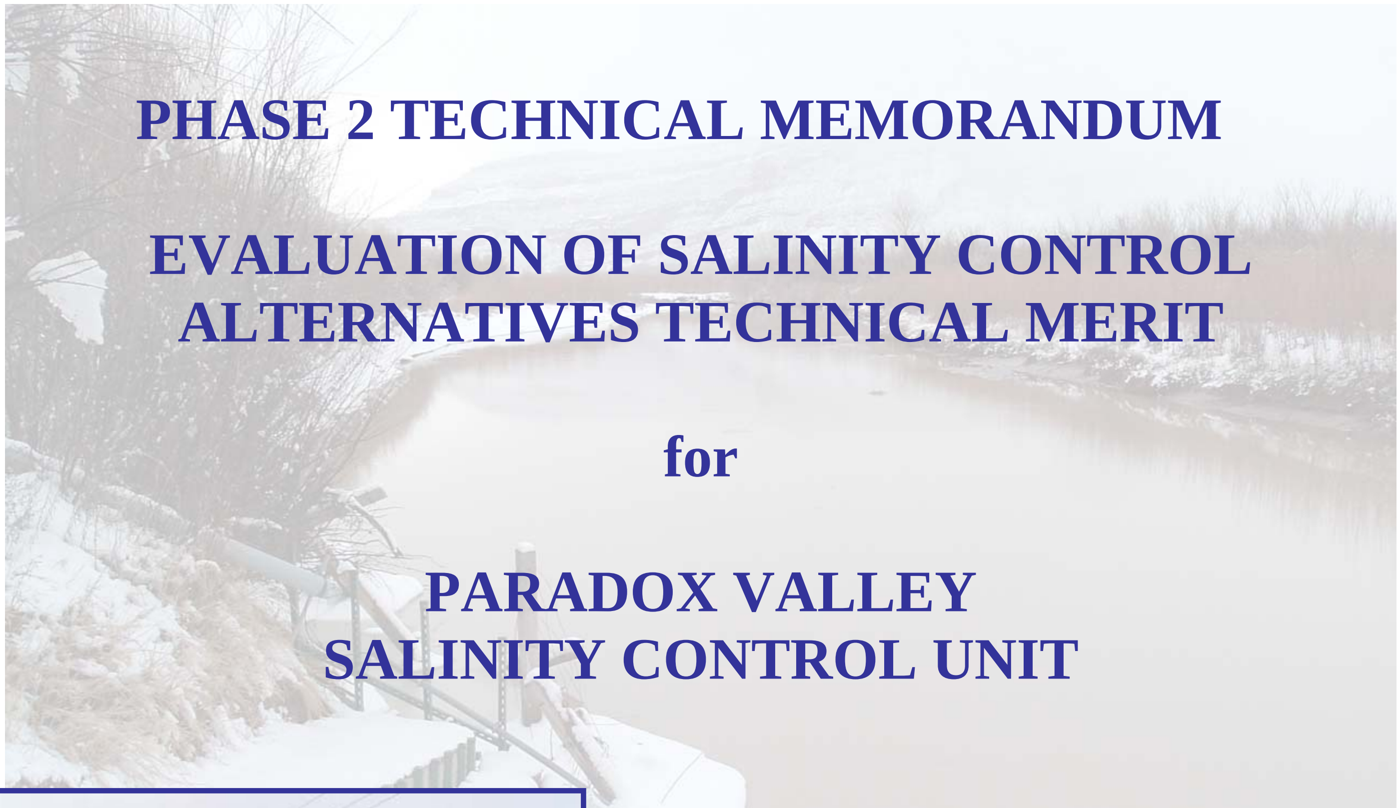
PHASE 2 TECHNICAL MEMORANDUM

EVALUATION OF SALINITY CONTROL ALTERNATIVES TECHNICAL MERIT

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, 10 have been identified for additional evaluation. Two of the four options included in Alternative 6 will be evaluated further, with the other two being eliminated from further evaluation. This technical memorandum will justify the elimination of 6 of the identified alternatives, and discuss the technical merits of the remaining 10 alternatives. Utilizing the numbering system used in the Phase 1 Technical Memorandum, the following alternatives have been eliminated from further consideration:

- Alternative 6C: Product recovery from brine;
- Alternative 6D: Burning salt water;
- Alternative 7: Enhanced leakage pits;
- Alternative 8: Salt bricks;
- Alternative 10: Diversion tunnel;
- Alternative 13: Increase consumptive use by phreatophytes;
- Alternative 15: Line bed and banks of Dolores River; and
- Alternative 16: Fresh water cutoff wells.

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 6A: SAL-PROC;
- Alternative 6B: Vibratory Shear Enhanced Process;
- Alternative 9: Conventional evaporation basins;
- Alternative 11: Agricultural land management;
- Alternative 12: Line West Paradox Creek wetlands; and
- Alternative 14: Integrated evaporation pond and treatment approaches.

As the technical merits of these alternatives were further evaluated, some very rough cost estimates were made. These cost estimates were generated to determine if the cost per ton of salt removed was even close to the range of values that was acceptable. Alternatives with very high cost per ton of salt removed should be removed from future economic and environmental evaluation. Alternatives with cost per ton of salt removed in a reasonable range will be further evaluated in the Phases 3 and 4 technical memoranda.

Alternatives Eliminated From Further Evaluation in Phase 1

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 alternative, the Constraints section for each alternative in the Phase 1 Technical Memorandum contains more information than is presented here.

Alternative 6C: Product Recovery From Brine

Nearly all methods of processing the brine to produce a sellable product require very large evaporation ponds to concentrate the brine. Once the brine has been concentrated it requires further processing, which is usually very energy intensive. Alternative 9, the conventional evaporation basin, would likely be required as a starting point for product recovery from the Paradox Brine, with additional capital and operating costs needed to process the concentrated brine. Since additional costs would be involved in product recovery the product recovery costs will likely exceed the proceeds from the sale of the products. The stand alone evaporation basin will most likely be more economically viable since it would require no additional facilities.

In addition to similar costs for just the evaporation ponds needed for this alternative and Alternative 9, the chemical composition of the Paradox brine has less economically recoverable products (such as magnesium) than other brine sources that are only marginally viable. Facilities currently processing brine also have the benefit of economies of scale. The extraction rate of the Paradox Unit is very small relative to the volumes processed by viable commercial operations.

It is clear that Alternative 9 will be more cost effective than this alternative, given the many limitations. Therefore, there is no reason to expend further resources evaluating this alternative.

Alternative 6D: Burning Salt Water

Early research into this alternative indicates that more energy would be needed to burn the brine than would be necessary for electrolysis. With the knowledge that alternatives such as zero liquid discharge, and dewvaporation are more energy efficient than electrolysis, there is no benefit in further evaluation of this alternative.

Alternative 7: Enhanced Leakage Pit

The geologic conditions necessary to make this alternative possible do not exist in the Paradox Valley or adjacent areas. Therefore, no further evaluation can be justified.

