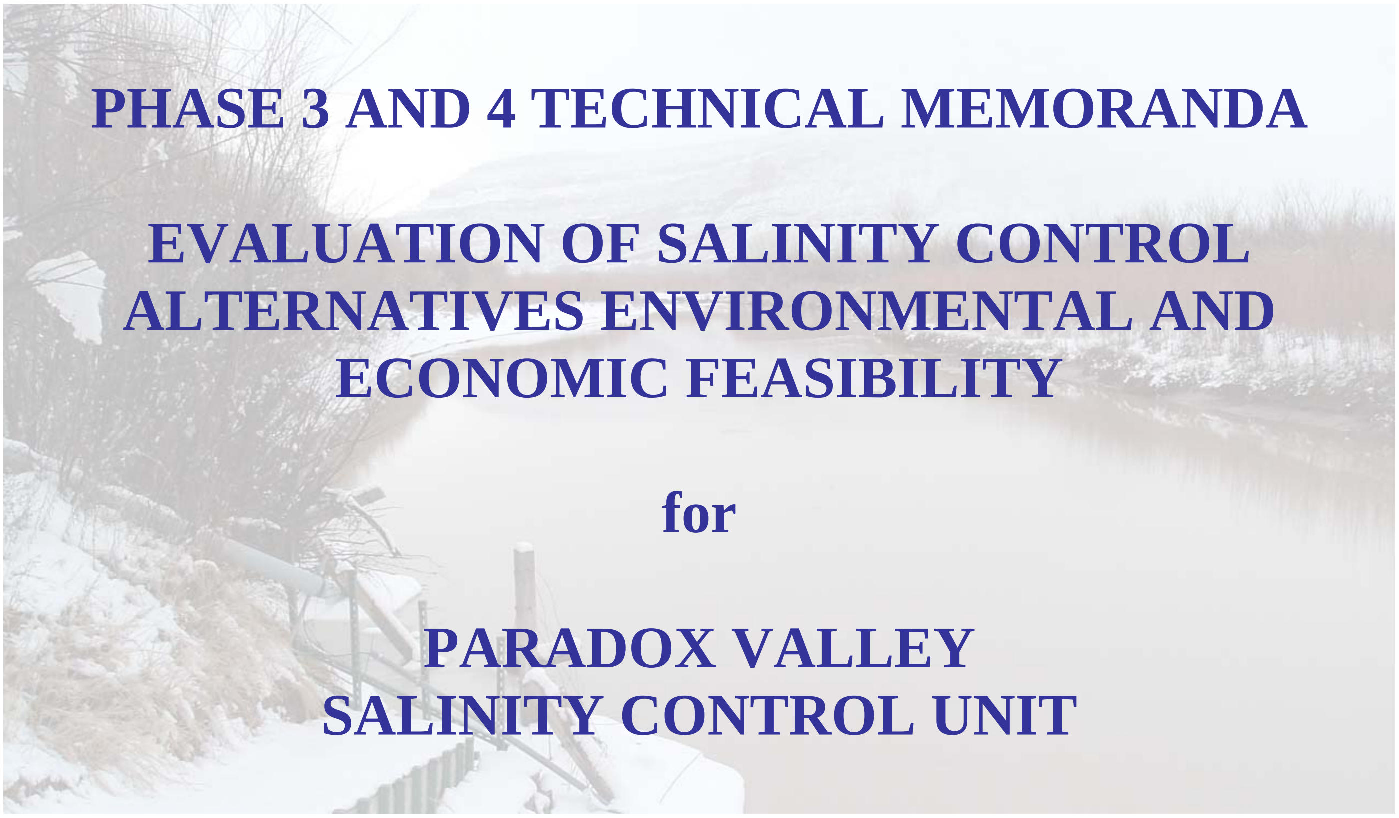

PHASE 3 AND 4 TECHNICAL MEMORANDA

EVALUATION OF SALINITY CONTROL ALTERNATIVES ENVIRONMENTAL AND ECONOMIC FEASIBILITY

for

PARADOX VALLEY SALINITY CONTROL UNIT

by

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Introduction

The Phase 1 Technical Memorandum, Identification of Potential Methods, identified 16 alternatives, with 4 options as part of Alternative 6, for reducing salt loading to the Dolores River. Of the 16 identified alternatives, 9 were evaluated for technical merit. During the evaluation of technical merit, Alternative 6A, SAL-PROC, and Alternative 12, Line West Paradox Creek Wetlands, were eliminated from further evaluation. This technical memorandum will justify the elimination of Alternatives 6A and 12 as well as discuss the environmental and economic feasibility of the remaining 10 alternatives. Utilizing the numbering system used in the Phase 1 Technical Memorandum, the alternatives to be further evaluated in this technical memorandum include:

- Alternative 1: Enhance existing injection system;
- Alternative 2: Additional injection well;
- Alternative 3: Divert West Paradox Creek;
- Alternative 4: Zero Liquid Discharge;
- Alternative 5: Dewvaporation;
- Alternative 6B: Vibratory Shear Enhanced Process;
- Alternative 9: Conventional evaporation basins;
- Alternative 11: Agricultural land management; and
- Alternative 14: Integrated evaporation pond and treatment approaches.

Alternatives Eliminated From Further Evaluation in Phase 2

This section provides justification for eliminating some of the initially identified alternatives from further evaluation. While this section will provide a specific reason for eliminating the alternatives, refer to the sections on Constraints in the Phase 1 Technical Memorandum for more complete information.

Alternative 6A: SAL-PROC

The primary advantage of the SAL-PROC process is that it has the potential to produce a commercial product. However, data shown previously indicates that the Paradox brine is mostly sodium and chloride rather than more marketable products such as magnesium, potassium or sulfate.

A recent SAL-PROC project being pursued by Geo-Processors in Australia has resulted in several implementation constraints, and will not be completed (Source: SKM, Keith Collett, personal communication).

Due to the problems implementing the process in Australia and the limited amount of more marketable products in the Paradox brine, the SAL-PROC process does not appear to be technically or economically viable for the Paradox project.

Alternative 13: Line West Paradox Creek Wetlands

The wetlands and wildlife ponds adjacent to the Dolores River in the brine inflow area cover hundreds of acres. Lining such a large area to reduce, but not eliminate, the salt loading will not be economically feasible. Alternative 3, Divert West Paradox Creek, can accomplish the same results at a much lower cost. Thus, this alternative has been dropped from further consideration.

If diversion of West Paradox Creek is infeasible, some benefit may be derived from limiting the time the wildlife ponds are filled prior to the migration season. Currently the wildlife ponds are filled whenever there is water in West Paradox Creek. Limiting the time the ponds are filled will limit the time that recharge of the aquifer is occurring. Thus, reducing brine inflow.

Phase 3 and 4 Evaluation Methodology

The approved "Approach to the Work" for Phases 3 and 4 provides that the FCE team will evaluate each candidate alternative for environmental and economic feasibility. To accomplish this objective, the remaining candidates were configured in a preliminary manner to identify the environmental issues associated with the alternative and the cost of implementing each alternative.

Environmental Feasibility Evaluation

FCE team members have contacted local, county, state, and federal agencies to determine the environmental issues associated with the various alternatives. The environmental issues identified for each alternative will be discussed in the body of this report. The general environmental impacts of the existing facilities are discussed as part of Alternative 1. Environmental issues related to the alternatives will only be discussed if they vary from the issues already addressed in Alternative 1. The relative ease or difficulty related to addressing the environmental issues will also be discussed in the evaluation.

Economic Feasibility Evaluation Methodology

An appraisal grade cost estimate has been prepared for each alternative to assess the relative merits of the various alternatives. The appraisal grade cost estimate includes: the capital costs associated with constructing the facilities associated with each alternative, the permitting and environmental mitigation costs estimated based on the environmental feasibility evaluation, and 30% of the capital costs for contingency and engineering. To allow comparison of the current brine disposal system to the alternatives, the capital costs are based on the cost to dispose of 230 gpm of brine (310 acre-feet), and/or 109,000 tons/year of salt. Some of the alternatives can be expanded to treat a larger volume of brine than is currently being injected. Some of the alternatives do not treat the brine but will reduce the volume of brine to be treated and/or improve the efficiency of brine treatment alternatives. For these alternatives, the cost and the salt reduction have been estimated and a cost per ton of salt removed was calculated. In association with the capital costs, the annual operation and maintenance costs have been estimated for each alternative. In evaluating the relative economics of specific alternatives, an estimate of the useful life of the alternative was made, and a discount rate of 4.875% was used, as provided in Reclamation's Federal Register Notice[1] dated November 16, 2007, to determine an annualized cost of capital. The annualized cost of capital plus annual O&M cost was then used to compare the current system to the alternative. The operation and maintenance costs for the current system are approximately $2.9 million. The alternatives that utilize the current extraction system will include a portion of the operation and maintenance costs. It is estimated that approximately $300,000 of the O&M costs are associated with the extraction system.

Alternative 1: Enhance Existing Injection System

This alternative represents the baseline by which the other alternatives being evaluated can be compared. The only enhancement to the current operation that has been identified is to concentrate the brine further before injection. The costs and environmental issues associated with the process to concentrate the brine will be discussed in other alternatives. The costs and environmental issues identified here are for the current operating conditions for the system. Namely, a brine injection rate of 230 gpm (310 acre-feet) and an average salt disposal of 109,000 tons.

Environmental Feasibility

When developing a plan for the control of brine inflow to the Dolores River in the Paradox Valley, the Bureau of Reclamation (BOR) originally intended to use a large evaporation basin. In addition to local opposition for the plan, the EPA recommended that deep well injection be used for brine disposal. Given the local opposition and EPA's recommendation, the current deep well injection system was built.

Environmental issues addressed in relation to the current system include:

Groundwater Quality. Whenever brine is injected into an aquifer there is concern that it may adversely impact a fresh water aquifer. The Leadville formation, where the brine is to be injected, already contains brine with a TDS of approximately 218,000 mg/l. The water in Leadville formation is unusable and injection of brine will only slightly increase the salinity of the in-situ water located 15,000 feet below the surface. The depth and isolation of this formation render migration of the brine to usable aquifers virtually impossible. The BOR obtained a Class V injection well permit pursuant to Underground Injection Control Regulations of the Environmental Protection Agency (EPA). To obtain this permit, BOR had to demonstrate that brine injection would not adversely impact fresh water aquifers. Near surface groundwater quality will not be impacted by deep injection.

