PHASE I TECHNICAL MEMORANDUM

IDENTIFICATION OF POTENTIAL METHODS

for

PARADOX VALLEY SALINITY CONTROL UNIT

by

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Introduction

Over 30 years ago, the Paradox Valley was identified to be a major contributor of salt loading to the Colorado River Basin. Operational since 1996, the Paradox Valley Salinity Control Unit (Unit) of the Colorado River Basin Salinity Control Project (CRBSCP) was designed to control natural brine inflow to the Dolores River by intercepting it, thereby preventing substantial salt loads from entering the river and degrading the water quality of the Colorado River's main stem. The brine is intercepted by pumping a series of nine shallow brine extraction wells adjacent to the river and disposing of it by injection into a 16,000 foot deep well to a brine reservoir. When the system is operating 230 gpm of brine is injected.

Well testing began in 1991 and over the history of the project more than one million tons of salt have been intercepted and disposed of. Since the Unit's conception, many and various changes have occurred to the deep well brine injection process with the process continuing to evolve. Over the years, studies and tests have been conducted to determine the life of the injection well. Current projections are that the injection well can be used for 10 to 20 more years. The Bureau of Reclamation (Reclamation) determined that probable alternatives needed to be evaluated in order to select the best options to continue brine removal into the future. It is hoped that new technologies for salt removal will be more cost effective than deep well injection.

The purpose of the Phase I Technical Memorandum is to document a preliminary list of candidate methods for controlling the salt load to the Dolores River at Paradox Valley. This will allow time to select an alternative and begin the required environmental studies prior to design, construction, and implementation.

Preliminary Candidate Alternatives

Key team members made a site visit on January 9 and 10, 2008, which is documented in a Trip Report to Reclamation. The Trip Report can be seen in Attachment A. As a result of this visit, team members collaborated to identify fifteen plausible alternatives including an initial technical screening of the technical adaptability and effectiveness of each potential method. Additionally, combinations of potential methods are identified in the Combined Alternatives Section, which identifies which alternatives can replace the current system and which can be used to improve the efficiency of the current or proposed system. Table 1 summarizes the alternatives with their respective advantages and constraints discussed in this report.

Table 1: Summary of Preliminary Candidate Alternatives

Alternative		Advantages	Constraints
No.	**Description**		
1	Enhance existing injection system	Optimize existing facilities	Limited opportunities Increased seismic activity
2	Additional injection well	Recent technological improvements Increased system flexibility Maintain reduced seismic activity	Siting challenge – drill through salt dome Relatively expensive Technical constraints
3	Divert West Paradox Creek (West Valley, last 5 miles)	Reduces infiltration to West Valley; potentially reduces brine volume to extraction wells, Relatively economical	Environmental Political (water rights)
4	Zero-liquid-discharge (ZLD)	Crystallizer technology demonstrated Suitable for application Optimize extraction schedule	Expensive, High power required Solar power not suitable in peak periods
5	Dewvaporation (DV)	Favorable innovative technology Recent technological improvements	Not demonstrated at project salinity levels
6	Other innovative treatment (SAL-PROC, Vibratory Shear Enhanced Process, Product Recovery from Brine, burning salt water)	Promising technologies (research level) Potential end product benefits (magnesium)	Not demonstrated extensively Single-vendor patent costs
7	Enhanced Leakage Pit	Eliminates surface storage	Application limited to Australia
8	Salt bricks	New opportunity Potential end product benefits	Technical rationale questionable Technique not demonstrated Single vendor
9	Conventional evaporation basins (1,400 acres)	Positive elimination of brine Relatively economical construction	Environmental waterfowl injury Land costs Requires bird netting
10	Diversion Tunnel (Dolores River Siphon Crossing of Paradox Valley)	Eliminates brine inflow to river Technique demonstrated in Combined Sewer Overflow applications	Technical challenges Residual seepage at other areas Expensive, Environmental
11	Agricultural Land Management (convert irrigated farmland to wildlife habitat)	Eliminate / reduce return flow 5-year demonstration Options (near river – Paradox Basin)	Institutional issues Environmental issues
12	Add liner to West Paradox Creek Wetlands (100 ± acres)	Reduce brine outflow Maintain environmental benefits Bentonite available locally Relatively economical	Requires cooperation of private owners,Wildlife damage to liner Approval of Division of Wildlife Critical construction scheduling
13	Increase consumptive use by phreatophyte growing	Salt uptake Wildlife attractions (SW Flycatcher)	Loss of agricultural lands
14	Integrated evaporation pond and treatment approaches	Optimize existing facility Process heat source for ZLD	Limited existing installations
15	Line bed and banks of Dolores to prevent upwelling of brine	Stop upwelling of brine Technically demonstrated (amphibious barge)	Residual seepage at other areas Construction impacts High cost
16	Fresh Water Cutoff Wells	Reduce or eliminate the circulation of groundwater through the salt dome thus eliminating the brine.	Understanding groundwater system well enough to locate wells Adversely impacting current wells and water rights, drying up wetlands

Alternatives 1: Enhance Existing Injection System

The Unit has constructed a series of vertical wells along the Delores River to intercept natural brine groundwater before it enters the river. The interception of this brine groundwater has been shown to reduce the inflow of brine to the river up to 90 percent. The brine ultimately is disposed in a deep injection well completed at a depth of approximately 16,000 feet below land surface (bls). In the past, flow rates to the injection wells were about 300 gpm at a pressure of 5,000 psi. However, the brine injection program has contributed to the occurrence of micro earthquakes in the region, resulting in the flow rate being reduced to approximately 230 gpm. Although micro earthquakes are still occurring at this lesser injection rate, the magnitude of the earthquakes is small and appears to be relatively insignificant.

Description of Alternative

One alternative being considered is to enhance the existing injection well operation. Extensive efforts have been undertaken by reclamation to maximize the injection rate while minimizing earthquake activity. Since prevention of increased earthquake activity is a project goal, it is doubtful that the injection rate of the existing well could be significantly increased. However, development of other potential alternatives (e.g. a solar pond) could increase the salt concentration in the brine. By increasing the salt concentration in the brine more salt could be disposed of while maintaining the current injection rate for the existing well. Methods to concentrate the brine will be discussed further in subsequent sections.

Advantages

- Further optimizes existing facilities.
- Disposal of brine with minimal handling.
- Proven technology in terms of the formation receiving the injected brine.

Constraints

- Requires the addition of another facility to significantly increase the existing salt injection rate.
- The effect of higher salt concentrations on the injection well is unknown. There is potential that higher salt concentration in the injected brine may permanently damage the injection well.

Alternatives 2: Additional Injection Well

As described in Alternative 1, the existing extraction wells and injection well has significantly reduced the salt loading to the Dolores River. However, the life on the current injection well has been estimated to be 10 to 20 years under existing conditions. To extend the life of the existing injection well or replace it, an additional injection well is being evaluated.

Description of Alternative

One option being considered for the disposal of the brine collected from the vertical well system is the installation of a second injection well. However, because the region is significantly fractured and faulted, micro earthquakes that can result from the injection process will be difficult to eliminate. Much care will be needed in the siting and design of the well, as well as the determination of the optimal injection rate. This second well would inject brine in the same Leadville Formation as the existing injection well. A site for an additional injection well has been identified west of the extraction area. This site is very close to an old oil exploration drill hole. The drilling log for this drill hole provides good information. However, installing an injection well in this location would require drilling through the salt dome for thousands of feet. There are challenges associated with drilling through and maintaining a well through a salt dome that can be overcome but must be addressed. Further details regarding the challenges associated with drilling through the salt dome will be provided in next phase of this project.

The purpose of this discussion is to provide a general assessment of the second injection well option. Based on the injection rate of the existing well, it appears that at least 230 gpm is achievable if the new well is completed in a similar injection zone in the valley through the salt dome to the Leadville formation below. More analysis needs to be done to determine if it is feasible to drill through the salt dome. Additional technical evaluation using existing data, including geologic logs from oil/gas wells, would determine if an alternative injection zone, still within the Leadville formation as required by the EPA, may be present in the area and may readily accept the injected brine. The possibility of using a lateral well to employ possible thin injection horizons would be included in this evaluation.

Advantages

- Optimizes existing facilities.
- Increased system flexibility with the utilization of two injection wells.
- Disposal of brine with minimal handling
- Proven technology in terms of the formation receiving the injected brine.

Constraints

- Cost appears to be between $40 and $60 million (not including the wellhead facilities) to install the second injection well.
- Long term O&M cost will increase with the operation of two wells.

- Inducing micro earthquakes is likely to occur at the new well site. The magnitude of the micro earthquake is predictable but unknown.
- The maximum injection rate with respect to geologic and seismic conditions is predictable but unknown.
- Life of a new injection well may be comparable to the existing injection well; conditions may favor a larger injection reservoir.

Alternative 3: Divert West Paradox Creek

The implementation of this alternative would represent an effort to reduce the amount of brine that flows into the Dolores River or has to be disposed of. Monitoring the salinity of the Dolores River for over 30 years indicates that the salt loading to the river is typically highest during the winter months. A number of factors may contribute to this pattern. Some of these factors are:

- Higher flows in the Dolores River during spring and summer increase the water level thereby restricting the flow of brine towards the river.
- The higher water level of the river pushes fresh water into the river banks where it picks up salt from the soil. At lower flow levels during the winter this water returns to the river with additional salt from the soil.
- A theory that needs more study to confirm is that West Paradox Creek recharges the fresh water layer above the brine thereby displacing some of the underlying brine. The displaced brine is forced towards the river at a greater rate than when recharge is not occurring. This displacement of the brine is occurring when the water level in the river is low. Therefore the pressure on the brine is increasing at the same time the resistance due to fresh water in the river is decreasing. During the irrigation season the flow in West Paradox Creek is diverted completely for irrigation. Thereby eliminating the recharge of fresh water adjacent to the river. During the summer the groundwater conditions are opposite of what is seen during the winter.
- The recharge area for the brine aquifer may not be in the Paradox Valley. Reclamation previously concluded that the recharge area may be the La Sal Mountains to the west or a combination of the La Sal Mountains and other areas around the Paradox Valley. This conclusion is supported by water quality data. The brine flowing into the river is primarily of a sodium chloride type which corresponds to the halite formation of the salt dome 600 feet plus below the valley surface. Fresh groundwater closer to the surface, which is recharged from the Paradox Valley, has more sulfate, bicarbonate, calcium and magnesium than is seen in the brine. This suggests that the brine is picking up the sodium chloride from the halite formation 600 feet or more below the surface and is not the same as groundwater near the surface. Groundwater deep enough to flow through the halite formation must originate outside the Paradox Valley. Knowing that the recharge area for the brine is outside the valley it is possible that the effect of aquifer recharge in the spring is not seen at the river until the following winter due to the distance between the recharge area and the river.