Alternative 8: Salt Bricks

The vendor of this process (XDOBS.com LLC) is proposing that the Bureau of Reclamation fund a test and demonstration project for their proprietary distillation process using Paradox Valley brine. The salt generated by the distillation process would then be used to test a variety of salt brick casting processes. While a small amount of testing appears to have occurred on the salt bricks, the document only offers a theoretical basis for their distillation process. Actual testing of the process does not appear to have occurred. The proposed distillation process appears to be similar to the dewvaporation that is being evaluated further in this document. With actual use of the dewvaporation process occurring, the evaluation of a similar distillation process that has not been tested cannot be justified.

If salt bricks can be an economically viable use for the salt, XDOBS.com can purchase the salt that may be generated by evaporation basins or other tested technology and use it to produce salt bricks. The Bureau of Reclamation should not fund a test of this unproven distillation process. However, if XDOBS.com is willing to fund their own research and testing, the Bureau of Reclamation may consider providing the brine for the testing. When testing results are available further evaluation may be justified.

Alternative 10: Diversion Tunnel

This alternative would be very expensive and has the potential to simply cause the brine to enter the Dolores River in a different location. The diversion tunnel would prevent any brine from entering the river in the current brine inflow locations, but the brine would still need to be removed somehow or it would rise to the surface and/or flow into the river below the tunnel. 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 other proposed methods.

This alternative would further reduce the salt loading to the river but would not eliminate the brine. Since this alternative would be very expensive and does not eliminate the problem it has been removed from further consideration.

Alternative 13: Increased Consumptive Use by Phreatophytes

This alternative involves using plants to remove fresh groundwater in the theory that reducing the volume of fresh groundwater will reduce the production of brine and thereby reduce the salt loading to the river. While phreatophytes may indeed reduce fresh groundwater flow towards the river it is likely that the areas that could support phreatophytes, such as willows and cottonwoods, are already doing it and planting more phreatophytes would require irrigation. Thus eliminating any benefit derived from the water removed by the phreatophytes.

Alternative 15: Line the Bed and Banks of the Dolores River

This is the same as Alternative 10, with a different method used to isolate the river from the brine. Thus, this alternative has the same problems identified for Alternative 10 and has been removed from further consideration.

Alternative 16: Fresh Water Cutoff Wells

The theory behind this alternative is that if the fresh water that becomes the brine is removed, then no brine will be created. The first problem with this is the difficulty in identifying where the recharge area for the water that becomes the brine is located. The investigation to understand the groundwater system would be very expensive and would likely determine that the source of the water is a regional aquifer that could not be isolated. If the source water for the brine could be removed, there is a possibility that the water would be replaced from another source. For example, the water level of the fresh water layer that "floats" on the more dense brine in the Paradox Valley may drop down far enough to come in contact with the salt dome, thereby becoming brine. Thus, eliminating the freshwater layer but not the brine. Given the very complicated groundwater system, the large expense necessary to understand the groundwater system, and the very limited potential for success, further investigation of this alternative cannot be justified.

Phase 2 Evaluation Methodology and Summary of Findings

This approved "Approach to the Work" for Phase 2 provides that, "the FCE team will evaluate each candidate alternative for technical viability." To accomplish that objective, the remaining candidates were configured in a preliminary manner to identify major structural components, their operational characteristics and relative cost, and cost effectiveness.

Volume of Brine to be Managed – The volume of brine pumped from the collection system and injected in recent years, (about 100 million gallons per year or 310 acre-feet per year (0.43 cfs) containing about 109,000 tons of salt per year), is significantly lower than was originally anticipated. However, the current collection well operating regimen is intercepting only about two thirds of the salt load. Therefore, any strategy for reconfiguring the facilities would need to be able to handle a maximum annual volume of about 420 acre-feet per year (0.58 cfs) of brine, and 147,000 tons of salt per year.

Evaluation Methodology – An effort was made to identify relatively comparable systems and their costs, to be able to assess the relative merits of the various alternatives. As to the cost and cost-effectiveness of alternatives considered in this report, only those available "ball park" costs were assessed and these were "scaled" to the specific configuration of that alternative, without attempting to bring them to a uniform cost estimate date or develop "comparable" estimates of cost for each alternative. This was done to provide a sense of relative economic merit and make recommendations as to whether a specific alternative should be further evaluated in Phase 3 (Environmental Feasibility). 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. Cost estimates made as part of this phase are very preliminary and will not be presented until they can be refined further in Phase 4.

This technical memorandum provides justification for eliminating some of the initially identified alternatives. Table 1 summarizes the recommendations and technical merit of the various alternatives

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

Table 1
Summary of Results

Alternative No.	Alternative Name	Relative Technical Merit	Expected Relative Cost Effectiveness ($/Ton)	Recommend for Evaluation in Phase 3
1	Enhance Existing Injection System	Poor	Excellent	Yes
2	Additional Injection Well	Good	Poor	Yes
3	Divert West Paradox Creek	Good	Good	Yes
4	Zero-Liquid-Discharge	Good	Fair	Yes
5	Dewvaporation	Unproven	Excellent	Yes
6(A)	SAL-PROC	Unproven	Unknown	No
6(B)	Vibratory Shear Enhanced Process (VSEP)	Questionable	Unknown	Yes
9(A)	Conventional Evaporation Basin – Radium Site	Good	Poor	Yes
9(B)	Conventional Evaporation Basin – East Paradox Valley	Good	Excellent	Yes
11	Agricultural Land Management	Good	Excellent	Yes
12	Add Liner to West Paradox Creek Wetlands	Good	Poor	No
14	Integrated Evaporation Pond and Treatment Approaches	Fair	Excellent	Yes

Conceptual Groundwater and Surface Water Interaction

Alternatives 3, 11, and 12 are 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. There are a number of observations that support this theory. These observations are:

1. Salt loading to the Dolores River typically decreases during the summer when West Paradox Creek is diverted for irrigation. During this period, the wetlands and ponds adjacent to the river in the brine inflow area are dry. Many graphs have been prepared showing this relationship. One of these figures is included in the attachments (see Figure A-1).
2. During the winter of 2003-2004, a landowner adjacent to the river in the brine inflow area constructed some ponds. When the ponds were filled from West Paradox Creek it was observed that salt loading to the river increased. It has also been observed that a decrease in the salt loading corresponded to the time when the ponds dried up. When water was plentiful in 2006 and the ponds didn't dry up, the salt loading to the river did not decrease as in previous years. The memoranda prepared by Andy Nicholas, Facility Manager of the Paradox Valley Unit, are included in the attachments.
3. In general, it appears the annual total salt loading is lower during drought years than it is during years with normal, or above normal precipitation (see Table A-1 in the