Water Rights. Extraction of brine adjacent to the Dolores River reduces the inflow to the river. As a result of the depletion to the river, caused by the extraction of brine, a water right has been obtained by BOR. In 1972, the BOR obtained a conditional water right for 4.94 cfs. This water

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[1] CHANGE IN DISCOUNT RATE FOR WATER RESOURCES PLANNING [Federal Register: November 16, 2007 (Volume 72, Number 221, Page 64669]

right has a priority associated with it. The priority of the water right will not allow continuous extraction. To compensate for the priority of the water right, BOR prepared an augmentation plan that would store water in McPhee Reservoir for release when depletions to the Dolores River occurred due to out-of-priority pumping of the brine extraction wells. The water right in McPhee Reservoir is for 700 acre-feet. Since current pumping is limited to 230 gpm (0.42 cfs), 310 acre-feet adequate water rights for the depletion to the Dolores River are in place.

Surface Water. Operation of the unit will cause a depletion to the Dolores River of 230 gpm or 310 acre-feet under current operating conditions. As mentioned above, BOR has water rights for this depletion. Operation of the Paradox Unit does not impact flow or water quality in the East or West Paradox Creeks. In the past, fresh water from the Dolores River has been pumped for mixing with the brine prior to injection. Fresh water extraction from the Dolores River is not currently occurring but may occur in the future. McPhee Reservoir was constructed on the main stem of the Dolores River upstream of the Paradox Valley in 1985 and provides mitigation for the small depletions resulting from the Paradox Unit. In 1996, BOR obtained additional water for release from McPhee Reservoir downstream to the Dolores River. These releases will more than offset the small depletion caused by operation of the Paradox Unit. The Paradox Unit does not discharge to the Dolores River or its tributaries. Therefore, surface water quality will not be degraded as a result of the unit. Water quality of the Dolores River is improved due to the extraction of the brine prior to its flow into the river.

Vegetation. Construction of the current facilities resulted in some permanent impacts. Small areas around wells, access roads, areas around the surface treatment building, and injection well facilities have the vegetation permanently removed. Other areas impacted by construction have been revegetated. The small depletion of groundwater inflow to the Dolores River has been replaced by releases from McPhee Reservoir. Removing some of the brine may result in fresher water being available for riparian vegetation in the brine inflow area. No further impacts to vegetation are expected from the operation of the unit.

Wetlands and Riparian Habitats. The most significant wetland habitat is located across the river from the brine well field on the west bank of the Dolores River. This wetland is dominated by tamarisk and is situated along the river and lower portions of West Paradox Creek. The wetland is supported by saturated soils resulting from the meandering of West Paradox Creek, summer storm runoff, snow melt, agricultural runoff, and possibly groundwater flowing from West Paradox Valley. Pumping brine from the east side of the river has not appeared to impact wetlands on the west side of the river. Removal of brine may actually improve the water quality of the groundwater supporting the wetlands.

Fisheries. Operation of the unit will deplete the flow in the Dolores River. However, releases from McPhee Reservoir will compensate for the small amount of inflow to the river prevented by pumping the brine. Removing some of the salt loading to the river will improve water quality thereby improving the fish habitat. Operation of the unit will improve the fishery.

Wildlife. Impact of the project on wildlife is limited to the disruption caused by human activity as a result of operating the unit on a long term basis. The small depletion to the Dolores River is compensated for by releases from McPhee Reservoir. The small footprint of the current system does not impact access to the river by wildlife and has caused little reduction of habitat.

Threatened and Endangered Species. The May 1997 DPR identified 10 threatened and endangered species that could be impacted by the Paradox Valley Unit. The BOR did not find any impact due to the project on any of the identified threatened and endangered species. The Fish and Wildlife Service (FWS) did not agree with BOR assessments relative to the endangered fish in the Colorado River. The Fish and Wildlife Service concluded that the Paradox Unit would jeopardize the continued existence of the Colorado Squawfish, humpback chub, bonytail and razorback Sucker resulting in the destruction or adverse modification of their critical habitat. The FWS conclusions are based on the assumption that any depletion to the Colorado River will adversely affect these endangered fishes. However, the FWS concluded that because the average depletion was less than the sufficient progress threshold, participation by BOR, i.e. payment of fees, in the Colorado River Recovery Implementation Program would mitigate the impact of the unit. BOR continues to disagree with the FWS, that operation of the unit would deteriorate water quality in the Colorado River, since the operation of the unit prevents over 100,000 tons of salt from entering the Colorado River. FWS has not altered its position since the Environmental Assessment (EA) was completed in 1997. FWS was contacted and indicated that the Black Footed Ferret (listed as endangered), Gunnison’s prairie dog (listed as endangered), and the Yellow-billed cuckoo (listed as a candidate species) may be present in the Paradox Valley. The status of the Gunnison Sage Grouse is currently in litigation and may be listed depending on the outcome of the lawsuit. FWS does not believe the Southwest Willow Flycatcher is in the area.

Cultural Resources: During permitting of the unit, several sites were identified on the lands acquired by BOR that are eligible, or may be eligible, to be on the national Register of Historic Places. The facilities associated with the unit were designed to avoid impacting any archaeological and historic properties. BOR and the Colorado State Historic Preservation Officer agreed that no effect on cultural resources would occur as a result of the construction, operation or maintenance of the unit facilities.

Air Quality: The extracted brine contains hydrogen sulfide. The current system is not closed and approximately 350 lbs/year is released to the atmosphere. The state of Colorado does not currently regulate this release. However, there is potential that this release may be regulated in the future.

Indian Trust Assets: There are no Indian Trust Assets in the Paradox Valley.

Environmental Justice: Analysis conducted as part of the 1997 EA indicated the minority and low-income groups would not be adversely impacted by the Paradox Unit.

All necessary permitting and mitigation efforts have been completed for the construction, operation and maintenance of the current Paradox Salinity Control Unit.

Economic Feasibility

In September 2003, the capital cost associated with the current brine injection system was identified to be $66,302,211. This is the most recent capital cost available. This capital cost includes the permitting, mitigation, and engineering costs, in addition to the cost of the extraction wells, injection wells, and associated facilities. Assuming a 30-year life span and 4.875% interest rate, the capital recovery cost is $4.25 million/year. The current system operation and maintenance cost is approximately $2.9 million annually. Operation of the unit began in 1996 and is expected to have a 30-year life span. Based on this information, the annualized cost of the system is $7,152,000/yr. Using the average salt removal tonnage, since the injection rate was reduced to 230 gpm, of 109,000 tons/year, the cost per ton of salt removed is $65.61/ton.

Alternative 2: Additional Injection Well

A second injection well was anticipated when the deep well injection plan was being developed and implemented. However, the cost of the first injection well precluded installation of the second injection well at that time. The proposed location of the second well is near the north side of the Paradox Valley near a former oil exploration well. This location will allow the second injection well to be completed in the same formation as the first well. The second well should not be hydraulically connected to the first injection well site due to faulting between the two sites. The infrastructure needed to connect a second injection well to the existing extraction system will be needed. This will include a crossing of the Dolores River since the proposed site is on the west side of the river. Approximately two miles of 10-inch HDPE pipeline is anticipated, plus a directional-drilled river crossing.

Environmental Feasibility

The environmental issues and impacts related to Alternative 2 have already been addressed and are expected to be similar to those previously delineated for Alternative 1 (Existing Injection System). With an additional injection well, inducing micro earthquakes is likely to occur. The magnitude of these additional earthquakes is predictable but unknown. Mitigation could be similar to activities with the existing well, including reduced injection rates and periodic resting. The EA for the existing system will need to be updated to reflect the second injection well but the effort required should be much less than needed for the original EA. New facilities associated with a second well will be a pipeline to connect the surface treatment facilities to the new injection well and the facilities associated with the injection well. Only the environmental issues related to these new facilities are addressed below.

Groundwater Quality. Whenever brine is injected into an aquifer there is concern that it may adversely impact a fresh water aquifer. The second injection well will discharge into the same formation as the current injection well. The BOR will need to obtain a Class V injection well permit pursuant to Underground Injection Control Regulations of the EPA for the second injection well. With all of the information available on the first injection well, it should not be very difficult to obtain an injection permit.

Water Rights. Extraction will not exceed current water rights even with a second injection well. No water rights issues are anticipated.

Surface Water. A second injection well will not alter operation beyond what is already permitted. However, the pipeline connecting the surface treatment facility to the second injection well may cross under the Dolores River. The river crossing will require a Section 404 permit from the Army Corps of Engineers. This permit should not be very difficult to obtain. However, the actual underground river crossing will be difficult since it will undoubtedly encounter brine in the excavation. This brine cannot be pumped into the river after sediment treatment, as is normal procedure due to the salt content. The brine will need to be disposed of in the current injection well or some other way. If costs allow, an overhead crossing of the Dolores River may be used to eliminate these problems.

Vegetation. Vegetation will be temporarily impacted by pipeline construction. The injection well facilities will be on land previously disturbed by oil drilling so significant vegetative impacts are not expected. .

Wetlands and Riparian Habitats. Pipeline construction will impact riparian areas adjacent to the river. The impact will be temporary and will be addressed in the Section 404 permit for the river crossing.

Fisheries. Impact on fisheries should not change from the current situation.

Wildlife. Impact of the project on wildlife is limited to the disruption caused by human activity as a result of operating the unit on a long term basis. The small footprint of the second injection well will not impact access to the river by wildlife and will cause little, if any, reduction of habitat.

Threatened and Endangered Species. No additional threatened and endangered species issues are expected as a result of a second injection well.

Cultural Resources: A cultural resources survey will need to be conducted prior to any construction. Any sites identified will need to be avoided.

Air Quality: Hydrogen sulfide will be handled in the same manner as it is in the existing system.

The addition of a second injection well appears to be environmentally feasible.

Economic Feasibility

Capital facilities for an additional injection well system would include:

- Second injection well (assumed to be an 5½-inch bore to a depth of 16,850 feet);
- Second wellhead; and
- Additional surface facilities to test well and pipeline.

The existing extraction wellfield and pipeline have sufficient capacity to supply two injection wells, and expansion and/or upgrading is not required. Although some minor expansion of the extraction system may improve unit efficiency.

If the second well replaces the current well, the capital costs, including contingencies and engineering, are projected to be about $84.4 million (2008 dollars). Annualized over 30 years at 4.875% interest, capital recovery is approximately $5.41 million/year. Annual O&M costs are projected to be about $2.9 million/year. Resultant total annual cost would be $8.31 million/year. The resultant unit cost of salt removal, at 109,000 tons/year, is $76.2/ton.

Existing injection pressure falloff data and analysis suggest that a second injection well operated alternately with the existing injection well would prolong the life of each well thereby reducing the annualized cost. If the second injection well is installed to operate in conjunction with the existing well, the additional capital costs will be the same $84.4 million. However, if the wells are alternately operated, the life expectancy of the wells will more than double. For this study it is assumed that the life expectancy of the wells will be 60 years to be conservative. Annualized over 60 years at 4.875% interest, capital recovery is approximately $4.37 million/year. Since the two wells will be operated alternately, the power costs, staffing costs, and part replacement costs should not change dramatically. The total cost to operate both wells and extraction facility is approximately $3 million/year. Resultant annual cost would be $7.37 million/year. The resultant unit cost of salt removal, at 109,000 tons/year, is $67.6/ton.