Recently the Colorado Division of Wildlife Resources constructed three ponds adjacent to the Dolores River to provide habitat for migrating birds in the spring. These ponds are filled when flow in West Paradox Creek is available. Water is available in West Paradox Creek before and after the irrigation season. Reclamation personnel at the site have observed that increases in the salt loading to the river appear to coincide with the filling of one of these ponds. Additional data and analysis will be necessary to demonstrate this particular relationship. Whether recharge of the fresh water layer by West Paradox Creek causes the increased salt loading cannot be definitively answered at this time but increased salt loading to the river does correspond to the time when recharge adjacent to the river is highest.

In noting this apparent cause and effect relationship it may be possible to reduce the salt loading to the river during the winter by eliminating the groundwater recharge adjacent to the river by West Paradox Creek. It is also possible that the annual salt loading of the river may be the same but more uniform throughout the year with this change. A more uniform salt loading would allow a uniform pumping rate to be more effective at removing the brine.

Description of Alternative

To eliminate or reduce the groundwater recharge adjacent to the river there are a number of alternatives that may be used. Some of the alternatives are:

- Relocate West Paradox Creek so that it discharges farther south where salt loading is not currently occurring. If in fact recharge close to the river does increase salt loading then this has the potential to create another source of brine.
- Place West Paradox Creek in a concrete lined head ditch from where it enters Paradox Valley, along the contour, to a location where the Dolores River exits Paradox Valley. Buried pipe laterals from the head ditch would provide pressurized water service for sprinkler irrigation of farmlands having irrigation water rights from West Paradox Creek. New (replacement) wetlands would be created at the end of lined head ditch in an area not underlain by the collapsed anticline.
- Pipe West Paradox Creek directly to the river from a distance that would preclude recharge adjacent to the river.
- Clay line or relocate the wildlife pond that appears to be contributing a large amount of recharge.
- Fill the wildlife ponds only during the bird migration instead of keeping the ponds full throughout the winter as is now the practice.

Implementing this alternative may reduce the salt loading or make the salt loading more manageable but it will not eliminate the need for other brine disposal methods to be used.

Advantages

Technically this alternative will be easy to implement and can potentially reduce the salt loading of the river. The cost of implementing this alternative will be relatively low. Once construction is complete there will be very little operating and maintenance costs.

Constraints

Constraints associated with this alternative are:

- Changing the location or flow patterns of West Paradox Creek may impact water rights.
- Residents of Paradox Valley may object to relocating or changing West Paradox Creek.
- Relocating West Paradox Creek may simply relocate the problem.

- The recharge area is marshy when West Paradox Creek is flowing. The area may be classified as wetlands. Changes will dry up this area, possibly impacting wetlands. However, the area is heavily overgrown with tamarisk trees which are undesirable.
- The landowner and/or Wildlife Resources may not be cooperative regarding changes to or relocation of the pond(s).

Alternative 4: Zero-Liquid-Discharge

Due to the in-land location of the Unit and current limitation with deep-well injection causing seismic activity, zero-liquid-discharge (ZLD) is being considered as an alternative brine management strategy.

Description of Alternative

ZLD can be achieved through the configuration of many different disposal processes. Some of these processes include electro-dialysis reversal (EDR), membrane distillation, a brine concentrator, a crystallizer, and evaporation ponds. The most appropriate treatment train must be selected on a case-by-case basis. For the Paradox site, it is assumed that the brine treatment train will consist of a concentrator, followed by a crystallizer and small evaporation ponds.

To reduce the volume of concentrate by as much as 98%, a concentrator is used as the first step in brine management. The concentrator process uses heat exchangers, deaerators, and vapor compression to convert liquid concentrate into a concentrated slurry. The brine temperature is one of the biggest factors to effect concentrator performance. The higher the temperature, the higher a concentration can be achieved. However, thermal energy is required to heat the brine so additional equipment and energy is required resulting in larger O&M costs. A concentrator with only cold evaporation does not need a heat supply, but its concentration rate is lower resulting in the need for a larger size unit, therefore a greater capital investment, to achieve the same water process capacity. A site specific economical analysis must be done to determine the ideal operating conditions of the concentrator for Paradox.

The concentrated slurry produced by the concentrator can be reduced to a dry solid cake via a crystallizer. The cake can then be hauled away for disposal to a landfill. While the crystallizer is a proven technology and has been demonstrated in several locations, it is a very expensive method. It is not only energy intensive, but solid salt disposal in a landfill can be expensive.

Evaporation ponds are a viable alternative for a small volume of concentrate so they follow both the concentrator and crystallizer. Since Paradox has relatively level terrain and low land costs, evaporation ponds are an option at this site. Evaporation ponds are constructed to allow water from concentrate to evaporate while leaving behind salts in the base of the pond. The cost of ponds is mainly driven by concentrate volume, land and earthwork costs, salinity of the concentrate, and evaporative area required. Regulations require impervious lining and monitoring wells, which increases the cost of evaporation ponds significantly. Liners are important, however, to prevent saline water from leaking into groundwater aquifers.

Advantages

The ZLD process described above has many advantages. It appears to be a good option for Paradox at this time in the study because it allows for disposal of brine in an area where surface water and sewage disposal is not an option and deep-well injection is causing seismic activities. The concentrator and crystallizer are proven technologies that have been demonstrated to work efficiently at various other inland locations. Since the evaporation ponds will be relatively small and land is available, they are a logical last step in achieving ZLD. ZLD will allow optimization of extraction from the existing wells by providing a process to dispose of the brine.

Constraints

There are some disadvantages with selecting ZLD as the brine disposal method. The cost for ZLD is typically much higher than other options both in capital investments and operating costs due to the mechanical equipment and large amounts of energy required. Paradox currently has a limited power delivery potential, which may not be enough to supply the high power requirements of the concentrator and crystallizer. Solar power is being evaluated, and although Paradox has clear days approximately one half of the year, solar power will need to be stored for use beyond peak weather periods. The related features of some innovative, developing systems will need to be explored.

ZLD is a proven technology that is suitable for this application, but cost, power supply and solid waste disposal requirements need to be evaluated in more detail to be considered viable in Paradox.

Alternative 5: Dewvaporation

Description of Alternative

Brine is re-circulated in the tower until the salts reach the level of chemical saturation and begin to precipitate. Dewvaporation is a specific process of humidification-dehumidification desalination. Brine is evaporated by heated air which deposits fresh water as dew on the opposite side of a heat transfer panel. The energy needed for evaporation is provided by the energy released from the formation of dew. As the salinity of the brine increases, evaporation takes place at a lower temperature. Therefore, the optimal operating temperature for crystallization (140°F) is lower than for brackish water concentration (190°F).

Precipitation occurs at the air – saturated brine interface rather than at the brine – plastic interface. This prevents buildup, scaling and fouling of the plastic heat transfer walls. After precipitation, the crystal remains suspended and flow to the bottom of the tower with the concentrating brine. The slurry can be dewatered using a centrifuge or a belt press (Beckman, 2004)[1].

Advantages

- Cost-effective construction and operation compared to reverse osmosis (RO) and vertical tube evaporators because it operates at T < 200°F and slightly above atmospheric pressure.
- Dewvaporation has an economic niche in brine concentration and crystallization applications of 1,000 to 10,000 gallons per day (gpd) capacity.
- Dewvaporation is a humidification-dehumidification (HDH) process (i.e., a thermal process that operates below the boiling point of water). Other HDH processes require two heat transfer towers (or zones) to transfer heat from a massive flow of water. Dewvaporation, on the other hand, only requires one tower making it more energy efficient.
- Field tests have been conducted at two Arizona facilities.

Coronado Generating Station (CGS) Blowdown Concentration Performance

A pilot study at the Salt River Project (SRP) Coronado Generating Station demonstrated that Dewvaporation successfully reclaimed 1.2% saline cooling water blow-down to 20% saline effluent at a distillate capacity of 200 gallons per day. The Dewvaporation towers (four towers in series) reduced the blow-down stream from 213 gallons per day to 13 gallons per day.

[1] Beckman J, (May 2004) Brine Reduction to Crystallization by DEWVAPORATION™

Recovery

The four towers averaged 16.4 pounds of distillate water per hour with an energy reuse factor of 8.5. The initial total dissolved solids (TDS) concentration of the feed was between 10,000-15,000 mg/L. The final discharge was over 200,000 mg/L TDS, representing a 95% recovery.

Operational Reliability

During the one month study period, the system operated 24/7 in a real world environment with no energy efficiency degradation.

Arizona Public Service Company (APS) Red Hawk Crystallizer

The blow-down from cooling the plant was to be concentrated through a conventional vapor recompression evaporator. The brine from the evaporator was then to be processed through a thermal (boiling) crystallizer to separate out solids. The crystallizer had a problem with fouling by saturated nitrate in the water. Nitrate may not be problematic for the Paradox brine, but sampling should be done for confirmation.

Dewvaporation successfully crystallized a 15 gallon sample of the reject from the Red Hawk evaporators. Consequently, a 250 gallon per day Dewvaporation crystallizer was fabricated and installed. Operation information is not yet available.

Constraints

The major constraint of the Dewvaporation alternative is expected high costs. Although costs are expected to be lower than the existing crystallizer at CGS, costs may be quite high for the Paradox project.