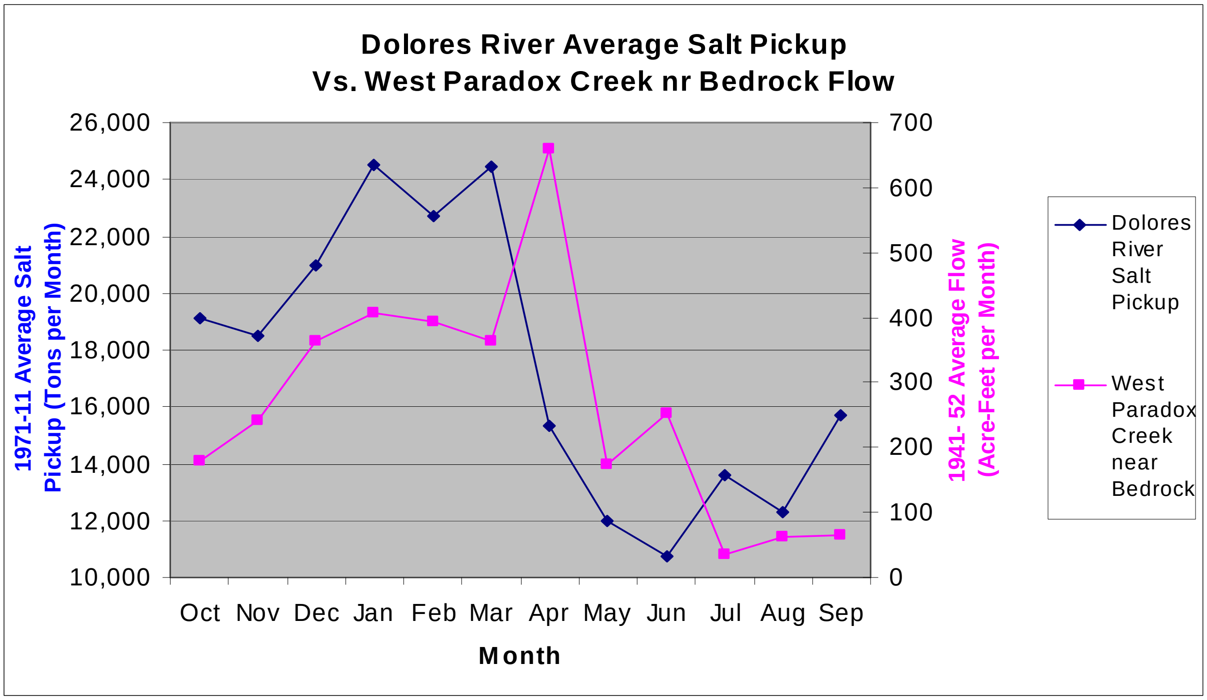
Attachments). The correlation between annual precipitation and annual salt loading is not perfect, but there does appear to be a pattern. The fact that the correlation is not perfect indicates the complexity of the system, suggesting that other factors, such as the ponds mentioned above, impact the salt loading rate.

4. When the Paradox Valley Unit was being developed in the 1970s over 200,000 tons/year of salt was estimated to be flowing into the Dolores River. In the last 7 years the combination of injected brine and salt loading to the river averages about 147,000 tons/year. Between these times much of the irrigation in the valley has converted from flood to sprinkler irrigation. Pumping of the fresh water layer has also likely increased. This observation suggests that improved irrigation efficiency has contributed to the reduction in total salt loading.

Flow records were kept for two sites on West Paradox Creek between 1944 and 1952. The first site is the West Paradox Creek near Paradox, which is at the west end of the Valley, before irrigation water is diverted. The second site is the West Paradox Creek near Bedrock, which is near the confluence with the Dolores River. Charts generated from this data (see Figures A-3 to A-9 in the Attachments) indicate that the flow of West Paradox Creek near Paradox is largely diverted during spring runoff and the irrigation return flow returns to the creek as drainage accretions during the fall and winter. During the 1944-52 period, West Paradox Creek contributed approximately 3,100 acre-feet per year to the Dolores River, while approximately 6,200 acre-feet were diverted for irrigation. Since the valley is underlain by a salt formation, it is logical that some portion of the 3,100 acre-feet per year that is not consumptively used is contacting the salt dome and contributing to the brine that is surfacing in the river and being pumped from the collection wells.

The patterns of historical Dolores River salt loading and the historical flow of West Paradox Creek near Bedrock have a similar shape, as shown in the Figure 1:

Figure 1



Data collected between 2000 and 2006 show that an average of 37,000 tons per year of salt and 4,100 acre-feet per year flowed into the river as it passed through the Paradox Valley. Most of the flow entering the Dolores River is relatively fresh runoff, therefore, if the 37,000 tons per year was comprised solely of 260,000 mg/l brine, it would be contained in about 110 acre-feet per year of brine.

Between 2000 and 2006 the collection wells withdrew an average of 310 acre-feet and 109,000 tons per year from the groundwater system. Therefore, a total of 420 acre-feet and 147,000 tons per year of salt reached the Dolores River and collection wells combined. From Figure 1 it can be assumed that some part of the 3,000 acre-feet per year of West Paradox Creek agricultural deep percolation could contact the salt dome. If only 420 acre-feet per year or 14 percent thereof reaches the Dolores River and collection wells, 14 percent of any prevented deep percolation would directly reduce the Paradox Valley salt load. For example, if the recharge to the aquifer beneath West Paradox Valley was reduced by 100 acre-feet this would correspond to a 14 acre-foot reduction in brine volume. Assuming a 260,000 mg/l brine this corresponds to a 4,900 ton reduction in salt loading. This estimate is based on data that is over 50 years old and some assumptions as to the correlation between salt loading and the flow of West Paradox Creek. Data representative of current conditions should be collected to verify conclusions drawn based on this theory

Whether, some of the irrigation infiltration contacts the salt dome (or not) reducing recharge in the western Paradox Valley should reduce the flow of brine towards the river. The fresh water layer above the brine in the west Paradox Valley provides the gradient (pressure) that creates the flow of brine towards the river. Reducing the recharge will reduce the gradient (pressure) that causes the brine to flow towards the river. Therefore, the rate of brine flow towards the river will be reduced if recharge is reduced. Additional groundwater data will be needed before any quantification of this reduction can be attempted.

For evaluating the salt load reductions associated with Alternatives 3, 11 and 12, it is assumed that 14 percent of reduced deep percolation reduces an equivalent quantity of 260,000 mg/l brine inflow to the Dolores River and the collection wells.

Alternative 1: Enhance Existing Injection System

In the Phase 1 Technical Memorandum it was proposed that the effectiveness of the existing system could be enhanced by concentrating the brine further before injection. Concentrating the brine, thereby increasing the amount of salt removed from the river, is technically feasible. Alternative 14 discusses the use of a solar gradient pond to concentrate and heat the brine. This is one method for concentrating the brine that appears to be feasible. Although concentrating the brine is technically feasible there is potential for the well to be damaged if components of the brine, such as calcium sulfate, become too concentrated. Calcium sulfate will create a scale in the well if concentrations exceed saturation.

The sodium chloride concentration in the brine is below saturation. Thus, the sodium chloride concentration of the brine can be increased and still be below the point at which precipitation occurs. However, other salts in the brine such as calcium sulfate may be near saturation in the brine. Further concentration of calcium sulfate or other salts may cause precipitation or scaling in the well. Adding to the complexity is the changing solubility of the salts with temperature. Some salts are more soluble at higher temperatures while solubility decreases for other salts as temperature rises. Solubility increases as temperature increases for sodium chloride while solubility of calcium sulfate decreases with increasing temperature. The injection formation temperature is currently 30 to 50^{o} F higher than the temperature of the injected brine. Therefore, precipitation or scale may not be a problem on the surface but may clog the injection well as temperatures increase in the well. Given the tremendous investment in the existing injection well any increase in the brine concentration should be modeled carefully before a higher concentration brine is injected.