Alternative 3: Divert West Paradox Creek

The success of this alternative is predicated on the theory that reducing groundwater recharge in the western portion of the Paradox Valley will decrease the volume of brine flowing towards the Dolores River. When originally conceived, this alternative was to pipe or line West Paradox Creek through the wetland areas adjacent to the river in the brine inflow area. With the theory that all groundwater recharge in the western Paradox Valley impacts salt loading, this alternative can be expanded to include the reduction of agricultural recharge in the valley. This would include lining or piping the open ditch system and lining or eliminating the numerous ponds in the valley. Combinations of creek bypass and reduction of agricultural recharge are also possible. By reducing West Paradox Valley recharge, the brine flowing into the river may be reduced dramatically.

It may appear that further evaluation of this alternative contradicts the decision to not evaluate Alternative 16, Fresh Water Cutoff Wells, further due to difficulties understanding the regional hydrogeology. However, there are two major differences between the two alternatives. The first is the difference between understanding the regional groundwater system and understanding the local groundwater system. The success of Alternative 16 relied upon understanding where water from the regional aquifer interacts with the salt dome to produce brine. Little if any data is available to determine this. Data has been collected within the Paradox Valley that provides some understanding of the groundwater system in the valley. Previous groundwater studies have focused on the local rather than the regional system. The second difference is that we can identify the sources of fresh water recharge in the Paradox Valley and eliminate some of them, such as leaking ditches and canals, at the surface. Intercepting regional groundwater will require deep wells and expensive studies to identify where to put the wells. Controlling freshwater recharge in the Paradox Valley has a much greater chance of success than finding and extracting fresh water in the regional aquifer before it contacts the salt dome.

There are four possible configurations of this Alternative, as follows:

3(A) Piping West Paradox Creek through the reach where it spreads across a large area and recharges the aquifer adjacent to the Dolores River;

3(B) Replacement of the current system of open ditches and ponds with a pressurized irrigation system, ;

3(C) Piping West Paradox Creek from the existing diversion dam at the west end of the valley and conveying the water to the Dolores River near the existing highway bridge. ; and,

3(D) Piping West Paradox Creek from the existing diversion dam at the west end of the valley and conveying the water to the Dolores River near the existing injection well along with the replacement of the current system of open ditches and ponds with a pressurized irrigation system.

The environmental feasibility of these four configurations is similar and is discussed below.

Environmental Feasibility

Technically this alternative is simple. However, it creates many challenging environmental issues and an Environmental Impact Statement (EIS) will need to be prepared. The environmental issues related to this alternative are identified below.

Groundwater Quality. The point of this alternative is to reduce fresh water recharge in the area. With the reduction in fresh water recharge, the groundwater levels are expected to drop. The reduction of fresh water recharge is also expected to increase the salinity of the fresh groundwater near the surface. Groundwater inflow to the river, and thereby brine inflow to the river, will be reduced.

Water Rights. Piping West Paradox Creek may actually increase the volume of fresh water flowing into the Dolores River by reducing the evaporation losses. Water rights on West Paradox Creek will be met through deliveries from the creek bypass facilities. Therefore, West Paradox Creek water rights would not be impacted.

Surface Water. Modifications to West Paradox Creek and at the outlet to the Dolores River will require working with the Army Corps of Engineers to obtain a Section 404 permit. Unlike other states, the State of Colorado relies exclusively on the Army Corps of Engineers to regulate all activities that impact streams, creeks or rivers. Under this alternative, all flow in West Paradox Creek, other than high flow events, would be diverted into the pipeline.

Domestic Water Supplies. Water supplies for some homes and businesses in the West Paradox Valley are derived from local domestic wells. A program to reduce leakage from canals, ditches, and farm fields may adversely affect those wells. Depending upon the option selected, it may be necessary to integrate development of a rural domestic water system into this alternative. Depending upon ability to pay and other factors, the local community may be able to assume a part of the cost of such a system.

Vegetation. Diverting West Paradox Creek will reduce or eliminate the water supported vegetation areas along the creek. Under provisions of the Fish and Wildlife Coordination Act, this loss of vegetation will need to be mitigated.

Wetlands and Riparian Habitats. Diverting West Paradox Creek will dry up an unknown portion of the wetlands at the lower end of the creek adjacent to the Dolores River. Under provisions of the Clean Water Act and the Fish and Wildlife Coordination Act, this loss of wetlands will need to be mitigated with in-kind replacement of an equivalent acreage of comparable quality wetlands. The replacement wetlands would need to be located in an area where leakage would not cause salt loading to the Dolores River.

Fisheries. West Paradox Creek is diverted completely for irrigation during the irrigation season. However, return flows keep water in sections of the creek year round. Due to sections of the creek being dry for much of the year, West Paradox Creek is not likely to support a year round fish population in the area impacted by this alternative. Fish from the Dolores River or from perennial areas above irrigation diversions may use sections of the creek that would be impacted by this alternative when water is available. These potential impacts will need to be addressed in an EA/EIS. Flows in the Dolores River may increase slightly due to the diversion of West Paradox Creek thus, improving the Dolores River fishery.

Wildlife. Any wildlife that uses the wetland and riparian vegetation will be impacted by the diversion. Impacts to wildlife will need to be identified in an EIS and may need to be mitigated.

Threatened and Endangered Species. Because this alternative will impact flows in a tributary to the Colorado River and will impact wetlands, threatened and endangered species become an important issue to be addressed in an EIS. BOR participation in the Colorado River Recovery Implementation Program will likely address the endangered fish in the Colorado River but not any species impacted by changes to wetlands.

Cultural Resources: A cultural resources survey will need to be conducted prior to any construction. Any sites identified will need to be avoided or mitigated.

Air Quality: This option should have no air quality issues to be addressed.

The diversion of West Paradox Creek as proposed would create significant environmental concerns and require in-kind mitigation of the habitat, wetlands, and species that would be impacted.

Economic Feasibility

The construction costs associated with these options will include the cost of environmental permitting, studies, and mitigation, which are difficult to quantify at this juncture.

Option 3(A) -- Diversion of the lower 3,200 feet of West Paradox Creek. The construction and permitting costs (with contingencies and unlisted items) are estimated to be $1.3 million ($300,000 for the actual construction and $1 million for the permitting effort). Operation and maintenance costs for the pipeline will be less than $5,000 per year. The expected life of the pipeline is 50 years. Based on this information, the annualized cost of the system is $75,000/yr. Due to the limited time frame that the creek would be diverted, the reduction in salt loading will be less than the 5,000 tons previously estimated although it will still occur during the most effective time period. It is estimated that salt loading can be reduced by 4,000 tons/year. Using this salt removal tonnage, the cost per ton of salt removed is $18.75/ton. As mentioned before, additional measurements should be made to better quantify the reduction in salt loading before any permitting or design efforts are made.

Option 3(B) -- Replacement of the current system of open ditches and ponds with a pressurized irrigation system. It is estimated that there are approximately 46 miles of canals and ditches that can be replaced by a pressurized irrigation system. The current system serves about 4,000 acres of irrigated farmland, mostly (75%) using sprinkler irrigation. Reconstruction of this delivery system would cost about $1,000 per acre or $6 million for the entire system (with contingencies and unlisted items), including $2 million for the EIS. Operation and maintenance of the system will be turned over to the local irrigation company so there should not be any annual Federal O&M costs. The expected life of the pressurized irrigation delivery system is 50 years. Based on this information, the annualized cost of the pressurized irrigation system would be about $322,000/yr.

Assuming that re-use of tail water and return flow is now being accomplished; deep percolation without system improvements is estimated to be about 0.5 acre-feet per acre. Approximately 3 acre-feet of water is diverted for each of 4,000 acres. This corresponds to about 2,000 acre-feet per year of deep percolation. It is assumed that half of the deep percolation could be eliminated by system improvements. Assuming 14% of the 1,000 acre-feet becomes brine, a pressurized irrigation system could reduce brine inflow by 140 acre-feet. Additional measurements will need to be made to validate these assumptions. With brine at 250,000 mg/l, the salt loading can be reduced by 48,700 tons/year. Using this salt removal tonnage and the combined annual equivalent cost of the pressurized irrigation system ($322,000 per year), the cost per ton of salt removed is $6.61/ton.

BOR has no jurisdiction over the irrigation system in West Paradox Valley. This alternative would need to be instituted by the local irrigation company. BOR may encourage the irrigation company to pursue salinity control funding for the project but cannot make the irrigation company install the improvements.

Option 3(C) -- Piping West Paradox Creek from the existing diversion dam at the west end of the valley and conveying the water to the Dolores River. To accomplish this, a 6-mile, 30-inch diameter pipeline would start at the current irrigation diversion structure and discharge near the bridge over the Dolores River. A 30-inch pipe will handle nearly all flows in West Paradox Creek except for a few days during spring runoff. The existing channel would still be used for these peak flows. The cost to install this proposed system would be approximately $12 million (including contingencies and unlisted items). An EIS would add $2 million to the cost, so the total construction, engineering, and permitting costs are estimated to be $14 million. Operation and maintenance of the system will be turned over to the local irrigation company so there should not be any annual Federal costs. The expected life of the pipeline is 50 years. Based on this information the annualized cost of the system would be about $752,000/yr.

Without replacement of the current system of open ditches and ponds associated with irrigation activities, the pipeline diversion would be limited to those quantities of water that are not needed for downstream irrigation on West Paradox Creek. Current diversions for irrigation dry up West Paradox Creek at the upper and lower ends. Assuming that the natural channel would handle only the infrequent flood flows and non-irrigation flows, excess water entering the wetlands along the Dolores River would be prevented, resulting in a salt load reduction of about 8,000 tons per year. Using this salt removal tonnage and the annual equivalent cost of the pipeline ($752,000 per year), the cost per ton of salt removed is $94/ton.

This option would require coordination with the local irrigation company since BOR has no jurisdiction over the diversion structures in West Paradox Creek. The diversion pipeline design would also need to address all water rights downstream of the initial diversion.

<u>*Option 3(D)*</u> -- Piping West Paradox Creek from the existing diversion dam at the west end of the valley to the Dolores River along with replacement of the current system of open ditches and ponds with a pressurized irrigation system. The combined cost of these two systems (with contingencies and unlisted items), including a $2 million EIS would be about $18 million. Operation and maintenance of the system would be turned over to the local irrigation company so there should not be any annual Federal O&M costs. The expected life of both the pipeline and the pressurized irrigation delivery system is 50 years. Based on this information, the annualized cost of the diversion pipeline and pressurized irrigation system would be about $967,000/yr.