Another constraint is the limited capacity of installations. The system at the Coronado Generating System produces 213 gpd of distillate. The CGS proposal would produce 100,000 gpd of distillate and 6 tons of solids per day. (This is 10 times the quoted economic niche of 1,000-10,000 gpd). The proposed unit will be able to concentrate brine to near saturation at 27%.

Alternative 6: Other Innovative Treatments

This alternative has been divided into three options. These options remove the majority of salt and other minerals but still require some method to dispose of brine reject. Thus, implementation of any of these options will still require some method of brine disposal. However, the volume of brine to be disposed of is far less and may be offset by the production of sellable products.

Alternative 6A: SAL-PROC

Inland disposal of brine is a challenge at Paradox. One alternative for brine disposal is SAL-PROC, a patented GEO-Processors technology. This emerging technology may help to reduce the volume of brine disposal while producing a commercial product.

Description of Alternative

SAL-PROC is a process which acts to solidify salt and extract dissolved elements from saline waters to produce various salts and chemical compounds. It is a technology that not only reduces brine discharge volume by up to 80%, but also may produce commercial chemical products. Treatment of the brine streams relies on closed-loop processing and fluid flow circuits.

The process involves multiple steps, including evapo-cooling and traditional chemical processing. The first step in the process is reaction and separation. The type of reaction depends on water quality, but the first product produced is typically either magnesium hydroxide or precipitated calcium carbonate. This step is either followed by more reactions producing other products or by concentration steps. During the concentration steps, brine is increasingly concentrated until a "salting point" is reached. This may be achieved through any volume reduction method, such as evaporation and crystallization or a brine concentrator. The last step in the process is the separation of salt products, which may be of commercial grade and, therefore, marketable. There will be a small amount of residual liquid remaining at the end of the processes that must be disposed.

SAL-PROC has gone through more than 10 years of technology development with pilot trials and public demonstrations having been conducted. These trials have shown capital and operating costs to be dependent upon water quality.

Advantages

SAL-PROC is an environmentally friendly process that produces commercial products which have been licensed for use in the manufacture of ecoproducts such as synthetic fertilizers and sealants for lining ponds and landfills. Not only does it produce ecoproducts, but the process itself uses no hazardous chemicals. In addition to this environmental benefit, SAL-PROC may also provide an economic benefit to brine management. Since the brine solution is being concentrated, there is a significant reduction in salt load and volume, minimizing discharge requirements and cost. Costs may also be offset through sale of mineral products. Another advantage of SAL-PROC is that modules can be custom built in size and configuration to meet site-specific conditions and requirements. There is no specific infrastructure constraint. SAL-PROC is a process which has both environmental and cost benefits.

Constraints

Many of the costs benefits associated with SAL-PROC rely on a local market interested in purchasing the manufactured salt. Since Paradox is a fairly remote location, a local market may not be available. Also, cost depends on the value-added products capable of being produced from the given brine constituents in Paradox. Pilot testing would need to be conducted to determine what products are possible. In addition to the possible lack of a local market, SAL-PROC is a single-vendor process so costs may be higher than other concentrate strategies. Labor costs may also be slightly higher than other alternatives because although the system is relatively simple to operate, temperature, conductivity, flow rate, and pH need to be monitored routinely.

While the technology has been widely developed, licensed, and patented outside of the United States, limited use has been demonstrated in America.

Alternative 6B: Vibratory Shear Enhanced Process (VSEP)

VSEP is a membrane technology, developed by New Logic Research Incorporation, to treat highly concentrated brine. It creates shear at the membrane surface through vibrations to greatly reduce colloidal fouling and polarization of the membrane. This allows for treatment of high TDS streams, such as those found in Paradox.

Description of Alternative

The VSEP unit consists of four components: a driving system, membrane module, torsion spring, and a system for controlling vibration. The driving system is used to generate vibrations, which results in throughput rates 5-15 times higher than conventional membranes in terms of GFD. The module is built as a vertical plate and frame, resulting in a small horizontal footprint with as much as 2,000 square feet in a 4’ x 4’ area. The torsion spring transfers vibration to the membrane module from the system controlling the vibration.

VSEP uses torsional oscillation, produced by sinusoidal shear waves propagating from the surface of the membrane, at a rate of 50 Hz to repel colloidal particles from the surface of the membrane. The solids are held in suspension above the membrane surface as a parallel layer, which acts as a nucleation site for mineral scaling allowing water clear access to the membrane surface beneath. The thickness of this layer is a function of both pressure and filtration rate. When the parallel layer becomes too large, it can be washed away via gentle tangential cross-flow.

Vibration of the membrane surface not only repels particles, but also lowers the available surface energy for nucleation. Energy for nucleation is available at all non-uniform sites of liquid/solid interfaces. The motion of the membrane results in a smoother solid surface with peaks and valleys less prominent and, therefore, less free energy for crystallization. This would normally lead to a super-saturated solution, but, instead, nucleation occurs in the parallel layer above the membrane. Nucleation can occur in this layer because the solids allow time for germination and development.

The conceptual capital cost provided by New Logic for treatment of 160,000 gpd RO concentrate is approximately $2.1 million. O&M costs for this same treatment scheme are estimated to be $280,000. While these numbers give a rough estimate for costs associated with VSEP, pilot testing should be done to verify system capacity on Paradox water and the associated costs.

Advantages

Because of the vibrations keeping colloidal materials in suspension, the VSEP is not limited by solubility of minerals or suspended solids. Filtration can occur at a rate as much as 15 times higher in flux per area than conventional membranes. Therefore, $1/15^{th}$ of the membrane area is required. Also, since the volume of brine is being reduced, smaller evaporation ponds are needed (reduction by as much as 98%). The combination of less membrane area and smaller evaporation ponds results in a much smaller overall system footprint. Since the Paradox location is fairly remote, another advantage of the system is its automation. Little operator involvement is required. Economically, since VSEP is a non-thermal process, operating costs tend to be less than other brine treatment alternatives. The VSEP process will require less land and may be more economically viable than other alternatives.

Constraints

Several constraints are associated with the VSEP process. Since it is a proprietary technology, there is only a single vendor. This may increase costs due to the lack of competitive bidding available. Also, acid and caustic cleanings required to maintain flux need to be conducted at relatively high frequencies, as much as twice per week when treating conventional RO concentrate. Because the VSEP process would be treating highly concentrated brine in Paradox, osmotic pressure can be extremely large, resulting in larger pumping requirements.

VSEP is a technology which has been widely used in the chemical processing industry, but the sustainability of VSEP to treat brine reject is still undergoing research and pilot testing.

Alternative 6C: Product Recovery From Brine

Description of Alternative

As demonstrated by product recovery from brine of the Great Salt Lake and other brine sources, an economic benefit can be derived from brine solutions. Products produced from brine include: magnesium, chlorine, sodium carbonate, bicarbonate, sodium chloride (salt), potassium sulfate, sodium sulfate, and magnesium chloride. The most common mineral produced from brine is common salt. Common salt is mostly sodium chloride but may also contain magnesium chloride and potassium chloride in significant amounts depending on the composition of the brine. Common salt produced from brine is typically not food-grade or table salt. The most common use of this salt is for melting ice on road ways or for water softeners. Common salt is the most easily produced mineral from brine.

Other products produced from brine include: the commercial fertilizer potassium sulfate, the dust suppressant magnesium chloride, the metal magnesium, chlorine gas and chemicals sodium carbonate, bicarbonate, and sodium sulfate.

Production of the above products nearly always starts with the concentration and/or evaporation of the brine in large solar evaporation ponds. Common salt is produced by letting the water in the brine completely evaporate and then simply loading the salt. Producing the other minerals involves concentrating the brine and then putting the brine through a chemical process to extract the mineral of interest. Production of magnesium requires electrolysis to break the chemical bond of magnesium chloride after a chemical process is used to isolate the magnesium chloride from the other salts. Magnesium chloride is isolated in the brine by adding calcium carbonate. Calcium carbonate and magnesium chloride react to make magnesium carbonate which is insoluble in water and settles out. The magnesium carbonate is reacted with hydrochloric acid to obtain a concentrated magnesium chloride solution that is processed into magnesium by electrolysis. The electrolysis is very energy intensive as is any process that breaks chemical bonds.

Brines from the Great Salt Lake are processed into magnesium metal, chlorine gas, potassium sulfate, and sodium chloride (common salt) products. When considering the potential for product recovery from the Paradox Valley Brine it will be useful to compare the chemical compositions of the Great Salt Lake, Paradox Valley brines and other brines. The following table summarizes the approximate chemical compositions of the dissolved solids in the brines.

Table 2: Summary of Approximate Brine Chemical Compositions (%)

Ion	Paradox Valley	Great Salt Lake	Ocean
Sodium	37.0	32.1	30.8
Potassium	1.2	2.3	1.1
Magnesium	0.5	3.7	3.7
Calcium	0.4	0.3	1.2
Chloride	58.2	54.0	55.5
Sulfate	2.7	7.6	7.7
Total	100	100	100

Table 2 shows that the dissolved solids in the Paradox Valley Brine are mostly sodium and chloride. The more economically recoverable products, magnesium, potassium, and sulfate are all a lower concentration percentage than in the Great Salt Lake. Thus a much larger volume of less desirable sodium chloride would need to be handled to produce the same amount of potassium sulfate, magnesium chloride, and magnesium than is handled to produce the same amount from the Great Salt Lake brine.

Advantages

The advantage of this alternative is that a product with economic value could be produced from the brine to offset the cost of brine disposal. Production of a product from the brine that can be sold reduces the amount of brine that would need to be disposed of.

The TDS value for the Paradox Valley brine is approximately 260,000 mg/l which is higher than the Great Salt Lake brine TDS of approximately 230,000 mg/l. Therefore, less energy (solar, gas, or electric) will be needed to concentrate the brine to saturation before future processing.