The Bureau of Reclamation has made a considerable effort to optimize the existing injection system. All other enhancements identified during this evaluation have already been studied and/or implemented prior to this study. It is recommended that the current brine disposal system continue to be operated. Increasing the concentration will make the operation more effective at disposing of salt but there is a significant risk of damaging the injection well. It appears that there are better alternatives available that have less risk.

This alternative will be evaluated in the next phases to provide a baseline for comparison against the other alternatives.

Alternative 2: Additional Injection Well

There are two primary technical issues relating to the feasibility of a second injection well on the Paradox project:

- Location
- Viability of drilling through the salt dome

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 but it should not be hydraulically connected to the first injection well site due to faulting between the two sites. The challenge associated with this site will be drilling through the salt dome. 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. The 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

Drilling through the salt dome in order to reach the desired Leadville limestone formation below appears to be technically viable. A river crossing where the excavation encounters the brine is also technically feasible. However, both will be very expensive. The costs will be identified as part of economic feasibility phase of this study.

This option should be retained for further evaluation.

Alternative 3: Divert West Paradox Creek

As mentioned above 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. By reducing the agricultural recharge, the brine flowing into the river may be reduced dramatically.

Short Diversion of West Paradox Creek

Flow records indicate that a pipe capacity of 50 cfs will handle all but the major storms. Flow is typically on the order of 20 cfs when not being diverted for irrigation. Assuming that the pipeline is sized to handle the majority of flows expected on West Paradox Creek a 36-inch diameter pipeline at a slope of 2% should be sufficient. The existing channel will still be needed to handle the few days when spring runoff exceeds the capacity of the pipeline or when there are large thunderstorms. A pipeline through the wetland area would need to be approximately 3,200-feet long to bypass the areas of high recharge. It is estimated that this pipeline could reduce approximately 5,000 tons of salt loading to the river each year. The 5,000 tons of salt removed is an estimate based on limited data. Data, such as groundwater levels (fresh and brine), flow in West Paradox Creek, and salt loading rates need to be collected on a regular basis before a more accurate estimate for salt removal can be made.

Full Replacement of Existing Irrigation System

This alternative involves piping West Paradox Creek from the existing irrigation diversion, and replacement of the current system of open ditches and ponds with a pressurized irrigation system. This pressurized irrigation system would allow application rates to be optimized to reduce agricultural recharge of the aquifer. 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 heavy spring runoff and during large thunderstorms. The existing channel would still be used for these peak flows. The diversion of West Paradox Creek has the potential to generate high pressures at the discharge to the river. This pressure could be used to generate power for the other aspects of the project. If the pressure is not used to generate power then pressure reducing valves and/or energy dissipation structures will be needed. Approximately 8 miles of 6 to 24-inch diameter pipe would be needed to replace the current system of ditches and ponds.

Although presented as part of the full replacement the piping or lining of West Paradox Creek in the western portions of the valley does not need to be included. The piping of the current system of ditches and on-farm improvements can likely be justified in the same manner as similar salinity control projects throughout the Upper Colorado River Basin. Namely, eliminate losses in open canals and ditches to reduce salinity of return flows. Environmental issues have the potential to make piping of West Paradox Creek difficult. However, replacing open ditches with a pressurized irrigation system should not encounter environmental problems.

Both the short diversion and full replacement of the existing irrigation system should be retained for further evaluation.

Alternative 4: Zero-Liquid-Discharge

Based on the work to date, ZLD remains as a proven technology. There are several industrial installations treating brine near the flow and salinity levels of the project. It will probably be necessary to only construct a crystallizer since the high salinity levels negate the need for a brine concentrator. This will help to keep the construction costs within manageable levels.

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 Paradox is approximately 3 MW (230 gpm system). This is over 3 times the power usage by the injection well.

Electricity can be generated from the sun in several ways. For a small or medium-sized application such as Paradox, photovoltaic cells can be used. A solar cell, or photovoltaic cell, is a device which converts light into electricity using the photoelectric effect. Photons in the sunlight hit the solar panel and are absorbed by semiconducting materials. Electrons are knocked loose from their atoms, allowing them to flow through the semiconducting material and to produce electricity. An array of solar panels then converts the solar energy into a usable amount of direct current electricity.

Figure 2 below is a graph of incident solar radiation available at Grand Junction, Colorado on a monthly basis. As can be seen, solar energy is not always constant. Summer months have more sunlight available, and hence, more solar energy available for use. Because solar energy is not continuously available (i.e., night time and cloudy days), storage is an important issue. Solar energy is most often stored as heat (thermal) or as electrical energy.

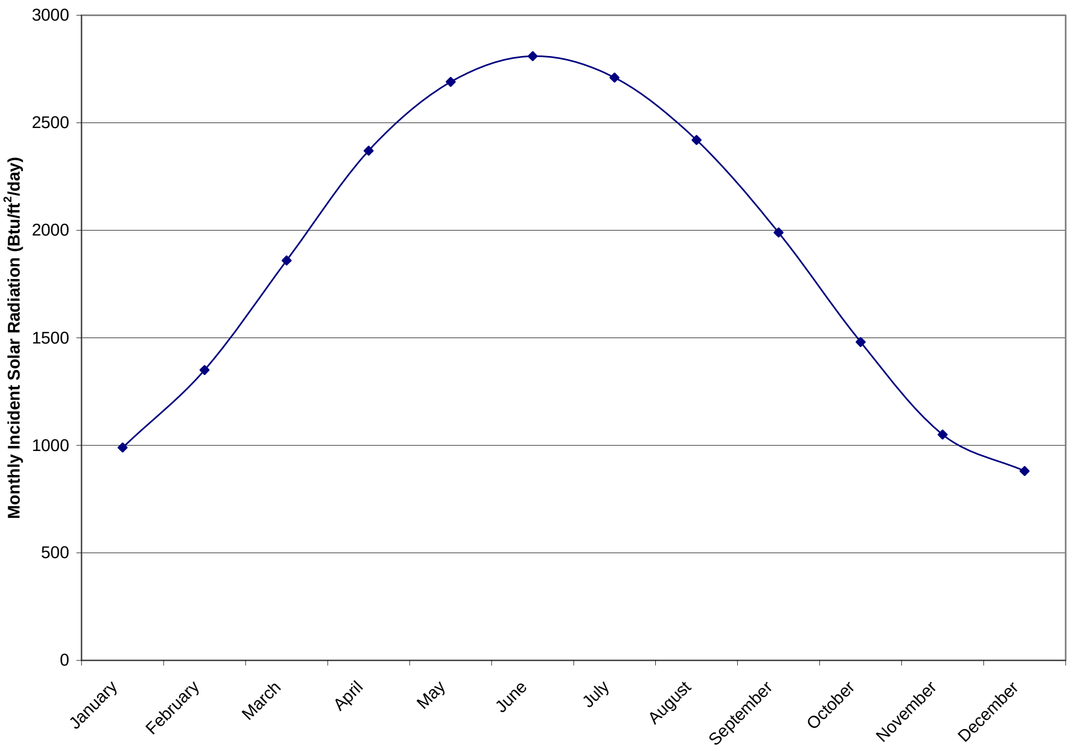


Figure 2: Average Incident Solar Radiation at Grand Junction, CO

Thermal storage uses various methods and materials to store solar energy. Solar energy can be stored thermochemically with phase change materials. Suitable materials include organics such as paraffins and fatty acids or inorganics such as salts, metals, and alloys. A paraffin wax thermal storage system consists of a solar hot water loop connected to a paraffin wax tank. During the storage cycle, hot water flows through the storage tank and melts the paraffin. Stored heat is then extracted from the tank as the wax resolidifies. Eutectic salts can also be used effectively because they are non-flammable, nontoxic, low-cost, have high specific heat capacities, and can deliver heat at temperatures compatible with conventional power systems.