The combination of Options 3(B) and 3(C) is estimated to reduce the salt loading by 56,700 tons per year. Using this salt removal tonnage and the combined annual equivalent cost of the pipeline and pressurized irrigation system ($967,000 per year), the cost per ton of salt removed would be about $17.05 per ton.

BOR would need to work with the local irrigation company as identified in options 3(B) and 3(C) to institute this option of Alternative 3.

As previously mentioned, before any permitting or design efforts are made, additional measurements should be made to better quantify the reduction in salt loading. Also, the cost of permitting and mitigation needs to be better defined, and the impact on domestic wells and the need/justification for a rural domestic water system to serve homes and businesses in West Paradox Valley need to be assessed.

Alternative 4: Zero Liquid Discharge

Zero Liquid Discharge (ZLD) is being considered as an additional brine disposal approach to supplement the existing injection well program.

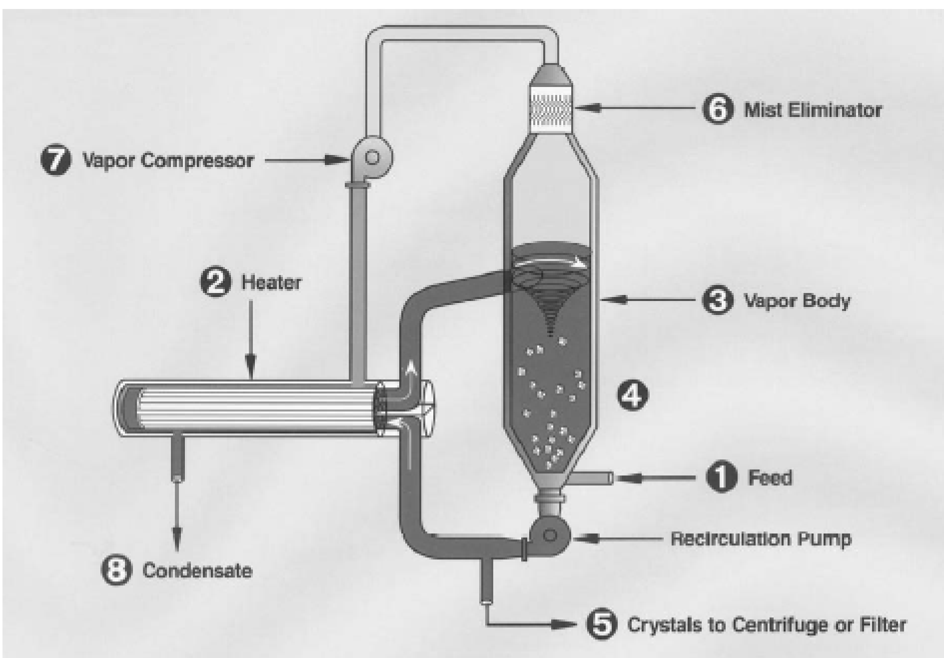
The ZLD system would consist of three components:

1. Brine crystallizer (BC)
2. Solar power for the BC
3. Solar gradient pond (SGP) for BC reject disposal, plus supplemental power

The system would be sized to handle a similar flow as the current operating brine volume of 310 acre-feet/year (approximately 300,000 gpd, or 200 gpm), and an average salt disposal of 109,000 tons/year.

A typical ZLD system includes a concentrator followed by a crystallizer. A concentrator is not required in Paradox because the brine is already concentrated to approximately 240,000 mg/l. Therefore, the brine can be fed directly into the crystallizer (BC) following pre-treatment for H_2S removal to prevent BC corrosion.

For large applications such as this, a forced-circulation, vapor compression crystallizer is commonly used. This type of crystallizer operates in an eight step process (see diagram below):



1. The first step is to feed the crystallizer with highly concentrated water.

2. Secondly, this feed water joins recirculating brine and is pumped into a heat exchanger. The type of heater exchanger used can vary, but a shell and tube type is common. Scaling in the tubes is prevented by keeping the brine under pressure. This pressure is provided by flooding of the tubes.

3. A small amount of recirculating brine is evaporated as it enters the crystallizer vapor body.

4. The evaporation of water from the brine in Step 3 leads to the formation of crystals. Brine which is not evaporated (a majority) is then recirculated back to the heater.

5. The crystals formed in Step 4 are purged from the system and sent to other systems, such as a centrifuge or evaporation pond, for further dewatering before disposal.

6. To remove entrained particles, the vapor produced in the crystallizer vapor body passes through a "mist eliminator."

7. Once particles have been removed, the vapor is compressed. The compressed vapor is used to heat the recirculating brine when it condenses on the shell side of the heater. Using energy in this manner eliminates the need for providing the system with excess steam.

8. Clean condensate from the heat exchanger is purged from the system.

There are several advantages to using this type of crystallizer. One advantage is the automatic wash systems and remote graphic controls. Since onsite monitoring is not required, installation in remote locations is possible. Another advantage is that crystallizers generally are skid-mounted and packaged with auxiliary equipment. Therefore, the installation process tends to be easier than other brine disposal options. A third advantage is that crystallizers have been installed in many areas of the United States and are a proven technology.

Cost and energy usage are typically the biggest constraints with ZLD systems since the process is energy intensive. A typical crystallizer uses 250 kWh/1000 gal of feed/hour. For a flow of 200 gpm at Paradox, 3,000 kWh/hr (26,000 MWhr/year) are needed for the crystallizer to operate.

Another requirement of crystallizers is that they need to be cleaned every 4-6 weeks. This involves purging the volume in the crystallizer body to a storage tank and flushing the unit with service water. This process usually takes between 12-36 hours. A sequential cleaning regime could be developed to reduce downtime to about 1%.

Crystallizers typically have two capacities: 75 gpm and 100 gpm. Either three of the 75 gpm crystallizers or two of the 100 gpm crystallizers could be used to meet the 200 gpm flow requirement. It is recommended to use two 100 gpm units, and apply a 95% plant utilization factor (PUF) to allow downtime for cleaning and preventive maintenance. As shown on the attached layout, dimensions are approximately 62' by 64'. Since two of these units are necessary to treat the current capacity, the total area required for crystallizers is about 11,000 sf, including space for a cleaning storage tank.

Solar Power for the ZLD System

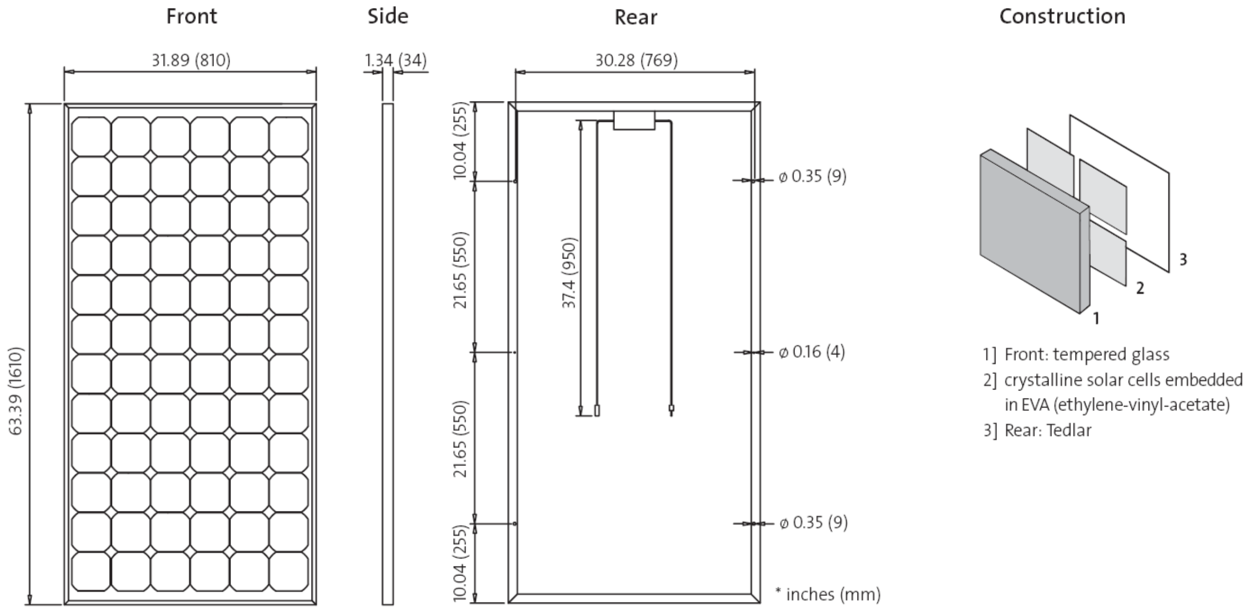
Since there is limited power supplied to the Paradox site, solar energy can be used to offset power requirements from the grid. Depending on the concentrating process chosen, the needed offset for the ZLD system is approximately 3 MW. For continuous operation of the system, additional capacity may be needed for both daylight operation and power to be stored in batteries for night time usage.