The process to produce an economic product from brine does not necessarily need to be taken to completion before a product can be sold. For example, a concentrated magnesium chloride brine could possibly be sold to US Magnesium for electrolysis. Thus, eliminating the need for the electrolysis equipment and associated emission control equipment as well as the high energy costs associated with electrolysis. The concentrated magnesium chloride brine could also be sold as the end product for dust suppression.

Constraints

Nearly all methods of processing the brine require very large evaporation ponds to concentrate the brine and/or are very energy intensive. US Magnesium utilizes 65,000 acres of evaporation ponds to take Great Salt Lake brine that is 0.4% by weight magnesium and concentrate it to over 8% which is needed for economic production of magnesium. The very large amount of land necessary is just not available in the Paradox Valley not to mention the environmental problems associated with large brine ponds.

The relatively low concentration of the more economically recoverable products from the brine, make it less likely that the cost of production can be recovered. The economies of scale likely necessary to make it economically viable are unlikely to be achieved at this site. For comparison 5,000,000 tons of salt per year are deposited in the US Magnesium's evaporation ponds as a by-product of the brine concentration process. US Magnesium does not have to dispose of this salt. In Paradox Valley the cost of disposal would have to be added to the production costs.

Alternative 6D: Burning Salt Water

In the last year a scientist working on using radio waves to destroy cancer cells discovered that a radio frequency field can break the bond between hydrogen and oxygen in salt water. The resulting hydrogen and oxygen can then be ignited. The burning of the hydrogen makes it appear that the salt water is burning. Hence the news stories usually refer to burning salt water.

As a result of radio waves breaking the chemical bonds between the hydrogen and oxygen atoms in water the water is separated from the salts or other ions in the brine. Once separated from the brine the hydrogen and oxygen can be burned to create pure water. This pure water could be discharged back to the river or possibly sold. As water is removed from the brine the salt concentrations will exceed saturation and salt will begin to precipitate. The solid salts can then be removed for disposal.

Description of Alternative

Using the process described above the water would be removed from the brine leaving the salt in a solid form to be sold or disposed of. The hydrogen and oxygen generated could be sold or burned to produce some of the energy needed to produce the radio frequency field. In simple terms this is very similar to using electrolysis to produce hydrogen and oxygen from water with the difference being that the energy is applied to the water by radio waves rather than directly by electrodes. If the process could be perfectly efficient it would be energy neutral, i.e. it would require no more energy than what is produced and it would not produce more energy than was used to sustain the process. However, there are inefficiencies in converting electricity to radio waves, water to hydrogen and oxygen and burning hydrogen to produce electricity in a generator. Thus, energy will need to be added constantly to keep the process going. Since this is such a recent discovery little research has been done to quantify the energy balance of the process. However, it is likely to be less energy efficient than electrolysis because this process includes the additional step of using electricity to produce the radio waves. This additional step adds more inefficiencies to the process. It is very likely that electrolysis can have the same results with less energy being used.

Advantages

- The process produces hydrogen and oxygen gas that could be sold to offset energy costs.
- Salt in a solid form would be easier to dispose of than a saturated brine.
- The process may produce more economically products such as magnesium.
- The hydrogen produced could be burned to offset energy demands.

Constraints

The process is so new that little research has been done. The process has been demonstrated at a laboratory scale but has not been used in any large scale applications. There are many issues that must be addressed before this process can even be evaluated for this application. Some of these issues are:

- The process is likely to require more energy than electrolysis.
- Will the use of concentrated radio waves have some unintended consequence such as causing release of chlorine gas , which is hazardous.
- The process has only occurred in a test tube. It is unknown whether this process would even work on a larger scale.
- At high intensity, will the radio waves create a hazardous condition.
- Will a saturated solution or highly concentrated solution prevent or decrease efficiency of the process.

If this process does prove to be viable, it will likely be a proprietary technology only available from one source. With only one source the cost of purchasing the technology will likely be high.

Alternative 7: Enhanced Leakage Pit

This option considers an innovative option similar to an existing facility in Australia.

Background Information – Mallee Cliffs Interception Scheme

The Mallee Cliffs Interception Scheme is located on the floodplain of the River Murray in Australia, 600 river miles from the river mouth. Here the river level is some 113 feet above sea level.

The scheme was implemented in 1994 and has operated successfully ever since. It comprises seven tube wells along the northern bank of the river, with a pumping capacity of up to 6 cubic feet per second (cfs). However, the scheme does not operate during floods, and the average annual output is 2.5 cfs, or some 1,800 acre feet per year. The salinity of the extracted groundwater is about 48,000 mg/L, giving an extracted salt load of close to 105,000 tons per year.

The extracted groundwater is pumped in a rising main to a 365 acre evaporation basin, set 13 miles back from the river. The basin site is at a height above sea level of about 190 feet, meaning the static lift in the rising main is about 80 feet. The basin is hard up against the boundary of the Mallee Cliffs National Park, home to the endangered Mallee Fowl (*Leipoa Ocellata*). Table 3 shows the sequence of geological strata out at the basin site.

Table 3: Geological Strata at the Mallee Cliffs Evaporation Basin Site

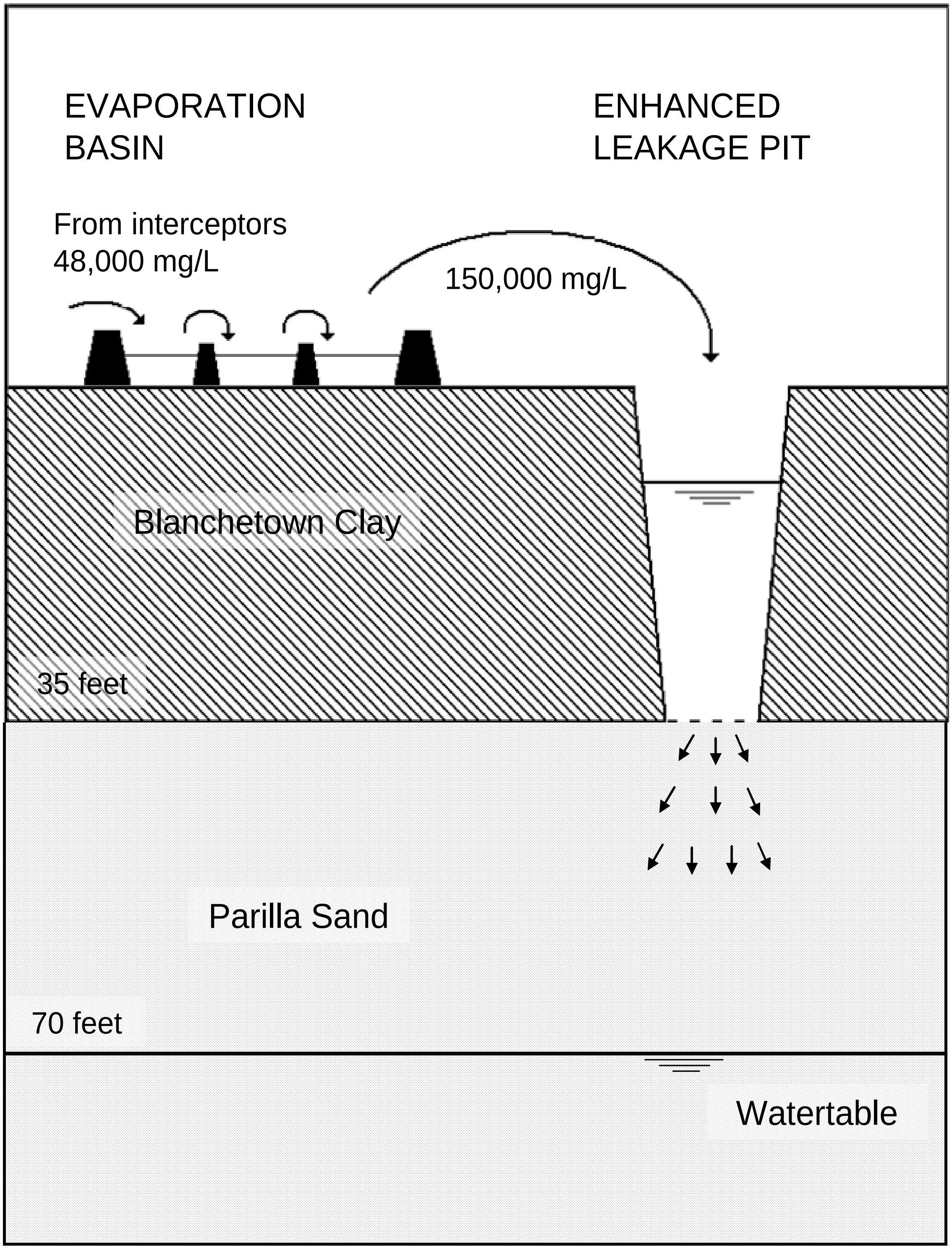
Formation Name	Height Above Sea Level		Description / Comment
	Top	Bottom	
Blanchetown Clay	+190 ft.	+155 ft.	A lacustrine unit consisting of mottled green to brown and red sandy clays that acts as a regional aquitard.
Parilla Sands	+155 ft.	-100 ft.	A marginal-marine to fluvial unit that acts as the regional aquifer. It underlies the whole of this general area and has a variable thickness. Horizontal conductivity is about 15 feet per day. Cemented layers are reported to occur within the Parilla Sands.
Bookpurnong Beds	- 100 ft.	?	Beds formed in a low energy, marine, shelf type environment. Low sedimentation rates and little agitation have resulted in a composition of grey to black plastic marine silty glauconitic clay.
((River Murray))	+ 113 ft. (water level)	+ 105 ft. (bed)	The River Murray has eroded down through the Blanchetown Clay and has formed a trench within the Parilla Sands, partly filled with permeable alluvial material.

Hydro-geological calculations originally determined that vertical leakage out through the basin floor would be sufficient to place a limit on salinities in the basin, and allow the basin to cope with inflows from the interceptor bores. This very soon proved to not be the case, and by 1995 the responsible authority was experimenting with an enhanced leakage pit to take concentrated brine from the final bay in the evaporation basin and dispose of it by vertical leakage. The exact date on which the pit was commissioned for service is not known, but it is presumed to be in 1996.

