET test.

Alternative 6 - Deep Well Injection Site

Deep well injection is a proven technology which has been put to good use in Florida and Texas disposing of RO brine. This alternative has the lowest upfront capital costs. The low capital outlay is offset by high energy costs. Pumping large amounts of brine into pressurized holes consumes large amounts of energy and therefore money. The pipeline to deep well injection alternative fell right into the mid-range of annualized costs.

O&M costs are highly dependent on the pressure needed to inject the brine into the receiving aquifer. The costs could be much higher or much lower then the costs portrayed in this document depending on the geological conditions if a suitable location is found.

Although, the brine is sequestered away from the environment, none of the water in the brine is reused in any manner.

The biggest intangible is that a site has not been identified in central Arizona after a fair amount of research has been done. If a suitable location is found close to the Phoenix metropolitan area this alternative would be a leading candidate for the best alternative.

Environment

Are the salts removed from the local environment? All of the alternatives do that except the Wetlands Surface Discharge alternative. Only the Pipeline to Yuma returns the salts to the sea where those salts were supposed to go before intercepted by man and diverted with the water via the CAP or SRP to the Phoenix metropolitan area. Three of the alternatives use evaporation ponds as the ending location of the salts. When the evaporation ponds useful life is over the salts will either be sequestered in place or moved to a lined land fill. The injection well puts the salts deep under the ground where they are isolated from drinking water aquifers. In the Wetlands Surface Discharge alternative, the salts would be moved out of the Phoenix metropolitan area to brackish groundwater located beneath the agricultural lands to the southwest of the Phoenix metropolitan area.

Is the brine put to beneficial use? There are two options for the final disposal of the brine in the Pipe line to Yuma alternative. The brine will be used to “sweeten up” the Salton Sea or send it down to the Ciénega de Santa Clara. Either way the brine is beneficially used. The Brine Concentrator and the Softening/RO/VSEP alternative recover water from the brine so that is considered a beneficial use. The Wetlands Surface Discharge alternative uses the brine to create or support existing wetland habitat. Only the Injection Well and Evaporation Pond do not use the brine in any beneficial manner.

Conclusion

In conclusion, numerous large and small RO facilities are in the design, planning or conception phase in the Valley. The large amount of brine produced from these facilities will be difficult to manage by the current methods employed in the local area, evaporation ponds and sewer disposal. A good solution to brine management could be the key to whether these RO facilities are constructed or not. A solution where the brine is moved out of the Valley to a regional processing center may be cost effective if several cities cooperated in the endeavor. A regional solution would also open up opportunities for other RO facilities to tag-along creating a synergy where more brackish water is treated through advanced water treatment techniques because there is a readily available solution to the vexing question; "What do we do with the brine?"

The size of the project, whether it was the 10 mgd or 30 mgd, did not change the relative ranking for the alternatives. Tripling the size of the projects did not make an alternative significantly better or worse relative to the other alternatives. Although, low energy alternatives are more attractive at the larger scale because the demand for energy in Arizona will continue to grow.

Several alternatives just don't seem worth pursuing. The brine concentrator concept just uses too much energy and money. Giant evaporation ponds are too capital intensive and all the water within the brine is wasted away. Giant evaporation ponds may create environmental hazards because of selenium, arsenic or other toxic ions concentrating in the ponds. While, deep well injection has some advantages as a disposal method, the right geology has not been located in central Arizona which would allow this alternative to be implemented.

The two alternatives which seem to have the most to offer are the "Softening/2nd RO/VSEP/Evaporation pond" and the "Wetland with Surface Discharge" on a local scale but possibly difficult to implement on the regional scale.

The "Softening/2nd RO/VSEP/Evaporation pond" alternative is relatively cost effective and also recovers much of the water from the brine which otherwise would be wasted. This alternative should be examined at many different magnitudes. It could be implemented as a zero liquid discharge (ZLD) brine management technique at a single RO facility which had sufficient space. It could be implemented by one or two cities working together which had two or three RO facilities located relatively close together. Or as this paper proposed, a regional solution could be implemented where several cities with several RO facilities worked together.

Further refinement to the concept should be examined. Because VSEP is a proprietary technology and maintenance costs of a large VSEP facility is suspect, other high technology systems could be examined. There are various different "chains of technologies" which could be linked together such as the HERO process, EDR, DewVaporation, etc. These "chains of technologies" would recover additional water from the brine and could be cost effective and environmentally friendly. Further research on high tech alternatives should be pursued through additional literature review and research in pilot or demonstration scale projects.

The “Wetlands with Surface Discharge” is attractive for different reasons. It has the lowest annualized costs of all the alternatives examined. Energy requirements are minimal. It supports habitat along the Gila River when other forces are acting on the River to dry it up. But there are a few environmental issues which need to be addressed. The first is that the Net Ecological Benefits rule would have to be successfully argued and accepted by ADEQ. The second is that while the regulated ions are sequestered from the environment, the majority of the salts are just moved further downstream.

While many engineers are looking for high tech, high energy solutions this alternative offers a low tech, low energy, green solution which would reduce the carbon foot print of brine management. If the regulatory hurdles can be over come this alternative offers a nifty method of brine management while keeping the Gila River habitat alive. At the small scale, this idea works well for West Valley communities.

The pipeline to Yuma is attractive. There are no engineering or economic reasons not to consider this alternative. This is a low tech engineering project and the costs are reasonable compared to the other alternatives and it does not consume lots of energy. It is the best solution environmentally, as it returns the salts to the ocean or supports the Salton Sea.

If California sees the possibility for a win-win situation, it may be possible to trade brine for a lesser amount of Colorado River water. California would get an abundance of water to improve the quality of the Salton Sea and Arizona would solve its brine disposal issues and get a lesser amount of potable water for its growing demands.

Or the brine could be discharged into the Sea of Cortez. In this option, the brine would support the Ciénega de Santa Clara wetlands before it eventually ends up in the ocean. Of all the ideas presented, this one is the only alternative where the salts end up where nature intended them to be.

All the alternatives can be implemented at a local level by individual cities or water providers on a smaller scale, except for the Pipeline to Yuma. The Pipeline to Yuma requires the Valley to work together for a regional solution.

High tech or low tech…regional solution or each city on their own…is there a solution for the Valley’s looming brine management challenges?