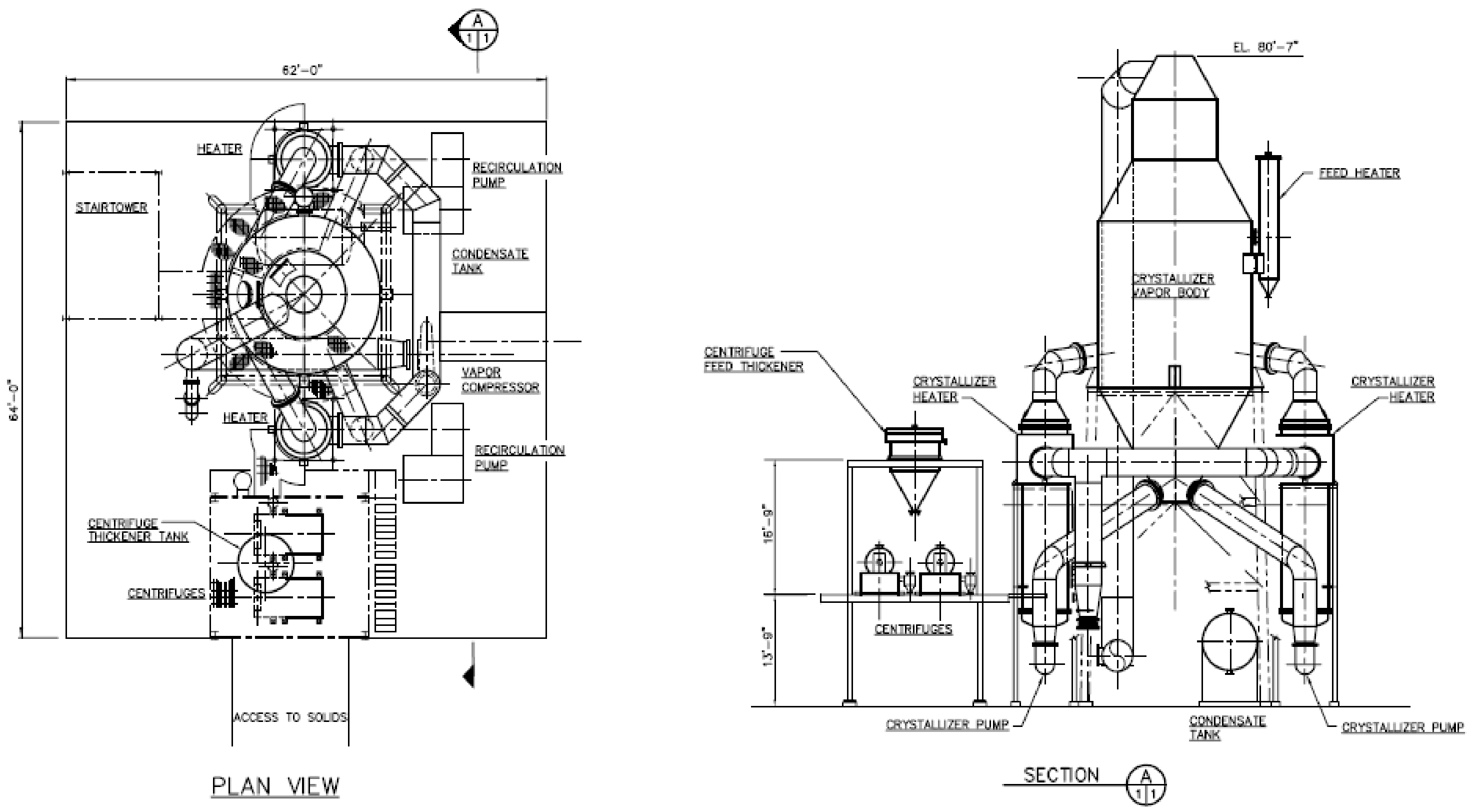
The Paradox solar complex will need to have three main components: photovoltaic cells, inverters, and batteries. Each one of these is discussed in detail below.

Photovoltaic Cells

Photovoltaic (PV) cells directly convert light into electricity. They are made from semiconductor materials such as silicon. A thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current. This electricity can then be used to power a load.

Below is a drawing of a PV module. Sizes listed on this drawing reflect a unit with maximum power of 175 watts so multiple modules will be needed for the Paradox system. Based on discussions with several vendors, approximately 5 acres are needed per MW. Therefore, a 3 MW solar complex would require 15 acres of land.





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PROPRIETARY

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PRELIMINARY GENERAL ARRANGEMENT

100 GPM VAPOR COMPRESSION CRYSTALLIZER SYSTEM

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The photovoltaic drawing reflects a stationary type module. Efficiency can be increased (15-20% more energy per year) if a tracker is installed which tilts the rows from side to side following the sun. Trackers are not recommended for cold areas, however, because of problems that may arise with the freezing of mechanical parts. Therefore, this type of module was ruled out for usage in Paradox.

One constraint with solar power in areas of snow is a decrease in production capacity when the panel is covered. One measure taken to combat this is installing panels 2 to 3 feet above the ground. Therefore, snow levels must reach this height before they would have an effect on the module's production capacity. Secondly, since the modules have an outside layer of black glass and are tilted at approximately a 20° angle, heat is conducted which melts the snow and it is able to slide off. Modules are tested and designed to be resistant to hail that is 1 inch thick and up to 60 mph. Therefore, panels should not be damaged by snow in the Paradox area and production will be slightly decreased only when snow pack levels reach above 3 feet.

Inverter

An inverter is needed to convert direct current (DC) into alternating current (AC). The solar panels will produce DC current, whereas the concentrating system will need AC power.

Batteries

Because solar energy is not continuously available (i.e., night time and cloudy days), storage is an important issue.

The most widely utilized method for energy storage is batteries. There are several types of batteries currently in use:

- Lead-acid battery
- Zinc bromine
- Sodium sulfur
- Nickel cadmium
- Vanadium redox

Based on efficiency levels and experience history, only the lead-acid battery appears viable for a Paradox solar system.

Lead-Acid Battery

Lead-acid batteries are the most common in PV systems because the initial cost is lower and they are readily available worldwide. In the charged state, each cell of the lead-acid battery contains electrodes of lead metal (Pb) and lead (IV) oxide (PbO_2) mixed with other materials in an electrolyte of sulfuric acid (H_2SO_4). In the discharged state, both electrodes turn into lead (II) sulfate ($PbSO_4$) and the electrolyte loses its dissolved sulfuric acid and becomes primarily water. Separators are used between the positive and negative plates of a lead acid battery to prevent short circuit through physical contact.

The size of the battery bank required depends on storage capacity needed, the maximum discharge rate, the maximum charge rate, and the minimum temperature at which the batteries will be used. Temperature has a significant effect on lead-acid batteries. For example, at 40°F the rated capacity is 75% while the capacity drops to 50% at 0°F. The battery in a PV system should be designed to supply needed power during the longest expected period of cloudy weather and should be sized at least 20% larger than this amount to verify the system will continuously operate.

While there are many different sizes and designs of lead-acid batteries, the most important designation is whether they are deep cycle or shallow cycle batteries. Shallow cycle batteries are designed to supply large amounts of current for a short time period and stand small amounts of overcharge without losing electrolyte. They can't tolerate being discharged more than 20% without severely shortening the life of the battery. Therefore, shallow cycle lead-acid batteries are not a good choice for PV cells. Deep cycle batteries, however, are designed to be repeatedly discharged by as much as 80% of their capacity and are, therefore, a good choice for PV modules. All lead-acid batteries fail earlier if they are not recharged completely after each cycle. Deep cycle lead-acid batteries which are sealed are relatively maintenance free and never need watering or an equalization charge. While sealed batteries are more costly, the maintenance free quality makes them more suitable for a remote location such as Paradox.

Batteries should be stored inside a building/trailer, with an approximate area of 2,000 sf.

Operation Schedule of the System

As long as there is power available to the brine disposal system, it will be operational. In order to maintain operation 24 hours a day, 6 MW of power would need to be produced during daylight hours: 3 MW to operate the system directly, and 3 MW for battery storage to operate the system overnight. The system would be operational for all clear or partly clear days. In the Paradox area, this is up to 240 days annually. Economics will dictate whether or not it is viable to oversize the solar system for 24-hour operation.

Solar Gradient Pond

A solar gradient pond (SGP) is proposed to be included in the ZLD system for final disposal of the crystals formed in the BC. SGP systems are further described in Alternative 14.

Environmental Feasibility

Most environmental issues relative to ZLD have been addressed for the current system. Namely, the environmental issues related to the system that extracts the brine and conveys it to a central location. It is assumed that the ZLD facilities will be constructed adjacent to the surface treatment facilities where BOR already owns property. The EA generated for the existing facility will need to be updated to reflect the ZLD system. Since the ZLD facility will utilize a relatively small area of previously disturbed land, updating the EA should not be very difficult

Groundwater Quality. The ZLD process will produce crystallized salt. This salt will need to be stored on-site before being hauled to a landfill for disposal. Although the groundwater beneath the facility is the brine that is being extracted, an impervious pad will be required to prevent the salt from leaching back into the groundwater during precipitation events.

Water Rights. ZLD will not impact any water rights beyond what is currently occurring.

Surface Water. A major factor associated with ZLD is that there is no liquid discharge that could impact surface water. Storm water from the facility will need to be controlled to prevent sediment loading to the Dolores River. A salt handling system will also need to be developed to prevent stockpiled salt from leaving the site in runoff.

Vegetation. Some black greasewood and seabite will be impacted by the ZLD facility. However, the impact will be minimal due to very limited vegetation. Soil in this area is very saline, which limits vegetation.

Wetlands and Riparian Habitats. No wetlands or riparian areas should be impacted by this alternative.

Fisheries. Impact on fisheries should not change from the current situation.

Wildlife. Impact of the project on wildlife is limited to the disruption caused by human activity as a result of operating the unit on a long term basis. The small footprint of the ZLD facility will not impact access to the river by wildlife and will cause little if any reduction of habitat.

Threatened and Endangered Species. No additional threatened and endangered species issues are expected as a result of this alternative.

Cultural Resources: A cultural resources survey will need to be conducted prior to any construction. Any sites identified will need to be avoided or mitigated.

Air Quality: Most of the extracted brine contains hydrogen sulfide. The hydrogen sulfide would be released to the atmosphere as a result of the ZLD process if the hydrogen sulfide is not removed from the brine prior to starting the ZLD process. Hydrogen sulfide is very toxic and highly corrosive. If the hydrogen sulfide is to be vented, some treatment will be required to eliminate the hazard. An air quality permit may be necessary if any hydrogen sulfide is to be released. Currently, hydrogen sulfide is being released and the state of Colorado is not regulating that release. A permit may be necessary in the future. A process that oxidizes the hydrogen sulfide, to produce a solid that can be disposed of with the salt, is included in this alternative.

A ZLD facility appears to be environmentally feasible.

Economic Feasibility

The two main components to the cost of the crystallizer are the capital cost and the energy cost. A single 100 gpm BC unit costs approximately $6.7 million for equipment, supply and design, and $4.5 million for installation. Therefore, the total cost for one 100 gpm unit installed is about

$11.2 million. The cost to provide and install two 100 gpm units is approximately $22.4 million. As mentioned previously, the energy required to operate a crystallizer is approximately 250 kWh/1,000 gal/hr. Therefore, a feed of 200 gpm would require 3000 kWh/hr (26,000 MWhr/year) for treatment. Assuming an energy cost of $.06/kWh, the result is a cost of $180/hr to power the crystallizers. If operation of the crystallizers is 24 hours a day and 346 days a year (allowing for cleaning and maintenance), energy costs would be approximately $1.5 million annually. However, the existing power system at Paradox does not have sufficient excess capacity for the ZLD system. Even considering partial power supply from the existing system (600 kW) and a solar gradient pond (50 kW), an additional power source (2.4 MW) is needed for the ZLD system. This would be met by the solar complex.

Solar Gradient Pond Cost

Capital cost of the SGP is expected to be about $1 million (refer to Alternative 14), and annual operation and maintenance (O&M) costs are estimated at $50,000.