Description of the Enhanced Leakage Pit at the Mallee Cliffs Evaporation Basin

The enhanced leakage pit is actually one of the borrow pits used to construct the embankments of the evaporation basin. It is shown diagrammatically in Figure 1. Intercepted groundwater at 48,000 mg/L passes through the evaporation basin where it becomes concentrated to 150,000 mg/L. It is then gravitated into the enhanced leakage pit, where the Parilla Sand is exposed in the base of the pit. The head maintained in the pit is typically 20 feet above the base. This head, together with the higher density of the brine, and the fact that the regional water table is about 35 feet below the pit base, creates an infiltration flow out through the base of 0.8 cfs (Woolley, 2000).

Figure 1: Enhanced Leakage Pit



Geophysical monitoring of the scheme has been conducted. The disposal of evaporated saline water via the enhanced leakage pit is causing a hyper-saline plume to develop. It appears that the disposal water travels vertically to the base of the (Parilla) aquifer and then moves south with the regional groundwater gradient. The permeability differences within the Parilla Sand cause the disposal water to "feather" laterally but this appears a minor effect. The movement away from the enhanced leakage pit is by convection with the regional flow, however some diffusion is likely to be occurring. The maintenance of a saline plume, rather than full mixing, will result in a suppressed observed water table. This enables greater volumes to be disposed over the life of the scheme which are constrained by water table rise under the basin and pit. While still speculative, if the plume retains the current character the implication is that the saline plume will not return to the river but run beneath it and the effect of the interception bores (Williams, 2000).

Practical Details of Enhanced Leakage Pit Operation

The bottom of the pit needs to be cleaned out periodically. This means that the brine flow has to be ceased and the pit allowed to drain and dry out. The site manager reports that an unidentifiable black material of organic appearance needs to be scraped off the bottom (B Amoafo, *pers comm*). It is also practice to scarify the bottom. The site manager's opinion is that the black material is something either washed into the pit or off the exposed batters. To combat this he has erected "fences" of fine mesh geo-textile to catch any moving material at the toes of the batters.

At one time thought was given to creating a second enhanced leakage pit at another borrow pit, but this has turned out to be unnecessary – the evaporation basin can accommodate a surcharge of volume while the existing pit is closed down for cleaning.

Parameters for a Possible Enhanced Leakage Pit at Paradox Valley

The Mallee Cliffs basin site is ideal for the use of an enhanced leakage pit. To re-capitulate, the aspects that make it ideal are:

- The tight Blanchetown Clay limits any lateral seepage from the pit.
- The depth of the Blanchetown Clay below the surface allows the Parilla Sand to be exposed without excessive excavation.
- The Parilla Sand has sufficient permeability to allow the concentrated brine to move vertically down.
- The regional water table is some 35 feet below the top of the Parilla – presumably helping the downwards movement of the brine plume.
- The base of the Parilla Sands aquifer (the Bookpurnong Beds) is some 200 feet below the bed of the River Murray, hence when and if the plume hits the base and begins to move laterally, it will be well below the level of the river bed.

The Paradox Valley geology is most likely not conducive to utilizing an enhanced leakage pit.

Development Issues

1. With a salinity of 256,000 mg/L there would be no need for evaporative pre-concentration – the brine could go straight into the pit and be disposed by infiltration. The high specific gravity of the brine would be an aid to infiltration. However, the viscosity of the brine at this concentration could inhibit infiltration and would need to be evaluated further.

2. Any insoluble solids in the brine such as iron sulphide would need to have been removed before introduction of brine to the pit. This also applies to the hydrogen sulphide content of the brine.

3. The pit would be somewhere on the Dolores floodplain in this example. Ideally it would be on the floodplain above the level of most floods. However, the earth excavated to form the pit would probably be sufficient to construct a double ring of very substantial flood control levees right around the pit.

4. The water level in the pit should be no higher than about 15 feet below the natural surface. This will ensure that even if the pit walls allow lateral seepage, any mound created will still be at least 15 feet below the ground level.

5. In this example 50,000 ton per year would be disposed. The volume of brine containing this load is 160 acre feet per year. To be conservative, it will be assumed that with 20 feet head above the base of the pit, the infiltration rate is only 0.5 inches per day, compared with 4 to 7 inches per day at Mallee Cliffs. Therefore, a pit base area of about 10 acres would be required. At the design infiltration rate, some 15 to 16 feet of water will infiltrate per year.

6. Theoretically, if a vertical plume develops and "holds" its shape, and assuming the porosity of the formation that the plume infiltrates is 20%, the front of the plume will advance vertically at 80 feet per year. It would soon encounter bedrock.

7. Much investigation would need to be done on the aspect of lateral movement, either when the plume encounters low permeability horizontal layers in the alluvial sediments, or hits bedrock. Would the pit be better placed upstream or downstream of the interception bore field?

8. Whether the pit would be better placed upstream or downstream of the interception bore field also needs to be evaluated.

9. Related project experience is limited to this Australian operation.

10. Would the infiltrated brine eventually make its way back to the river or fresh groundwater?

Advantages

- Simple in concept, and operates by gravity.
- Occupies only a relatively small area.
- Comparatively cheap to construct – simple bulk earthwork excavation.
- Can feed large quantities of salt underground.
- Operational costs are low (but monitoring could be extensive).

Constraints

- Only suited to certain geological settings, i.e., needs permeable sediments.
- Designers would need to prove the concept at any specific site by a pilot scheme.
- Designers need to think through the consequences of interruption of the flow of the vertical plume by any less permeable horizontal layers in the infiltrated aquifer, and the formations below it.
- Ongoing monitoring of subsurface performance is required.
- Periodic cleanout of the base of the pit is required – this necessitates an alternative destination for the brine while the pit is being dried out (a stand-by pit?).
- At Paradox Valley the brine is at about 80% NaCl saturation. Undue evaporation while in the pit might see salt precipitation on the pit base – perhaps bringing forward the periodic clean out.
- Even if a pit is decommissioned after (say) 30 to 50 years, there will still be movement of the brine that has infiltrated underground – this will need to be monitored.

References

Woolley, D.R. (2000): Mallee Cliffs Salt Interception Scheme Report for the Year to 30 June 2000. Department of Land and Water Conservation (NSW) internal report.

Williams, R.M. (2000): Mallee Cliffs Salt Interception Scheme: Movement of Saline Water. Department of Land and Water Conservation (NSW).

Alternative 8: Salt Bricks

XDOBS, an entrepreneurial company, has developed a process capable of treating highly saline waters such as those found in the Paradox Valley. Their innovative process uses proprietary distillation to separate salt from saline water. The resulting salt residue is then cast into molds, mixed with polymers and additives, and formulated into bricks which can be used for sustainable infrastructures.

Description of Alternative

The first step in salt brick formation is to be able to concentrate saline water sources to concentrations where salt reaches its saturation limit and begins to settle out (in excess of 300,000 mg/L). XDOBS uses a patented distillation process which cycles until all of the original water has been evaporated, leaving salt and other minerals behind. The distillation process uses both the ideal gas law and latent heat transfer with reduced pressure evaporation techniques to lower the boiling point of the input water. An induced vortex is also used to provide an increased air to water surface area via many small bubbles. The daily water evaporation requirement of about 250 tons of salt at Paradox Valley would require approximately 50 of the larger distillation units, each of which distill 4,730 gallons per day. Assuming 10 watts per gallon is required for distillation with these units, about 2,500 kWh per day would be required to distill the necessary water.

Following concentration, the remaining salt would then be formatted into bricks. There are two possible strategies to accomplish this. The fastest is to encapsulate the salt into a polyurethane foam mixture. This mixture provides for water proofing, insulation, and strength. Compression and baking with a plastic fiber mesh is a second alternative. Pressures between 200 and 1500 psi are required to press out the remaining water which is then cycled back through the distillation process. After one of these two possible brick casting methods is complete, the surface of the bricks is treated with a specialized polymer to create a water tight surface impervious to erosion. Additional liquid polymer may need to be added if compressive and tensile strength tests fail to meet minimum requirements. A 15 acre parcel of land would be needed adjacent to the site to allow for distillation, final drying, and casting operations.

The suggested use for the finalized bricks is to sell them for construction of renewable buildings. The current design for brick usage is a two wall system separated by 8 to 30 inches lined with waterproof stucco and HDPE plastic. Cavities will circle the entire structure and be divided into three foot wide segments plumbed together to form a series of thermal storage tanks. These tanks would be filled with water to be heated and chilled using renewable energy techniques. Water is planned to act as mobile thermal energy storage and allow for localized thermal control.

Advantages

The above method offers certain advantages. It provides an opportunity to use the current brine waste in a productive and sustainable manner. Instead of capital for deep well injection, if a market is established, salt bricks could be sold to help generate revenue. Also, if buildings are constructed in the proposed manner, less energy may be consumed for heating and cooling costs during the lifetime of that building. Lastly, the construction of salt bricks may help develop and establish a new process. A distilled water byproduct may also have a beneficial use.

Constraints

Despite the above mentioned advantages, this technology has many disadvantages. Formation of the bricks requires concentrating the brine to levels far beyond the salt saturation limit. This could lead to problems with salt corroding and interfering with operation of the pumps, valves, and other system components. Secondly, the salt bricks are not yet a proven technology and extensive testing would need to be conducted. Compressive strength, tensile strength, and longevity are a few such properties that would need to be tested prior to their acceptance as building materials. Even after testing, it is not guaranteed that the salt bricks would meet current regulations and requirements. Thirdly, much of the cost analysis assumes revenue will be generated from selling bricks. However, there is currently no market for salt bricks. Extensive funding would be needed for marketing and to establish a clientele. Also, no competitive bidding is available for this process. Since the process for salt brick formation is a proprietary technology, there is only a single vendor. Another disadvantage of this option is that while the use of bricks for a dual wall structure that allows energy to be stored in the form of heated or chilled water can reduce heating and cooling greenhouse gas emissions, more than 40,000 gallons of water would need to be stored in the walls of a 3,000 square foot home. This leads to the possibility of major flooding if a rupture in the walls were to occur. Also, storing water in the walls leads to difficulties in installing wiring and other necessary piping. Although not proven, it is estimated by XDOBS that the bricks may have a 100 year life span. It is not known what will happen to the building once the bricks begin to deteriorate. Salt may not only be leached back into the surrounding environment, but the structural integrity of the building may be compromised resulting in a liability for all involved parties.