Rechargeable batteries can be used to store electricity from a photovoltaic system. This system entails a photovoltaic power source connected to a battery bank via a charge controller and inverter. Lead acid batteries are the most common type of battery used with photovoltaic systems because they are relatively economical and readily available. Lead acid batteries have an energy density of about 110-140 kJ/kg and a charge/discharge efficiency of 70-92%. They typically cost between $150-200 per kWh. Sizing of lead batteries depends on the amount of storage desired. Typically, storage can not be for more than about a month due to the natural discharge of the battery. This is a feasible option for Paradox, but solar power would only be supplied for approximately 9 months of the year. During winter months, snow may interfere with the functioning of the solar panels. Since power can only be stored for about a month, it doesn't appear feasible to store power for usage during all winter months.

Electrical energy storage in the form of a battery would be needed and could store energy for up to a month. Although sunlight is still provided in the worst month of the year, snow may interfere with the operation of the solar panels. Therefore, power may only be able to be supplied approximately 9 months of the year. Land requirements are about 5 acres/MW so about 15 acres may be needed. These facilities could potentially be located within the 350 acres presently owned by Reclamation.

This alternative should be retained for further evaluation.

Alternative 5: Dewvaporation

The dewvaporation system would be designed to manage a brine volume of 420 acre-feet per year (382,000 GPD). Assuming that saturation and crystallization would occur with about 27% moisture, about 280,000 GPD of liquid would need to be removed from the brine. The approximately 147,000 tons/year of salt generated by this alternative would need to be disposed of in a licensed landfill.

Removal of this volume of liquid would require about twenty-two (28), 10,000 GPD Dewvaporation Units.

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

- Twenty-eight 10,000GPD Dewvaporation Units;
- One 9,000 square foot process building;
- 0.5 acres of Right-of-way;
- 241 million lbs of process steam/yr.;
- 533 MWHrs of electricity per year;
- 0.3 equivalent person years of O&M labor;

Pilot scale tests of this technology have been very favorable. However, it has not been used at the scale and proposed concentrations in this project. Preliminary cost estimates indicate that this alternative may have very favorable costs per ton of salt removed.

This alternative should be retained for further evaluation.

Alternative 6: Other Innovative Treatments

This alternative has been divided into two 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

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 recoverable 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).

The SAL-PROC process does not appear to be technically viable for the Paradox project and should not be evaluated further.

Alternative 6B: Vibratory Shear Enhanced Process (VSEP)

VSEP has primarily been used for the treatment of low-flow, high solids, industrial wastewaters. One study, held at Big Bear Valley in California, was conducted specifically to determine design and operational data for use in concentrate management. Assessment of the feasibility of VSEP, as well as key design parameters for the design of a full-scale facility, was determined.

Pilot studies show that both reverse osmosis and nanofiltration membranes can be used in the VSEP unit. Concentrate volumes can be reduced by up to 85% if a two-stage VSEP process is implemented. VSEP recoveries exceeding 85% result in a decreased flux and the need for high feed pressures, which are less than optimal operating conditions. Recoveries greater than 85% also resulted in an increase in the lifecycle costs of operating the VSEP. Acid and caustic cleanings are needed approximately twice a week, a relatively high cleaning frequency relative to conventional RO, to maintain flux. The RO membrane showed better performance than the NF membrane at a similar flux range. Permeate quality from the RO membrane was excellent, with chloride, TSS, TDS, and sulfate values being very small.

Since VSEP permeate has very good water quality, blending is possible to increase overall recovery of the facility. VSEP does significantly reduce concentrate volume. This makes the use of either a wetland or evaporation pond more viable because land requirements would be much smaller. VSEP has been shown to be a viable alternative for concentrate management. It produces very good quality permeate and can reduce concentrate volumes by up to 85%. However, a secondary step would still be needed to treat the concentrate.

VSEP is technically viable and could be included as a component of a multi-project program for Paradox. It should be retained for further analysis, with focus on the O&M costs, particularly for the high brine concentrations.

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 discussed below.

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, and was designed to hold 93,340 acre-feet with nearly 26,000 acre-feet allocated for flood control and surcharge capacity.

The volume of brine pumped from the collection system in recent years, about 100 million gallons per year or 310 acre-feet per year (0.43 cfs), is significantly lower than was originally anticipated. However, the current collection well operating regimen is intercepting only about two thirds 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 420 acre-feet per year (0.6 cfs) of brine.

The 1997 Supplement to the DPR contained cost estimates for the original, and a downsized project. Included in the following table are the cost estimate for the original Radium Site and downsized version. The reported costs were escalated to 1994 costs. No effort has been made to escalate costs to 2008 since the costs in 1994 dollars exceed the cost of another injection well. The projected cost per ton of salt removed will be far above what is acceptable. However, this alternative will be carried forward as a comparison for the other alternatives proposed.

	Original 1979 plan (October 1994 $$)	Downsized 1979 plan (October 1994 $$)
Description	(5 cfs)	(1.5cfs)
Brine well field	3,683,310	13,683,310
Hydrogen sulfide stripping plant	4,850,127	3,959,214
Brine pipeline	12,920,320	8,888,606
Brine pipeline pumping plants	9,565,574	6,410,077
Radium dam,dike, and evaporation pond	56,054,857	34,776,000
Transmission lines and substations	1.291,065	2,764,793
Permanent operating facilities	375,121	370,312
Operation and maintenance housing	835,607	120,231
Capitalized movable equipment	2,245,919	2,245,919
Service facilities	1,732,532	1,732,532
Depreciation and salvage	<3,034,636:>	<3,034,636:>
Emergency reserve O&M fund	329,434	256,092
Wildlife mitigation	1,067,653	496,555
Subtotal	91,916,883	62,669,005
Cultural resource program	18,035	18,035

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 420 acres of evaporation surface area would need to be in operation to provide for evaporation of the 420 acre-feet per year of collected brine.

At the current 109,000 tons per year collection rate, assuming nine 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. Only two or three ponds would need to be constructed over the 100 year project planning period.

To prevent seepage, the ponds would be lined with impervious material, such as butyl rubber, HDPE, PVC, 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 is 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 basins.

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 the Imperial Valley commercial fish rearing ponds.

Preliminary cost estimates indicate that cost for this alternative will be in the acceptable range. This alternative should be further evaluated in phases 3 and 4.

Alternative 11: Agricultural Land Management

Description of Alternative

This alternative proposes a five year demonstration program to 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 a single irrigation would be applied each year to establish a wildlife supportive cover crop.

There are about 1,100 acres of West Paradox Valley irrigated farmland within about two miles of the Dolores River. It is estimated that deep percolation from these farmlands amounts to about 1.0 acre-feet per acre, or 1,100 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 154 acre-feet per year.

The program could be modeled after the USDA Conservation Reserve Program with annual payments of $500 per acre. Preliminary cost estimates indicate that the cost per ton of salt removed is within the acceptable range. This alternative should be retained for further evaluation.