Solar System Cost

The cost associated with installing a 3 MW solar farm (including inverters) is approximately $19 million. This cost can vary due to several factors, including site conditions such as soil composition, weather, and electrical interconnections required during installation. Since there is a 30 year design life on the panels and a 25 year power guarantee, module replacement cost is not a major factor. However, it is recommended that a few spares be purchased at time of construction in case panels break due to vandalism or lightening strikes. O&M costs are about 0.5% annually of the capital cost. Therefore, it is expected that O&M costs for the solar complex would be $100,000/yr. This cost is to conduct a visual annual inspection of panels for any damage. It also includes the cost for an electrician to open all cabinets to check for debris and arching and inspect inverters and disconnects. If a dry weather period is experienced, water trucks may be needed to spray the panels once or twice a year.

The capital cost associated with inverters is included in the initial capital cost of the solar complex. However, inverters have a shorter life cycle than the solar modules and need to be replaced every 12 to 15 years. The replacement cost for a 0.5 MW inverter is $160,000. Therefore, to replace the inverters for the 3 MW solar farm, the cost would be approximately $1.0 million. The O&M costs associated with inverters are included in the 0.5% O&M costs for solar panels. Inverters need to be visually checked once annually to verify they are continuing to provide the required power.

The costs associated with batteries can vary depending on the type of battery chosen. An average value for turnkey battery storage is about $600,000/MWh. Therefore, assuming battery operation for 12 hours and 3 MW of storage needed, the capital cost associated with battery installation may approach $21 million. O&M costs for battery storage is also dependent upon the battery type chosen, but an average value is about $0.02/kWh. Using the same assumptions as with capital cost (12 hours of operation and 3 hours of storage), the annual O&M costs for battery operation are approximately $720/day. Based on weather data, there are approximately 240 fair and clear days at the Paradox site annually. This means the solar panels and batteries can be expected to run approximately 240 days annually. Therefore, the annual O&M cost for batteries at Paradox is expected to be about $200,000.

Scenarios

Four scenarios are considered in the economic feasibility of Alternative 4 (ZLD):

1. Operation for 8 months/year during daylight hours.
2. Operation for 8 months/year, 24 hours per day, with batteries providing night ZLD operations.
3. Operation for 8 months/year, daylight hours with solar power; 4 months/year, 24 hours/day with existing power supply excess capacity.
4. Operation for 8 months/year, 24 hours per day with solar power and batteries; 4 months/year, 24 hours per day with existing power supply excess capacity.

Production Options

Condition	Option			
	A	B	C	D
Operation Schedule • 8 months/year – Solar Power • 4 months/year – Existing Power Supply	• 	• 	• •	• •
Daily Schedule • Daylight – 12 hours • Day & Night – 24 hours	• 	 •	•(a) 	 •(b)
Salt Removal (tons/year)	35,000	70,000	41,000	76,000

(a) 8 months/year – solar power
(b) 4 months/year – existing supply, excess power

Cost Summary

Component	Scenario			
	A	B	C	D
	Day Only	24 Hours Day	12 Hours 12 Months	24 Hours 12 Months
Capital Cost ($M)				
• ZLD	22.4	22.4	22.4	22.4
• Solar Complex	14.5	29.0	14.5	29.0
• Batteries (night power)	-	18.0	-	18.0
• SGP	1.0	1.0	1.0	1.0
• H2S Stripping Plant	2.3	2.3	2.3	2.3
TOTAL	40.2	72.7	40.2	72.7
Capital Recovery ($M/yr) (4.875%, 30 yrs)				
• ZLD	1.44	1.44	1.44	1.44
• Solar Complex	0.93	1.86	0.93	1.86
• Batteries	-	1.15	-	1.15
• SGP	0.064	0.064	0.064	0.064
• H2S Stripping Plant	0.15	0.15	0.15	0.15
TOTAL	2.22	3.99	2.22	3.99
O&M ($M/yr)				
• ZLD	0.05	0.10	0.05	0.10
• Solar Complex	0.13	0.26	0.13	0.26
• Batteries (existing power)	-	1.60(a)	0.30	1.90(a)
• SGP	0.05	0.05	0.05	0.05
• H2S Stripping Plant	0.02	0.02	0.02	0.02
• Existing Extraction Wells	0.30	0.30	0.30	0.30
TOTAL	0.55	2.33	0.85	2.63
Annual Cost ($M/yr)				
• ZLD	1.49	1.54	1.49	1.54
• Solar Complex	1.06	2.12	1.06	2.12
• Batteries (existing power)	-	2.75	0.30	3.05
• SGP	0.12	0.12	0.12	0.12
• H2S Stripping Plant	0.17	0.17	0.17	0.17
• Existing Extraction Wells	0.30	0.30	0.30	0.30
• Salt Disposal	0.70	1.40	0.82	1.52
TOTAL	3.84	8.4	4.26	8.82
Salt Removal (tons/yr)	35,000	70,000	41,000	76,000
Unit Cost ($/ton)	109.7	120.0	103.9	116.1

(a) Includes battery replacement at $1.4 million/year

Alternative 5: Dewvaporation

When developing a plan for the control of brine inflow to the Dolores River in the Paradox Valley, the BOR originally intended to use a large evaporation basin. Subsequently, BOR chose to inject the brine into the Mississippian formation. This alternative would replace the current injection well with a Dewvaporation brine concentrator/crystallizer[2], with the crystallized salt solids being disposed of in a permitted land fill located about 25 miles from the current collection well filtering facility, near Naturita, Colorado.

The Dewvaporation system would be designed to manage the current operating brine volume of 330 acre-feet per year (300,000 GPD) and an average salt disposal of 109,000 tons. Assuming that saturation and crystallization would occur with about 27-percent moisture, about 220,000 GPD of liquid would need to be removed from the brine.

Removal of this volume of liquid would require about two hundred twenty (220), 1,000 GPD Dewvaporation units as well as land fill for disposal of 109,000 cu. yards per year of salt.

Environmental Feasibility

Most environmental issues relative to Dewvaporation have been addressed for the current system. Namely, the environmental issues related to the system that extracts the brine and conveys it to a central location. It is assumed that the Dewvaporation facilities will be constructed adjacent to the surface treatment facilities where BOR already owns property. The EA generated for the existing facility will need to be updated to reflect the Dewvaporation system. Since the Dewvaporation facility will utilize a relatively small area of previously disturbed land, updating the EA should not be very difficult

Groundwater Quality. The Dewvaporation facility will be sited in a location near the existing collection well filtering facility. In normal operations, the combined facilities would operate without any liquid discharge, and therefore there would not be any release of the brine to local surface water or ground water. Potential groundwater contamination concerns, with the existing conveyance pipeline and injection well, would be eliminated as those facilities would no longer operate. The Dewvaporation process will produce crystallized salt. This salt will need to be stored on-site before being hauled to a landfill for disposal. Although the groundwater beneath the facility is the brine that is being extracted, an impervious pad will be required to prevent the salt from leaching back into the groundwater during precipitation events.

Water Rights. Dewvaporation will not impact any water rights beyond what is currently occurring.

Surface Water. A major factor associated with Dewvaporation is that there is no liquid discharge that could impact surface water. Storm water from the facility will need to be controlled to

[2] Mr. Mike Clinton, a contributor to this document, retains a business interest in the Dewvaporation technology, stemming from litigation and a settlement agreement approved by the Maricopa County Superior Court, Arizona.

prevent sediment loading to the Dolores River. A salt handling system will also need to be developed to prevent stockpiled salt from leaving the site in runoff.

Vegetation. Some black greasewood and seabite will be impacted by the Dewvaporation facility. However, the impact will be minimal due to very limited vegetation. Soil in this area is very saline, which limits vegetation.

Wetlands and Riparian Habitats. No wetlands or riparian areas should be impacted by this alternative.

Fisheries. Impact on fisheries should not change from the current situation.

Wildlife. Impact of the project on wildlife is limited to the disruption caused by human activity as a result of operating the unit on a long term basis. The small footprint of the Dewvaporation facility will not impact access to the river by wildlife and will cause little if any reduction of habitat.

Threatened and Endangered Species. No additional threatened and endangered species issues are expected as a result of this alternative.

Cultural Resources: A cultural resources survey will need to be conducted prior to any construction. Any sites identified will need to be avoided.

Air Quality: Most of the extracted brine contains hydrogen sulfide. The hydrogen sulfide would be released to the atmosphere as a result of the Dewvaporation process if the hydrogen sulfide is not removed from the brine prior to starting the process. Hydrogen sulfide is very toxic and highly corrosive. If the hydrogen sulfide is to be vented, some treatment will be required to eliminate the hazard. An air quality permit may be necessary if hydrogen sulfide is to be released. A process that oxidizes the hydrogen sulfide to produce a solid that can be disposed of with the salt is recommended to prevent potential permitting issues and prevent corrosion of the equipment by the hydrogen sulfide.

In addition to the above issues, all necessary permitting and mitigation efforts will need to be completed for decommissioning the current injection well and delivery pipeline.

A Dewvaporation facility appears to be environmentally feasible.

Economic Feasibility

Based upon a Navajo Generation Station crystallizer proposal submitted to BOR in early 2004, such a system would have the following components:

- Two-hundred and twenty 1,000 GPD Dewvaporation Units
- One Hydrogen Sulfide Stripping Plant
- One 7,700 square-foot process building
- 0.4 acres of Right-of-way
- Piping and equipment installation

- 191 million pounds of process steam per year
- 433 MWHrs of electricity per year
- 1.00 equivalent person years of O&M labor
- Supplies and chemicals
- Land fill for salt disposal (109,000 cu. yards per year).

Based upon the 2004 NGS proposal, scaled up to 2008 costs, total capital costs for such a configuration (with contingencies and unlisted items) would be about $12 millon (2008 dollars). Annualized over 15 years at 4.875 percent interest, the annual debt service payment would be about $1,150,000.

Annual O&M, power, steam, and salt disposal costs would be about $3.5 million (2008 dollars).

These costs are incremental increases to the $300,000/yr. current O&M costs, for the collection wells and filtration facility. Therefore, the annual O&M cost for this alternative would be about $3.8 million/year.

The Dewvaporation Alternative would allow the collection and removal of 109,000 tons per year that now enter the Dolores River at an annual cost of $5 million per year and an incremental cost of about $45.84 per ton.

Alternative 6: Other Innovative Treatments

This alternative had been originally divided into four options. Of the four options originally proposed, only Vibratory Shear Enhanced Process (VSEP) has been carried forward from the technical feasibility phase.

Alternative 6B: Vibratory Shear Enhanced Process (VSEP)

VSEP has primarily been used for the treatment of low-flow, high solids, industrial wastewaters. VSEP concentrates the brine by extracting fresh water.

Environmental Feasibility

Many environmental issues relative to VSEP have been addressed for the current system. Namely, the environmental issues related to the system that extracts the brine and conveys it to a central location. However, VSEP can only concentrate the brine, not dispose of it. Hence another method of actual disposal will be necessary such as an evaporation basin, ZLD, or Dewvaporation. This section will only address the environmental issues specific to VSEP.