While this is a new opportunity with potential end product benefits, the constraints appear to outweigh the advantages.

Alternative 9: Conventional Evaporation Basins

During planning and development of the Paradox Valley Salinity Control Unit, serious consideration was given to the disposal of collected brine in conventional evaporation ponds. Planning assumed that the volume of brine would be about 1,200 million gallons per year or 3,600 acre-feet per year (4.9 cfs). Alternatives considered in the DPR included:

- The 3,630 acre Radium Dam evaporation pond located 21 miles to the southeast in Dry Creek Basin, which was designed to hold 93,340 acre-feet with nearly 26,000 acre-feet allocated for flood control and surcharge capacity;
- An evaporation pond in Sindad Valley, a salt anticline located 13 miles north of the collection system, requiring a 40 mile pipeline with 1,000 foot pumping lift; and,
- A series of eight conventional evaporation basins in West Paradox Valley. They would extend northwest of the collection well field for a distance of about two miles.

The volume of brine pumped from the collection system in recent years, about 100 million gallons per year or 300 acre-feet per year (0.4 cfs), is significantly lower than was originally anticipated. However, the current collection well operating regimen is intercepting only about 2/3 of the brine. Therefore, a conventional evaporation pond strategy to replace the existing injection well would need to be able to handle a maximum annual volume of about 150 million gallons per year, or about 460 acre-feet per year (0.6 cfs) of brine. As long as the current injection well is operating satisfactorily, the additional volume of brine needed to accomplish full removal of the salt load from the Dolores River would be about 50 million gallons or 150 acre-feet per year (0.2 cfs).

Description of Alternative

Under this Alternative a scaled down version of Radium Dam evaporation will be evaluated, reflecting the reduced brine disposal needs. Also, a series of evaporation ponds similar to that described in the 1978 DPR would be evaluated. The description of that alternative included in the DPR is as follows:

> "West Paradox Valley Evaporation Ponds
>
> At a pumping rate of 2 cfs or less, the brine could also be evaporated by a series of eight small ponds located adjacent to the well field and in an area extending to the northwest for about 2 miles. The hydrogen sulfide stripping plant would also be located on the northwestern side of the well field, and a buried pipeline would extend from the plant along the length of the ponds, with a separate turnout and valve for each pond. A pumping plant would be installed at the beginning of the pipeline. The ponds would be formed by excavating eight basins and using the excavated material to construct surrounding dikes that would range in height from 25'

> to 80 feet. The resulting ponds would vary in capacity from 1,670 to 8,900 acre-feet and in surface area from 130 to 500 acres. The combined capacities would be about 29,600 acre-feet. To prevent seepage, the ponds would be lined with impervious material, such as butyl rubber, vinyl, or treated clay derived from local shale formations such as the Mancos or Morrison. The ponds would be constructed one at a time as needed during the 100-year operational life of the unit, and the last one would not be completed until about the 70th year. As each one was filled with salt deposits, it would be covered with earth and seeded."

With an annual volume of 160 acre-feet (0.6 cfs) evaporation ponds similar to those proposed for West Paradox Valley may be feasible in East Paradox Valley as well. East Paradox Valley has some advantages over West Paradox Valley because it is less developed than West Paradox Valley and there is much less fresh water overlying the brine. East Paradox Valley was evaluated in the DPR but with an extraction rate of 2 cfs the only area that a large enough evaporation basin could be constructed had geologic problems. The smaller extraction rate (0.6 cfs) may make pond sites within East Paradox Valley feasible.

Advantages

This alternative is technically very simple to implement and concepts are very well understood. Capital costs may be significantly less than other proposed alternatives, especially with the reduced volume to be treated. As to the sequential evaporation ponds, the flexibility provided by phased construction, the extended long-term string of capital investment and the negligible operation and maintenance cost would be very attractive.

Constraints

The same problems identified when deep well injection was chosen as the preferred option still exist. Namely, local opposition, environment issues, and waterfowl injuries due to saturated salt conditions. Environmental permitting has only become more difficult and costly since the evaporation approach was proposed 30 years ago. The main constraint to implementing this alternative is management of the environmental considerations. Evaporation basins at the Great Salt Lake are used extensively by migratory waterfowl without environmental concern. However, even though the hydrogen sulfide would be removed, other potentially toxic elements may remain. Therefore, measures to prevent waterfowl from using the ponds may need to be included. One possible approach would involve installation of netting over the ponds similar to that used in Imperial Valley commercial fish rearing ponds.

Alternative 10: Diversion Tunnel

A diversion tunnel is a possible option to physically separate brine inflow, provided by the salt dome, from the passing flow of the Dolores River. Storage tunnels are a common technique used in the management of combined sewer overflow (CSO), primarily used in Mid-western cities that have combined sewer systems which convey wastewater and storm water in a single piping network.

Description of Alternative

Storage tunnels are widely embraced by water districts as a means to store excess sanitary sewer and storm water in order to control CSO which would otherwise flow directly into rivers and canals and deteriorate surface water quality. During heavy rainstorms when the combined sewer capacity exceeds the wastewater treatment plant capacities, the excessive combined sewer flow is diverted to storage tunnels providing for a gradual release of combined sewer flow to the wastewater treatment facilities following a heavy rainstorm. Without the storage tunnels, the treatment capacity of the wastewater treatment facilities would be surpassed and CSO would result. Notable large-scale projects include the Inline Storage Tunnel (IST) belonging to Milwaukee Metropolitan Sewerage District, and Tunnel and Reservoir Plan (TARP) belonging to Metropolitan Water Reclamation District of Greater Chicago. The IST is currently 19.4 miles long, 120’-330’ deep, 17”-32” in diameter, and has 24 drop shafts and a capacity of 405 MG. The TARP is currently 109 miles long, 240’-350’ deep, 35” in diameter, with a capacity of 1 billion gallons.

A diversion tunnel could be used to convey the flow of the Dolores River through the Paradox Valley, while effectively separating the river flow from underlying salt domes. The diversion tunnel could be constructed just above the salt domes at an approximate depth of 20 feet below surface elevation. The Dolores River flow would enter the diversion tunnel through a series of drop shafts designed to (1) dissipate energy of the falling flow to prevent damage of the structure, and (2) to minimize air entrainment using air vents to prevent limitations on the hydraulic capacity of the drop shaft.

Trenchless technologies include cured-in-place pipe, pipe jacking, slip-lining, fold and form, epoxy coating, pipe bursting, directional drilling, and micro-tunneling. For the scale of this project, which would require smaller diameters, micro-tunneling would likely be chosen as the required tunneling technique.

Advantages

A diversion tunnel would reduce the salt intrusion problem because the bottom of the tunnel would provide a physical barrier between the salt dome and the Dolores River flow. Furthermore, the technique has proven successful in the application of CSO management in appropriately diverting combined sewer flow during heavy flow periods.

The diversion tunnel could be provided to meet the needs of the salt intrusion management.

Constraints

A drawback to selecting the diversion tunnel as the preferred alternative is the high expected costs. Micro-tunneling over a span of 2-3 miles will yield high construction costs and limits the viability of this alternative. The diversion tunnel will also produce technical challenges during implementation, such as dewatering, environmental mitigation, and materials import to the remote site.

A diversion tunnel may prevent brine from entering the Dolores River in the current location but the brine will surface and possibly enter the river in another location unless extraction continues. Extraction and disposal will still be needed. The tunnel would only improve the efficiency of the removal of salt from the Dolores River. Additional issues may be in-stream flow and water rights.

Alternative 11: Agricultural Land Management

A January 6, 1976, report by the US Geological Survey postulated that a major source of recharge to the salt producing aquifer could be from deep percolation associated with the irrigated farmland of the West Paradox Creek Valley. Neither the 1978 DPR nor the 1997 supplement to the DPR address the option of controlling the recharge to the saline aquifer. The general assumption appears to have been that the recharge comes from distant mountain ranges.

A method used successfully in other areas to limit salinity contribution to tributaries of the Colorado River has been to improve the irrigation efficiency. This would be a likely alternative presented in this report if there was potential for improvement of irrigation efficiency in the Paradox Valley. However, nearly all irrigation in the Paradox Valley is already by sprinkler and the few that are not have plans to install sprinkler systems in the near future. There may be some potential to line or pipe open ditches but that would be included as part of the diversion of West Paradox Creek.

Comparing salt loading with the flow that enters the Dolores River between the USGS gauging stations at and below Bedrock provides topical evidence that the amount of salt loading is somewhat related to the amount of flow entering the River as it passes through the Paradox Valley.

Description of Alternative

Under this alternative a regional groundwater flow study will be conducted to assess the likely recharge to the saline aquifer from irrigated agriculture deep percolation. It is likely that the model results will be approximate and only provide an idea of the cause/effect relationship. In order to validate the model assumptions and results, a five year demonstration program would be conducted, where those irrigated farmlands nearest to the Dolores River would be leased and used for wildlife habitat purposes. To retain the agricultural viability of those lands, the lands would be tilled and one irrigation would be applied each year to establish a wildlife supportive cover crop. The program could be modeled after the USDA Conservation Reserve Program.

Advantages

The opportunity to reduce the volume of collected brine that must be managed is very attractive. Also, the limited term program would not involve any irretrievable commitment of resources and, should the program objectives not be achieved, the leasing program could be terminated and the land returned to its historical agricultural use.