Alternative 12: Add Liner to West Paradox Creek Wetlands

The 300 acre West Paradox Valley wetland pond nearest to the Dolores River would be lined with clay, butyl rubber, HDPE or plastic membrane. To prevent damage from grazing cattle, the pond area would be excavated when dry to a depth of two feet, the liner installed, and the excavated material replaced over the liner. The volume of excavated material would be about 1 million cubic yards. After more in-depth investigation, it may be found that the entire pond may not need to be lined and/or a local clay formation may provide the needed water-tight material.

Water is maintained in Pond 3 for about 100 days per year. When water has been in the pond, an incremental additional Dolores River salt load of 50 tons per day has been observed. Accordingly, lining Pond 3 may be able to prevent as much as 5,000 tons per year from entering the Dolores River.

Preliminary cost estimates indicate that synthetic liners would exceed the acceptable cost per ton of salt removed. However, if a locally available source of clay can be found the cost may become acceptable. This alternative is not recommended for further evaluation.

Alternative 14: Integrated Evaporation Pond and Treatment Approaches

Overall Concept – Under this alternative, the fluid being pumped into the injection well would be concentrated to 300,000 mg/l. About 72 acre-feet per year of fluid from the higher salinity (260,000 mg/l) collection wells would be delivered to the injection well. An additional 258 acre-feet per year/yr. of collection well pumping would be stripped of hydrogen sulfide and delivered to a 2-acre solar gradient pond (SGP) having a depth of 15 feet. The SGP would evaporate about 2 acre-feet per year of brine and provide the heat energy needed to concentrate and dispose of the remaining brine. About 143 acre-feet per year of 320,000 mg/l reject from the brine concentrator would be blended with the 72 acre-feet per year of filtered (260,000 mg/l) pumped water, and the blend (215 acre-feet per year of 300,000 mg/l brine) containing about 87,000 tons per year would be delivered to the existing well for injection. The impact on the injection well of increasing the salinity of the injected brine is unknown. There is potential that the higher salinity could destroy the well.

Operation of the Solar Gradient Pond – Of the 258 acre-feet per year of collected brine delivered to the SGP, two acre-feet would evaporate. 143 AF/yr. would be returned to the injection well and the remaining 115 acre-feet per year would be concentrated to a near solid state. Assuming that saturation and crystallization would occur with about 27 percent moisture, approximately 78 acre-feet per year or about 70,000 GPD of liquid would need to be removed from the brine. Removal of this volume of liquid would require about seven (7), 10,000 GPD Dewvaporation Units.

Operation of the Brine Concentrator – The 2-acre solar gradient pond could produce about 200 GPM of 185º F brine. Total flow to the seven Dewvaporation Units would be 210,000 GPD or about 150 GPM, of which one-third would evaporate and two thirds would become reject water. Although it may be possible to recapture the 78 acre-feet per year of the 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.

Program Features

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

- Two acre Solar Gradient Pond with Piping;
- Seven 10,000 GPD Dewvaporation Units;
- One 2,500 square foot process building;
- 0.4 acres of Right-of-Way;
- 0.2 equivalent person years of O&M labor;
- Land fill for 21,000 tons per year of salt disposal

Alternatives 4 and 5 contemplate the use of zero liquid discharge (ZLD) technology and Dewvaporation 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 boiling stage while evaporating water from the surface as a conventional solar evaporation pond.

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.

This alternative should be carried forward for further evaluation.

Consultation, Coordination and Selection of Phase 3 and 4 Alternatives

After completing the technical evaluation of the alternatives it is recommended that the following alternatives be evaluated further as part of Phases 3 and 4.

- 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.

The alternatives removed from further consideration were technically unfeasible or preliminary cost estimates indicated costs greater than $200/ton of salt removed.