The following are two major environmental constraints associated with VSEP:

- Very high energy use caused by the extensive power that would be required to produce high feed pressures to overcome the osmotic pressures, related to the near-saturation salt levels in the Paradox brine; and

- Very high use of acid and caustic chemicals that would be needed for expected constant process plant cleanings.

Quantitative estimates of these impacts cannot be made without further research and bench/pilot testing of the VSEP process. However, the following environmental impacts can be expected.

Groundwater Quality. The VSEP process will produce a concentrated brine. This concentrated brine has the potential to degrade groundwater quality further if released. The concentrated brine will need to be handled to prevent any release to the groundwater.

Water Rights. VSEP will not impact any water rights beyond what is currently occurring other than increasing the fresh water in the Dolores River if it is discharged to the river. Due to the quality of the water, BOR may be able to sell the water as culinary water to residents in the Paradox Valley.

Surface Water. Surface water resources would need to be protected from the concentrated brine. If fresh water from the system is discharged to the river, a discharge permit will be needed. The discharge permit should be easy to obtain due to the quality of the water being discharged.

Vegetation. Some black greasewood and seabite will be impacted by the VSEP facility. However, the impact will be minimal due to very limited vegetation. Soil in this area is very saline, which limits vegetation.

Wetlands and Riparian Habitats. No wetlands or riparian areas should be impacted by this alternative.

Fisheries. Impact on fisheries should not change from the current situation other than a possibility of improving water quality by discharging very clean water.

Wildlife. Impact of the project on wildlife is limited to the disruption caused by human activity as a result of operating the unit on a long term basis. The small footprint of the VSEP facility will not impact access to the river by wildlife and will cause little if any reduction of habitat.

Threatened and Endangered Species. No additional threatened and endangered species issues are expect as a result of this alternative.

Cultural Resources: A cultural resources survey will need to be conducted prior to any construction. Any sites identified will need to be avoided.

Air Quality: Most of the extracted brine contains hydrogen sulfide. The VSEP process may not prevent the hydrogen sulfide from getting into the fresh water. Hydrogen sulfide in the fresh water would make it unusable. Hydrogen sulfide may also damage the VSEP unit. A hydrogen sulfide stripping unit should be included as part of any VSEP unit. If the hydrogen sulfide is to be vented, some treatment will be required to eliminate the hazard. An air quality permit will be necessary if any hydrogen sulfide is to be released. Due to the toxicity of hydrogen sulfide permitting of any releases will be difficult if not impossible. A process that oxidizes the hydrogen sulfide to produce a solid that can be disposed of with the salt is recommended.

A VSEP facility appears to be an environmentally feasible component to a brine treatment system.

Economic Feasibility

The extremely high TDS levels in the Paradox brine would require the following VSEP process provisions:

- Multiple RO/NF membrane trains, with resultant significant cost increase;
- Very high feed pressures and feed pump/electrical equipment cost increases;
- Special provisions and costs for expected constant membrane cleaning;
- Extensive cleaning chemical deliveries, storage, and dosing;
- Major risk of membrane scaling, notwithstanding the extensive cleaning regimen.

Quantitative estimates of these costs are not possible without bench/pilot testing, which could be undertaken if VSEP is required in a multiple – project program.

Alternative 9: Conventional Evaporation Basins

When evaluating this alternative it became apparent that two options were possible for the use of a conventional evaporation basin. These two options are a smaller version of the Radium Site proposed in the 1979 DPR and evaporation basins in East Paradox Valley.

Environmental Feasibility

The environmental issues related to evaporation basins at the Radium Site or in the East Paradox Valley are the same. The environmental feasibility analysis is presented here for both options while the economic feasibility analysis for the options will be presented separately. The EA prepared for the current system will require fairly substantial additions to address the issues associated with the evaporation basins. The larger effort required is due to the large area impacted by construction of an evaporation basin and the fact that it will also be used as a landfill for the salt. Although the environmental issues associated with both sites are similar, it should be noted that the EPA has already expressed strong opposition to the Radium Site.

Groundwater Quality. The Colorado State Department of Health and Environment, Solid and hazardous Waste was contacted to identify the environmental issues related to an evaporation basin. The salt in the evaporation is not considered a hazardous waste but the state will still require a double liner for the evaporation basins. The double liner may be 2 feet of clay (secondary) plus a synthetic liner (primary). It may also be two synthetic liners. The ponds will also need a groundwater monitoring system. A permit from the state of Colorado will be needed before any construction activities can take place.

Water Rights. The use of evaporation basins will not impact water rights.

Surface Water. The evaporation basins would be designed such that runoff will be diverted away from the evaporation basins and discharge from the basins will not occur.

Vegetation. A large area will be disturbed to build the evaporation basins. The vegetation impacted will likely be black greasewood, seabite, pinyon juniper, sage brush, cacti, yucca, salt brush, and some grasses. Some mitigation may be required if the area is shown to be critical habitat.

Wetlands and Riparian Habitats. No wetlands or riparian areas should be impacted by this alternative.

Fisheries. Impact on fisheries should not change from the current situation.

Wildlife. Impact of the project on wildlife is expected to be greatest on migrating birds. The FWS may require that all birds be prevented from use of the evaporation basins by using nets or a noise making device. There is some conflict on this issue. The draft EIS for the Radium pond referenced a Colorado State University study that indicated the concentrated brine would not be a concern for migrating birds. It should also be noted that the evaporation ponds around the Great Salt Lake are used extensively by birds with apparently no negative impacts. However, for this discussion it is assumed that birds may need to be prevented from using the evaporation basins. The basins will also remove some habitat for upland species. This loss of habitat may require mitigation.

Threatened and Endangered Species. There is some potential that an endangered species' habitat will be impacted by the evaporation basins. Such impacts, if they occur, will likely require some mitigation. The assessment of the impacts and any mitigation would be part of the NEPA process.

Cultural Resources: A cultural resources survey will need to be conducted prior to any construction. Any sites identified will need to be avoided.

Air Quality: Most of the extracted brine contains hydrogen sulfide. Due to the very toxic and corrosive nature of hydrogen sulfide, the brine cannot be discharged to the evaporation basin until the hydrogen sulfide has been stripped from the brine. A hydrogen sulfide stripping unit should be included as part of any evaporation basin plan. A process that oxidizes the hydrogen sulfide to produce a solid that can be disposed of with the salt is recommended.

EPA has expressed in the past a concern about wind blown salt. When salt precipitates out, it crystallizes and becomes a rock-hard mass. Two examples of this were observed by the BOR while preparing the 1978 Definite Plan Report, one on the Malaga Bend Experimental Salinity Alleviation Project in New Mexico and the other at Texas Gulf Sulfur at Moab, Utah. Both have a large pond with large amounts of precipitated salts around the edges. Vegetation around the two areas showed no sign that any salt had blown from the pond. The prevailing winds in the area, as measured at BOR stations at Bedrock are from the southwest. Any minor quantities of windblown salt would be carried to the northeast and in the direction of the alkaline/saline-tolerant vegetation. Records show the winds are at their most forceful in spring when the ground is dampest, further reducing the possibility of an airborne dust problem.

The only noxious odors associated with the brine stem from hydrogen sulfide gas, which would be stripped from the brine before it reaches the evaporation pond. There would be no odors from bacteriological factors at the evaporation pond itself; because of severe osmotic pressure associated with brine, the pond would be essentially lifeless. Salt is not considered to be any worse than wind borne dust, but the dust issue will likely need to be addressed in an air quality permit application.

In addition to the above issues, all necessary permitting and mitigation efforts will need to be completed for decommissioning the current injection well and delivery pipeline.

An evaporation basin appears to be an environmentally feasible treatment option. However, the environmental issues to be addressed are more complex than for some of the other alternatives identified.

Economic Feasibility

Alternative 9(a): Conventional Evaporation Basin – Radium Site

The original Radium Dam evaporation basin was to be located 21 miles to the southeast in Dry Creek Basin, had a surface area 3,630 acres, was designed to hold 93,340 acre-feet with nearly 26,000 acre-feet allocated for flood control and surcharge capacity, and was assumed that about 5 cfs of brine would need to be evaporated.

The volume of brine pumped from the collection system in recent years is about 100 million gallons per year or 310 acre-feet per year (0.43 cfs).

Under this Alternative 9(A), the Radium Reservoir facility would be further downsized to reflect the smaller volume of brine now being collected.

Based upon the scaled up 1997 cost estimates contained in the Supplemental DPR and indexed to 2008 costs, total capital costs for such a configuration (with contingencies and unlisted items and without waterfowl netting) would be about $103 million (2008 dollars). Annualized over 100 years at 4.785 percent interest, the annual debt service payment would be about $5.06 million per year.

Annual O&M costs would be about $3.6 million per year (2008 dollars).

The debt service and annual O&M costs of $8.66 million (2008 dollars), when compared to a total salt removal of 109,000 tons per year suggests a removal cost of $79.45 per ton.

Alternative 9(b): Conventional Evaporation Basin – East Paradox Valley

A series of evaporation basins could be formed in East Paradox Valley by excavating the 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. At any one time, 330 acres of evaporation surface area would need to be in operation to provide for evaporation of the 330 acre-feet per year of collected brine.

At the current 109,000 tons per year collection rate, assuming 9 acre-feet of volume for every 42,000 tons, about 23 acre-feet per year of accumulated salt would need to be contained in the ponds. Over 100 years, the accumulation of solids would be about 2,300 acre-feet (about 8 feet of depth in a 330 acre evaporation basin). Only one or two ponds would need to be constructed over the 100 year project planning period. When filled with salt, an evaporation basin would be decommissioned by sealing the top and mounding the site in a manner to assure that precipitation runs off, thus preventing moisture infiltration.

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. As each one was filled with salt deposits, it would be covered with earth and seeded and a replacement pond would be developed.

A Hydrogen Sulfide stripping plant would be included and it is assumed that the existing collection well and conveyance system would have the pumping capability to deliver the collected brine to the nearby evaporation basin.

For cost estimating purposes, we have assumed that the initial construction would involve development of one 330 acre pond with an average depth of 10 feet (3,300 acre-feet of storage capacity, which would be 80 percent filled with solids in a 100 year period). Based upon recent experience at the Palo Verde Nuclear Generating Station near Phoenix, double Butyl rubber lined evaporation ponds are costing from $250,000 to $450,000 per acre (2006 dollars). Since there is no recoverable groundwater under the East Paradox Valley, a lesser sophisticated lining approach may be acceptable. At the lower range of costs, 330 acres of evaporation ponds would have a capital cost of about $125 million (2006 dollars).

It is assumed that a Hydrogen Sulfide stripping plant could be located adjacent to current filtration equipment and would have a capital cost of about $4 million.