Constraints

The main constraint to implementing this alternative is concern with lost economic activity associated with the irrigation and agricultural operation. Already an active upland bird and waterfowl hunting economy is evolving in the area and the resulting tourism economy may offset some of the local economic impact of this alternative. Another approach to addressing these concerns could involve establishment of a “job creation” fund to attract business employment opportunities that could benefit from the labor pool and resource base of the area.

Alternative 12: Add Liner to West Paradox Creek Wetlands

Description of Alternative

This alternative is similar to Alternatives 3, 11, and 13 in that its goal is to limit the groundwater recharge to the system. The difference being that this alternative would prevent the water from recharging the aquifer rather than removing the recharge water. The ponds, marshes and wetlands would be lined with a natural low permeability material such as bentonite. Incorporating bentonite into the soils would allow the wetland vegetation to continue to grow along the banks of the Dolores River while reducing the infiltration of water. This alternative would increase surface runoff to the river.

If lining the whole area flooded by West Paradox Creek proves to be unreasonable, lining the wildlife ponds referenced in Alternative 3 may still be justified. Particularly the southernmost pond that appears to lose the most water.

Currently in the Paradox Valley there is a layer of relatively fresh water that "floats" on the brine. The thickness of the fresh water layer generally gets thinner as it approaches the Dolores River with the brine surfacing in sections of the river. The thinning of the fresh water layer results from a combination of factors. The first is the pumping of fresh water for agricultural use. The second is the constant mixing of the brine and fresh water as it moves towards the river. Understanding this process it follows that reducing the volume of fresh water available to mix with the brine would reduce the volume of brine to be treated.

Advantages

As with Alternatives 3, 11 and 13 this alternative will reduce the volume of groundwater flowing to the Dolores River with hopefully a corresponding reduction in the volume of brine flowing into the river. Reduced brine volume translates into less brine to be treated or disposed of. This alternative would not permanently impact wetlands and would maintain the environmental benefits of the area. Existing flow patterns for West Paradox Creek would not be altered Water rights would not be impacted. Finally, the cost of implementing this alternative is expected to be relatively economical in comparison to other treatment alternatives.

Constraints

This alternative would require the cooperation of the landowner and Colorado Division of Wildlife. After implementation wildlife and cattle have the potential to create holes in the liner compromising its effectiveness. Burrowing animals could dig tunnels through the liner thus creating conduits for groundwater recharge. The hooves of animals such as deer and cattle can punch a hole through the liner when it is saturated. Finally, construction scheduling is critical so as to not impact wildlife and find a time when it is dry enough for the liner to be installed.

Alternative 13: Increase Consumptive Use by Phreatophyte Growing

Description of Alternative

A review of the groundwater discussion on page III-3 of the May 1997 Paradox Valley Unit Final Supplemental Definite Plan Report/Environmental Assessment and the graphs titled "Estimated Dolores River Salt Pickup Through Paradox Valley" for years 2000 through 2007 indicate a seasonal fluctuation in the brine groundwater picked up by the Dolores River. Generally the brine inflow to the Dolores River reaches its lowest level sometime during spring or summer and its highest level during fall and winter. There is no data on Dolores River salinity levels before the Paradox Valley was settled and irrigated agriculture began; therefore, it is not known if this seasonal fluctuation is a natural occurrence or the result of agricultural well pumping or both. It is known the ground water consists of a reasonable fresh water layer sitting on top of brine. The fresh water layer is thickest at the west end of Paradox Valley and narrows vertically as the valley reaches the Dolores River. The Valley slopes gently from the west and east towards the Dolores River which cuts across its middle. At the Dolores River the brine and fresh water layers are intercepted by the river. It is reasonable to assume the agricultural pumping may cause at least in part this seasonal variation based on the fact the pumping is up gradient from the Dolores River and may lower water table levels sufficiently to reduce the hydraulic gradient towards the Dolores River.

Any reduction in the amount of brine available to the Dolores River to intercept would result in less water to inject or at current injection rates result in a higher percentage of salt removed. If the assumption that agricultural pumping and its corresponding consumptive use of fresh water has reduced the hydraulic gradient of the brine flow to the river is correct, then a potential alternative to further reduce brine uptake would be to increase consumptive use of fresh water on the west side as far back from the river as possible. One potential way to do this is to plant additional phreatophytes (cottonwood trees and willows). Another is to increase consumptive use and thus pumping of water on the agricultural lands. This could be done by conversion of a portion of the agricultural land to cotton wood tree forests.

Advantages

Any significant reduction in the amount of brine that must to be intercepted by the east well field will result in a corresponding cost reduction in project O&M and potentially increase of the useful life of the existing interceptor wells and injection well. The Supplemental DPR Biological Assessment indicates the project has the potential to increase habitat for the endangered Southwestern Willow Flycatcher. The project is at the extreme northern end of their nesting range. The biological assessment states salt cedars in marshy areas may increase habitat. Mature cotton wood trees and their associated under story located near slow moving open water also have potential to supply good habitat.

Constraints

The increase in consumptive use of surface or groundwater currently flowing into the Dolores River has several major constraints. First, a water right will have to be obtained for the use.

Second, the additional depletion of water from a Colorado River tributary will be viewed by the US Fish and Wildlife Service as an adverse impact on the Colorado River endangered fish species. Third, the increase in consumptive use is the difference between the current water consumed by what is growing on the land and what will be consumed by its replacement. Based on consumptive use studies of salt cedar, cottonwood trees and alfalfa hay the additional consumptive use at best will be one acre foot per acre. Forth, the natural spread of phreatophytes (salt cedar) near the river may have covered all the viable land at this point. If this is the case additional wells and pumping will be required.

Alternative 14: Integrated Evaporation Pond and Treatment Approaches

Alternatives 4 and 5 contemplate the use of zero liquid discharge (ZLD) technology to reduce the collected brine to a solid state to be disposed in a permitted land fill. These alternatives need electric power and heat energy for their operation.

Solar gradient evaporation ponds collect heat at the bottom of the pond through a fluid inversion process where the heavier brines settle to the lower level of the pond and collect the available atmospheric and solar heat energy. Such ponds typically provide process heat at near the boiling stage while evaporating water from the surface as a conventional solar evaporation pond.

The current injection well is injecting brine that is about 250,000 mg/l. It is likely that the concentration of the brine could be increased without adversely impacting the operation of the injection well. The collection well salinities vary from 210,000 to 270,000 mg/l and collecting the water from the lower salinity collection wells for concentrating is easily accomplished with the current collection and treatment facility configuration.

The integration of the ZLD technology with a small solar gradient evaporation pond to provide heat energy to further concentrate the brine along with continued use of the existing injection well could provide potential to remove additional salt from the Dolores River without increasing the volume of injected brine.

Description of Alternative

Under this alternative the injection well operating characteristics would be assessed to determine whether injection of a more concentrated fluid could be accomplished. A facility configuration would be developed using the flow from the lower salinity collection wells stripped of hydrogen sulfide being delivered to ZLD equipment. A solar gradient pond of about 13 acres would be installed to evaporate about 13 acre-feet per year of brine and provide the heat energy needed for the ZLD equipment. The ZLD equipment would operate solely as a brine concentrator without the crystallizer or centrifuge components. The objective would be to increase the concentration of the injected brine to the level where all of the available brine is extracted through the existing collection wells, concentrated and injected.

Advantages

The ZLD brine concentrating process described above has many advantages. It is a good option for Paradox because it takes full advantage of the sunk cost and operational learning experience of the currently installed facilities. The concentrators are proven technologies that have been demonstrated to work efficiently at various other inland locations. Since the evaporation ponds will be relatively small and land is available, the integration of these varied technologies could provide a cost effective method of treating and disposing of the amount of brine that needs to be collected to achieve full removal the salt load entering the Dolores River.

Constraints

The main constraint to implementing Alternative 14 involves the amount of heat and electrical energy that will be needed to concentrate the collected brine.

Solar Gradient Ponds and ZLD are proven technologies that are suitable for this application, but cost and power supply requirements need to be evaluated in more detail to be considered viable in Paradox.

Alternative 15: River Grout Blanket to Seal Dolores River

The Paradox Salinity Control Unit design has been premised on an assumption that although 200,000 tons per year of salt enter the Dolores River, only 180,000 tons per year could be collected through the collection well system. This leaves about ten percent of the brine uncollected and assumed to enter the Dolores River.

All of the brine that currently up-wells into the bed and banks of the Dolores River could be held below the river for collection through the existing collection wells. This could be accomplished by placing a membrane liner beneath the stream for the approximate three miles where it passes over the collapsed Paradox salt anticline.

For nearly forty years, the Bureau of Reclamation has developed canal lining approaches that involve the installation of synthetic liners such as butyl rubber and various plastics. The Bureau has also developed grouting procedures for creating impermeable sections of dams, their foundations and abutments.

Description of Alternative

This alternative 15 involves placing an impermeable barrier beneath the bed and banks of the Dolores River as it passes over the Paradox Valley collapsed salt anticline. Various lining and grouting materials and technologies will be assessed to determine the best approach to sealing the riverbed and banks. The objective would be to configure a lining method that is most effective while minimizing cost and construction impacts.

Advantages

The overall effectiveness of the Paradox Salinity Control Unit could be enhanced through this alternative. The liners and grouting techniques are proven technologies that have been demonstrated to work efficiently throughout the western states including areas with climates similar to the Paradox Valley.

Constraints

The main constraint to implementing this Alternative involves the possible construction and Dolores River fishery impacts. If a physical liner were to be used, the bed and banks would need to be excavated, possibly causing fishery disruption. However, there would be an opportunity to reconfigure the streambed in a way that enhances the fishery. If the grouting approach is used, there would be only temporary stream disturbance while the grouting equipment moves along the river channel.

This alternative will not eliminate the need for continued extraction of brine. If the brine is not extracted it will rise to the surface and create an evaporation basin adjacent to the river or the brine will find another pathway to the river. Thus, this alternative may improve the efficiency of brine removal but it will not eliminate the need for continued brine extraction.