ATTACHMENT A

DATA

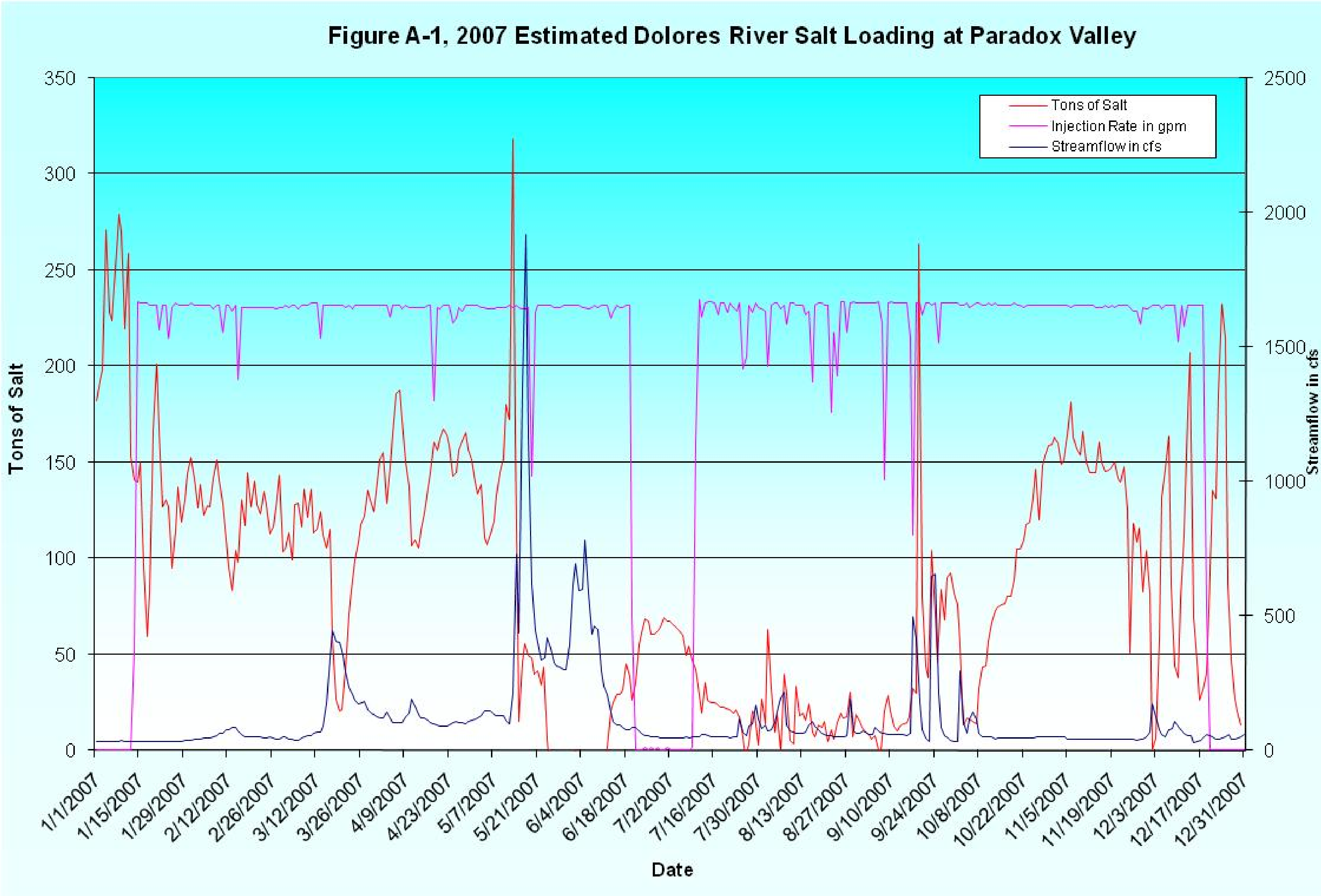


Figure A-1, 2007 Estimated Dolores River Salt Loading at Paradox Valley
Tons of Salt
Injection Rate in gpm
Streamflow in cfs
Tons of Salt
Streamflow in cfs
Date
350
300
250
200
150
100
50
0
2500
2000
1500
1000
500
0
1/1/2007
1/15/2007
1/29/2007
2/12/2007
2/26/2007
3/12/2007
3/26/2007
4/9/2007
4/23/2007
5/7/2007
5/21/2007
6/4/2007
6/18/2007
7/2/2007
7/16/2007
7/30/2007
8/13/2007
8/27/2007
9/10/2007
9/24/2007
10/8/2007
10/22/2007
11/5/2007
11/19/2007
12/3/2007
12/17/2007
12/31/2007

MEMORANDUM

06/09/06

To: File

From: Andy Nicholas, Facility Manager
Paradox Valley Unit (PVU)

Subject: Private Ponds/Wetlands on West Side of Dolores River – Paradox Valley, Colorado

During investigations for salinity control at Paradox Valley in the 1970's, salt loading in the Dolores River at Paradox Valley averaged 500 to 600 tons per day (PVU Final Environmental Statement, pg. B16, March 1979). In 1993, during the injection test to determine the rate at which Paradox Valley Brine could be disposed in the injection well, salt loading in the Dolores River averaged 345 tons per day according to available USGS data. As the injection test progressed and eventually, as the plant was brought into full production, the average daily salt load was reduced to 180 tons per day in 1999. During this period, the area across and slightly upriver from the upper well field was a natural wetland as the water from West Paradox Creek diffused from the creek's main channel and spread over a relatively large area near its confluence with the Dolores River.

From 1998 to 2004, western Colorado experienced below normal precipitation (**Figure 1**) which depleted the amount of West Paradox Creek water from reaching the wetland area and consequently caused the area to dry out. During that period, a general decline in Dolores River conductivity was observed (**Figure 2**).

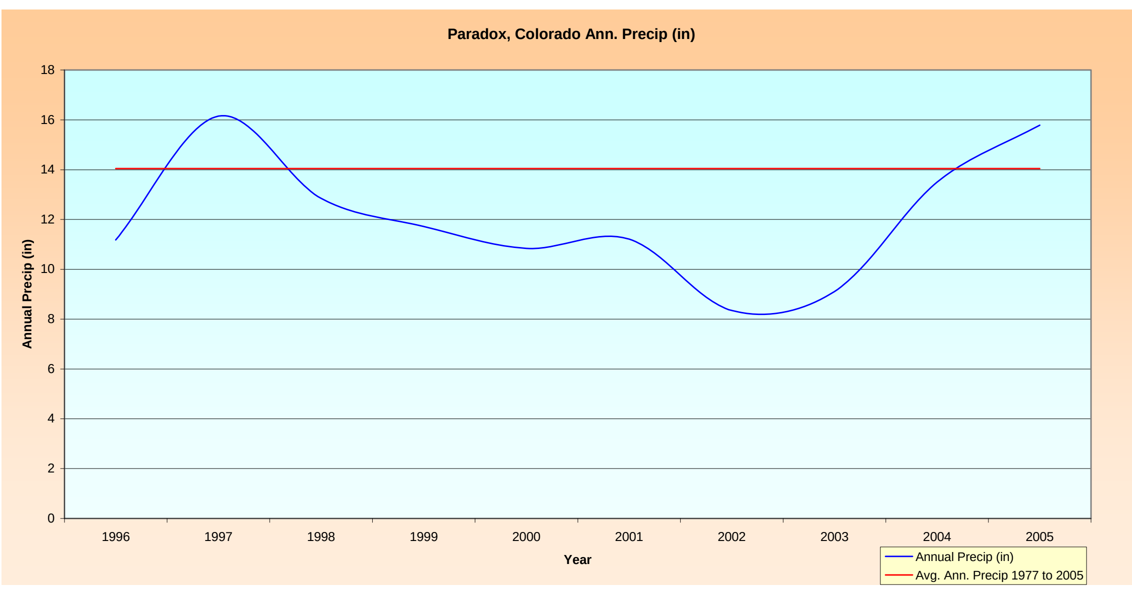


Figure 1

In late 2003, a land owner on the west side of the Dolores River constructed a series of shallow ponds in the wetland area. During that time salt loading at Paradox Valley was estimated at less than 50 tons per day (**Figure 2**). In early 2004, water from West Paradox Creek was diverted into the ponds, filling the ponds with water. Concurrently, an increase in conductivity in the Dolores River was observed (**Figure 2**). In March of 2004, as the irrigation season began, water was diverted before reaching the ponds and they dried up. As the ponds dried up, the conductivity in the river returned to very low readings.

After the irrigation season in late 2004, the ponds were again filled with water and again the conductivity increased significantly in the river. The winter of 2004/2005 was one with above average precipitation which provided abundant water resources throughout the 2005 irrigation season and allowed the ponds to remain full all summer. The ponds have remained full during the 2005/2006 winter and the conductivity in the river has not returned to the low levels observed during periods when the ponds/wetlands were dry.

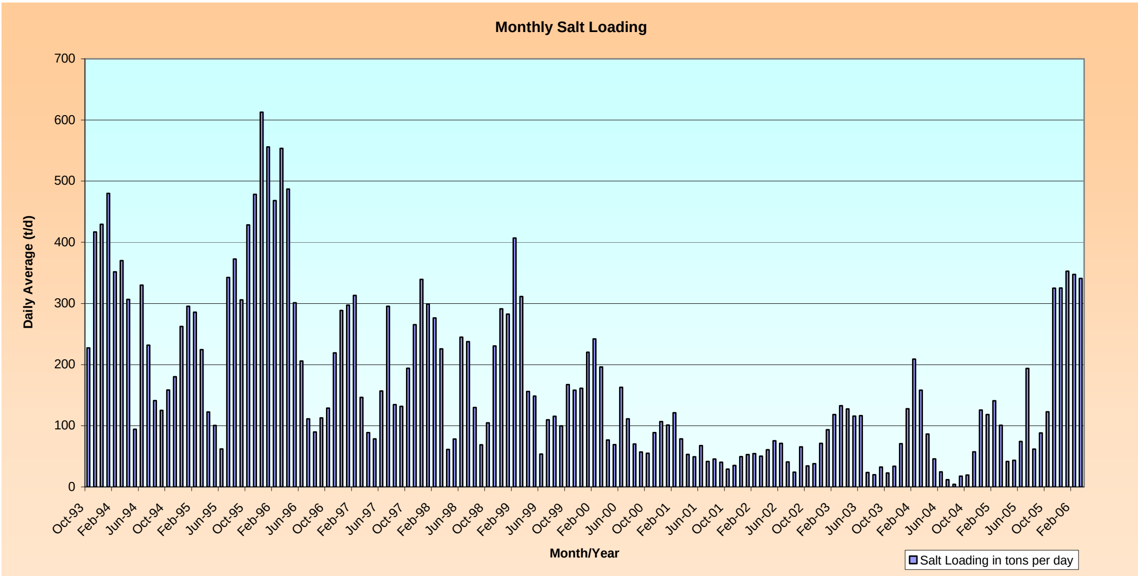


Figure 2

There appears to be a direct correlation between increased salinity observed in the river and both the natural wetlands that previously existed and water in the ponds. The appearance is that the natural brine aquifer below the wetland/ponds is being raised and commingling with the fresh West Paradox Creek water. As the level of the aquifer is raised it may be allowing additional brackish discharge into the Dolores River.