Because of the conflict over migratory bird exclusion from evaporation ponds, costs have been calculated below for ponds without and with waterfowl netting.

<u>*Without Waterfowl Netting*</u> -- Capital costs for the evaporation pond and Hydrogen Sulfide removal facility (with contingencies and unlisted items) would be about $129 million (2008 dollars). With the evaporation pond cost annualized over 100 years and the hydrogen sulfide removal facility annualized over 30 years at 4.875 percent interest, the annual debt service payment would be about $6.4 million per year.

Annual O&M costs would be about $75,000 (2008 dollars).

The debt service and annual O&M costs of $7.15 million per year (2008 dollars), when compared to a total salt removal of 109,000 tons per year, suggests a removal cost of $65.60 per ton.

With Waterfowl Netting -- Capital costs for the possibly needed waterfowl netting (with contingencies and unlisted items) would be about $93 million (2008 dollars). Annualized over 15 years at 4.875 percent interest, the annual debt service payment would be about $8.9 million per year. Adding these incremental costs to those above, would result in a total capital cost of $220 million and an annual debt service of about $15.35 million per year.

Annual O&M costs would be about $75,000 (2008 dollars).

The debt service and annual O&M costs of $15.1 million per year (2008 dollars), when compared to a total salt removal of 109,000 tons per year, suggests a removal cost of $147.71 per ton.

Alternative 11: Agricultural Land Management

Description of Alternative

This alternative proposes a five year demonstration program to be conducted, where those irrigated farmlands (1100 acres) nearest to the Dolores River would be leased and used for wildlife habitat purposes. It is estimated that deep percolation from these farmlands amounts to about 0.5 acre-feet per acre, or 550 acre-feet per year. Based upon analysis of flow and salt loading from the West Paradox Creek agricultural area, placing these lands in a conservation reserve would reduce deep percolation into the saline aquifer by about 14% thereof, or 77 acre-feet per year.

Environmental Feasibility

Environmental issues associated with this alternative are very limited since it involves taking private land and using it for wildlife habitat. However, since this is a federal project there will need to be NEPA compliance. The NEPA compliance for this alternative is expected to be fairly easy.

This alternative is environmentally feasible.

Economic Feasibility

The program would be modeled after the USDA Conservation Reserve Program with annual payments of about $65 per acre, resulting in an annual cost of about $71,500 per year. The USDA Conservation Reserve Program is currently paying $65/acre for highly productive land in the Grand Valley. It is expected that the rate in the Paradox Valley will be less. However, to be conservative, a rate of $65/acre is assumed for this alternative. With a reduction of 77 acre-feet per year of 250,000 mg/l brine reduction, the associated salt load reduction would be about 26,800 tons per year, with a resulting cost-effectiveness of about $2.67 per ton.

Alternative 14: Integrated Evaporation Pond and Treatment Approaches

Overall Concept. Under this alternative, overall collection well pumping would be increased to 465 acre-feet/year to increase the salt removal by 50 percent and eliminate the current salt loading to the Dolores River. Also, the fluid being pumped into the injection well would be concentrated to 300,000 mg/l. About 72 acre-feet/year of fluid from the higher salinity (260,000 mg/l) collection wells would be filtered and delivered to the injection well. An additional 393 acre-feet/year of collection well pumping would be stripped of hydrogen sulfide and delivered to a 2.5-acre solar gradient pond (SGP) having a depth of 15 feet. The SGP would evaporate about 2.5 acre-feet/year of brine and provide the heat energy needed to concentrate and dispose of the remaining brine. About 238 acre-feet/year of 312,000 mg/l reject from the brine concentrator would be blended with the 72 acre-feet/year of filtered (260,000 mg/l) pumped water and the blend (310 acre-feet/year of 300,000 mg/l brine) containing about 126,000 tons per year would be delivered to the existing well for injection.

Operation of the Solar Gradient Pond. Of the 393 acre-feet/year of collected brine delivered to the SGP, two acre-feet would evaporate, 238 acre-feet/year would be returned to the injection well, and the remaining 153 acre-feet/year would be concentrated to a near solid state. Assuming that saturation and crystallization would occur with about 27-percent moisture, about 120 acre-feet/year or about 107,000 GPD of liquid would need to be removed from the brine. Removal of this volume of liquid would require about eleven 10,000 GPD Dewvaporation Units.

Operation of the Brine Concentrator. The 2.5 acre solar gradient pond could produce about 250 GPM of 185ºF brine. Total flow to the eleven Dewvaporation Units would be 242 GPM of which one-third would evaporate and two-thirds would become reject water, which would be returned to the solar gradient pond at about 100º. Although it may be possible to recapture 120 acre-feet/year of evaporated fluid as distillate, such collection may become problematic and, for the purpose of this analysis, it is assumed that the saturated vapor from the Dewvaporation units is vented to the atmosphere.

Environmental Feasibility

The feature unique to this alternative is the solar gradient pond. The environmental issues relative to a Dewvaporation unit have been discussed previously. The solar gradient pond is similar to the evaporation basins with the exception that the pond will be much smaller and in a different location. The solar gradient pond will be approximately 2 acres in size. The pond will be in the current extraction area, possibly where evaporation ponds were formerly located.

Groundwater Quality. The Colorado State Department of Health and Environment, Solid and hazardous Waste was contacted to identify the environmental issues related to a solar gradient pond. The brine/salt in the pond is not considered a hazardous waste but the state will still require a double liner. The double liner may be 2 feet of clay (secondary) plus a synthetic liner (primary). It may also be two synthetic liners. The ponds will also need a groundwater monitoring system. A permit from the state of Colorado will be needed before any construction activities can take place.

Water Rights. The use of evaporation basins will not impact water rights.

Surface Water. The pond would be designed such that runoff will be diverted away from the ponds and discharge from the basins will not occur.

Vegetation. A relatively small area will be disturbed to build the ponds. It is likely that the area has already been disturbed. The vegetation impacted will likely be black greasewood and seabite which is poor habitat. However, some mitigation may be required if the area is shown to be critical habitat for an endangered species.

Wetlands and Riparian Habitats. No wetlands or riparian areas should be impacted by this alternative.

Fisheries. Impact on fisheries should not change from the current situation.

Wildlife. Impact of the project on wildlife is expected to be greatest on migrating birds. The FWS may require that all birds be prevented from use of the evaporation basins using nets or a noise making device. Cost estimates do not include netting to prevent bird use of the solar gradient ponds.

Threatened and Endangered Species. There is little potential that an endangered species' habitat will be impacted by the pond. However, mitigation will be required if the ponds impacts and endangered species. The assessment of the impacts and any mitigation would be part of the NEPA process.

Cultural Resources: A cultural resources survey will need to be conducted prior to any construction. Any sites identified will need to be avoided.

Air Quality: Most of the extracted brine contains hydrogen sulfide. Due to the very toxic and corrosive nature of hydrogen sulfide, the brine cannot be discharged to the pond until the hydrogen sulfide has been stripped from the brine. A hydrogen sulfide stripping unit should be included as part of any pond. A process that oxidizes the hydrogen sulfide to produce a solid that can be disposed of with the salt is recommended.

A solar gradient pond appears to be an environmentally feasible when included with other treatment alternatives.

Economic Feasibility

Based upon a Navajo Generation Station crystallizer proposal submitted to the BOR in early 2004, such a system would have the following components:

- Two and one-half acre Solar Gradient Pond with Piping
- One-hundred ten 1,000 GPD Dewvaporation Units
- One Hydrogen Sulfide Stripping Plant
- One 3,850 square foot process building
- 3 acres of Right-of-way
- Piping and equipment installation
- 217 MWHrs of electricity per year
- 0.6 equivalent person years of O&M labor
- Supplies and Chemicals
- Land fill for 37,500 tons per year of salt disposal.

Based upon the scaled-up 2004 NGS proposal, total capital costs for such a configuration (with contingencies and unlisted items) would be about $12.9 million (2008 dollars). Annualized over 15 years at 4.875 percent interest, the annual debt service payment would be about $1.23 million per year.

Annual O&M costs would be about $1.1 million (2008 dollars).

These annual debt service and O&M costs are incremental increases to the $2.9 million current O&M costs and $8.462 million debt service for the collection wells, filtration facility, and injection well. Therefore, the annual debt service and O&M cost for this alternative would be about $13.7 million/year.

The Integrated Evaporation Pond and Treatment Alternative would allow the collection and removal of 159,000 tons per year that now enter the Dolores River at an annual cost of about $85.90 per ton.

Summary of Findings

Table 1, below, summarizes the relative technical, environmental, and economic merit of the alternatives considered in this phase of the investigations. The Final Report will summarize all prior work and include recommendations on needed measures to address technical uncertainty and other future actions.

Table 1
Summary of Results

Alternative No.	Alternative Name	Relative Technical Merit	Environmental Feasibility	Capital Cost ($ Millions)	Tons of Salt Removed per Year	Expected Relative Cost Effectiveness ($/Ton)
1	Existing Collection and Injection System	Good	Excellent	66.3	109,000	66
2A	Replacement Injection Well Only	Good	Excellent	84.4	109,000	76
2B	Additional Injection Well operated with Current Well	Good	Excellent	84.4	109,000	68
3(A)	Divert Lower West Paradox Creek	Good	Poor	1.3	4,000	19
3(B)	West Paradox Pressurized Irrigation	Good	Excellent	6.0	48,700	7
3(C)	Divert West Paradox Creek	Excellent	Poor	14.0	8,000	94
3(D)	Divert West Paradox Creek with Pressurized Irrigation	Excellent	Poor	18.0	56,700	17
4A	ZLD – 8 months only during daylight	Good	Excellent	40.2	35,000	110
4B	ZLD – 8 months, 24 hrs per day	Good	Excellent	72.7	70,000	120
4C	ZLD – 8 mo. Daylight only, 4 mo. 24 hrs/day	Good	Excellent	40.2	41,000	104
4D	ZLD 12 mo, 24 hrs/day	Good	Excellent	72.7	76,000	116
5	Dewvaporation	Unproven	Excellent	12.0	109,000	46
6(B)	Vibratory Shear Enhanced Process (VSEP)	Questionable	Good	unknown	109,000	unknown
9(A)	Conventional Evaporation Basin – Radium Site	Good	Fair	103.0	109,000	79
9(B1)	Conventional Evaporation Basin – East Paradox Valley Without Nets	Good	Fair	129.0	109,000	66
9(B2)	Conventional Evaporation Basin – East Paradox Valley With Nets	Good	Good	220.0	109,000	148
11	Agricultural Land Management	Good	Good	$71,500/yr.	26,800	3
14	Integrated Evaporation Pond and Treatment Approaches	Fair	Good	12.9	159,000	86