Alternative 16: Fresh Water Cutoff Wells

An alternative that was briefly evaluated in Chapter VI of the 1978 Definite Plan Report was to intercept the fresh water before it can circulate through the salt dome and becomes the brine which flows into the Dolores River. This alternative was not carried beyond the very early stages of the plan formulation due to difficulties identifying a specific recharge source and the expectation of limited results. For this alternative to be viable, the specific source of water that circulates through the salt dome and surfaces in the Dolores River would need to be identified. However, there may not be a single source of fresh water that becomes brine. It is very possible that the groundwater circulating through the salt dome is part of a regional groundwater system, with recharge areas well outside the Paradox Valley.

Description of Alternative

If a sole source or a limited number of recharge areas for the Dolores River brine can be located, then a series of fresh water cutoff wells could be installed to prevent this water from coming in contact with the salt dome. Removing the water that becomes the brine, in theory, will stop the flow of brine into the Dolores River. The fresh water pumped from the cutoff wells could be discharged to the Dolores River, or be provided to agricultural users in the Paradox Valley.

Advantages

The advantage of this alternative is that the source of the brine can be eliminated and the pumped fresh water can be put to beneficial use. While the cutoff wells would be deeper than the extraction wells by the river, they will not be nearly as deep as an injection well and would not require any specialized equipment. Capital and operating and maintenance costs would likely be far less than the other alternatives that treat or dispose of the brine. There is also a usable product (fresh water) rather than a waste (salt) resulting from this alternative.

Constraints

There are a number of constraints associated with this alternative. To even evaluate this alternative, an extensive groundwater study would be necessary. While groundwater models have improved, they are only as good as the information used to create the model. The many monitoring wells needed to understand the groundwater system would be very expensive. A large amount of money could be spent preparing a hydrologic model of the area, only to find that the hydrologic conditions needed for cutoff wells to work do not exist.

Groundwater systems are very complicated. Removing fresh water from one area may simply allow that water to be replaced by another source. For example, if recharge from the La Sal Mountains is intercepted, then the fresh groundwater on top of the brine in West Paradox Valley may drop down to replace the intercepted water. This currently fresh water could then come in contact with the salt dome. Thus, the fresh water currently pumped for agricultural uses may be lost, while the amount of brine generated is unchanged. This example also shows how current wells and water rights could be impacted by this alternative.

Regardless of how well the groundwater system is thought to be understood, there will always be the potential that an unknown hydrologic feature will cause the failure of the cutoff wells. While this alternative may be less expensive than other alternatives, there will always be a significant chance of complete failure or of limited results.

Combined Alternatives

Many of the alternatives identified above can be viewed as ways to optimize the use of the current deep well system or to improve the efficiency of proposed treatment alternatives while other alternatives have the potential to replace the current injection system. The following alternatives have the potential to replace the existing injection well:

- Alternative 2: Additional injection well. This could replace the existing injection well or provide additional capacity and/or a backup.
- Alternative 4: Zero Liquid Discharge. This alternative would eliminate any need to dispose of brine after processing.
- Alternative 7: Enhanced Leakage Pit. Like an evaporation basin all brine could be pumped to this facility. Although, some storage would need to be available for when the pit was being cleaned and scarified.
- Alternative 8: Salt Bricks. All original water will be distilled with the residual solids being used in the bricks.
- Alternative 9: Conventional Evaporation Basins. Prior to developing deep well injection the preferred alternative was evaporation at the proposed Radium Evaporation Pond. This is still a technically feasible alternative although the environmental constraints may be even harder to overcome now.

The following alternatives can potentially improve the efficiency of salt removal for the existing system or improve efficiency of the other alternatives.

- Alternative 3: Divert West Paradox Creek. This alternative has the potential to reduce the volume of brine that needs to be removed to achieve the same salt load reduction.
- Alternative 11: Land Management Modifications. By changing the groundwater recharge the volume of brine flowing towards the Dolores River may be reduced.
- Alternative 12: Add Liner to West Paradox Creek Wetlands. As with the two above alternatives this may reduce the groundwater recharge and thereby the volume of brine to be removed.
- Alternative 13: Increase Consumptive Use by Phreatophytes. This may decrease the volume of brine flowing to the Dolores River by increasing the consumptive use of groundwater thereby reducing groundwater flow.
- Alternative 14: Incorporate Evaporation Pond (Solar Pond). This alternative would concentrate and increase the temperature of the brine. If the injection well is still in use this would allow a larger mass of salt to be disposed of while injecting the same volume of brine into the well. For treatment options that remove water by distillation such as ZLD the solar pond would reduce the volume of water to be distilled and heat the brine so that less energy will be needed to distill the remaining water in the brine. For Dewvaporation the brine will be concentrated closer to the point of precipitation needed by the process. Dewvaporation also must heat the brine but not to the extent needed for ZLD. The innovative treatments in Alternative 6 all require some concentration and

would benefit from concentration in a solar pond. Finally, concentration of the brine near the extraction well would reduce the volume of brine to be pumped to the evaporation pond, thereby reducing pumping costs.

Dewvaporation and the innovative treatment options discussed in Alternative 6 produce a solid or chemical product that hopefully can be sold or disposed of cheaply but there is still a brine product that must be disposed of. The volume of reject brine is far less than the volume pumped from the extraction wells but it still must be disposed of. This small volume of reject could be injected into the current well or evaporated in a much smaller evaporation basin

The final two alternatives (Dolores River Siphon Crossing and grout blanket) both prevent the brine from entering the Dolores River. However, without brine discharge to the river the brine would rise to the surface making the Paradox Valley an evaporation pond or the brine would find another pathway into the river. To prevent these negative results the brine must continue to be pumped. Therefore, the brine must still be treated or disposed of with one of the methods described above. These alternatives would further reduce the salt loading to river but would not eliminate the brine.

Consultation, Coordination and Selection of Phase 2 Alternatives

A draft of this document has been reviewed by staff from the Bureau of Reclamation as well as by members of the Colorado River Basin Salinity Control Work Group. The written comments of the Work Group are contained in a letter dated February 21, 2008, a copy of which is included in Attachment B of this report.

As a result of that consultation and coordination, Reclamation staff has directed that the Phase 2 evaluations be conducted only on Alternatives 1, 2, 3, 4, 5, 6a, 6b, 9, 11, 12 and 14

ATTACHEMNT A

TRIP REPORT

TRIP REPORT - JANUARY 9 – 10, 2008 SITE VISIT

PARADOX VALLEY SALINITY CONTROL UNIT

On January 9, 2008, members of the Franson Civil Engineers Team (the Team) visited the Paradox Valley Salinity Control Unit (Unit) in the area of Bedrock, Colorado. Team members included Layne Jensen, Bill Everest, Walt Fite and Michael Clinton. The purposes of the site visit were to (1) familiarize the Team with the current physical layout and condition of Unit facilities, (2) obtain copies of available operational data and documentation, and (3) observe areas adjacent to the Unit collection system to identify possible alternative methods of achieving the Unit's salinity control objective.

The Team stayed in Moab, Utah, on the evening of January 9 and traveled through La Sal to Bedrock on the morning of January 9th. A heavy snow storm began as the Team traveled to Bedrock. We arrived in Bedrock about 10:00 AM and met with Reclamation's Facility Operations Specialist, Andy Nicholas. Mr. Nicholas introduced us to members of his staff, as well as on-site employees of the contractor operating the Unit's facilities.

The Team spent the morning with Mr. Nicholas, who provided a number of file reports describing the planning and construction of the Unit. We also discussed the current operational strategies, including the current injection strategy, which includes twice yearly shutdowns to rest the well. Mr. Nicholas indicated his feeling that the current injection strategy has minimized both seismic and injection well back-pressure concerns, although the long-term operational viability of the injection well is still a concern.

We spent significant time discussing how the saline aquifer is being recharged. Mr. Nicholas indicated that he has seen little evidence of Dolores River water entering the collection well system. In reviewing a graph showing daily Dolores River flow and daily salt loading, the Team observed that there have been short-term occurrences when changes in river flow (stage) result in inverse changes in daily salt loading – this suggests that there may be a "bank storage" process operating within the banks of the Dolores River. Mr. Nicholas also told the Team that he has observed saline rivulets along the West Bank of the Dolores River when an adjacent wildlife pond (Pond No. 3) is filled. There may be a possibility that when the pond was excavated, the excavation cut into the gravel formation that connects the halite beds and the Dolores River. The option to line Pond 3 was discussed.

We also discussed the Unit's operational results. The Unit has been injecting about 110,000 tons of salt per year, while salt loading to the Dolores River has been reduced by about 150,000 tons per year. We discussed possible reasons for this anomaly, including the influence of recent drought conditions on West Paradox Creek, as well as improved irrigation methods (side roll and center pivot sprinklers) on irrigated farmland in West Paradox Valley. The irrigated farmland supports a population of about 200 people living in the West Paradox Creek Basin.

We discussed the availability of groundwater monitoring data. Mr. Nicholas told us that they have 40 groundwater monitoring wells – water levels are read at the beginning and end of each operational shutdown period. It appears that those data could be used to calibrate a model of the groundwater flow network. Mr. Nicholas indicated that Reclamation owns 340 acres in the area.

Following lunch, Mr. Nicholas drove the Team on a tour of the area. Sites visited included most of the collection wells, two of the EC Meter sites on the Dolores River, the abandoned Union Carbide evaporation pond site, the facility where the flow from the collection wells is monitored and filtered before being transmitted by pipeline to the injection facility, the Conoco Well location (possible site for an additional injection well), farmland on the west side of the Dolores River, the wildlife ponds (including Pond 3) and the injection well location. Because power to the facility was shut off for maintenance reasons, we did not enter the injection facility. Team members took many photographs during the field tour.

Following the field tour, the Team returned to Moab via Grand Junction because of the ongoing snow storm.

On January 10, the Team met in Moab and developed a list of additional information that would be requested from Reclamation. The Team also developed a preliminary list of alternatives before returning to their respective offices.

ATTACHEMNT B

Colorado River Basin Salinity Control Forum
Work Group Phase 1 Technical Forum Comments

Insert Attached Work Group Comments Here