The wetland that existed prior to construction of the ponds and now the ponds may be contributing a substantial amount of salt to the river by elevating the local aquifer. It would benefit the CRBSCP, downstream users, and the landowner to find a solution if a relationship does exist between the ponds/wetland and increased salt load in the river.

MEMORANDUM

06/14/06

To: Files

From: Andy Nicholas, Facility Manager
Paradox Valley Unit (PVU)

Subject: Private Ponds/Wetlands on West Side of Dolores River

On April 24, 2006, I contacted Rick Schnaderbeck, FWS, regarding information on the nature of the grant that funded construction of the ponds on Greg Irwin's property across the river from the Upper Well Field. I explained to Rick my suspicion of a correlation between increased salinity in the river when water was diverted into the ponds. We discussed my theory of the water leaking from the ponds thereby elevating the brackish aquifer and promoting additional discharge into the Dolores Riverbed. Rick asked if I would like to have a meeting or conference call with FWS, BOR and the landowner and I suggested that I talk to Greg Irwin first to determine his interest in conducting a test. The test would be to essentially allow the ponds to dry out in order to observe any apparent correlation of salinity reduction in the river.

A couple of days later I spoke with Greg Irwin and he agreed to divert the water from the pond closest to the river, since that pond seems to have the greatest influence on the changes in river salinity.

On approximately May 1, 2006, I observed the level in the ponds and they were full.

I again observed the ponds on May 12 and noted that the levels in all three ponds had dropped significantly.

On May 22, I noted that the easternmost pond, the pond closest to the river was dry. The other two pond levels were approximately the same level or slightly lower than on May 12.

Each month I use the attached spreadsheet to calculate estimated salt loading in the Dolores River through Paradox Valley. The two sites measuring the electrical conductivity are USGS operated and maintained stations. Site 009EC is located at the Bedrock Bridge as the river enters the valley. Site 090EC is located in the canyon north of the valley as the river exits the valley.

Historically, as the river stream flow decreases, salt loading increases. Since May 1, the stream flow has decreased from approximately 110 cfs to approximately 75 cfs on May 25, yet the salt loading is *decreasing*, which indicates an apparent correlation between the easternmost pond drying up and salt loading in the river.

On June 12, I noted that the easternmost pond, the pond closest to the river was dry, the middle pond was almost completely dry, and the westernmost pond still had some water, but was very low.

On June 9, the estimated salt pickup through Paradox valley was 72 tons per day. On June 13, the estimated salt pickup was 55 tons per day.

The USGS had equipment problems from June 1 through June 8, so the data from EC090 for that period is lost.

Figure A-2

West Paradox Creek nr Bedrock 00060, Discharge, Acre-feet per Month

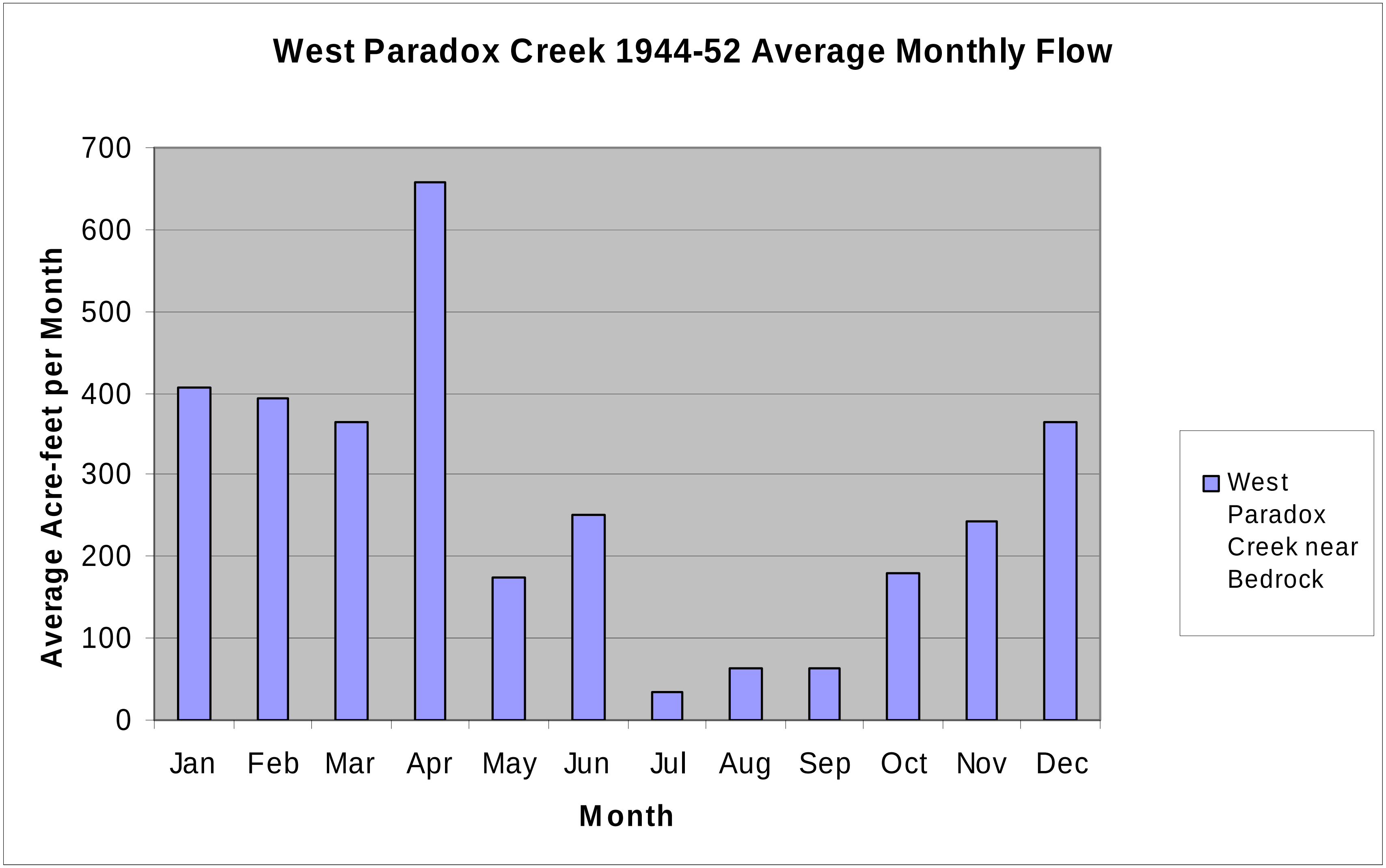


Figure A-3

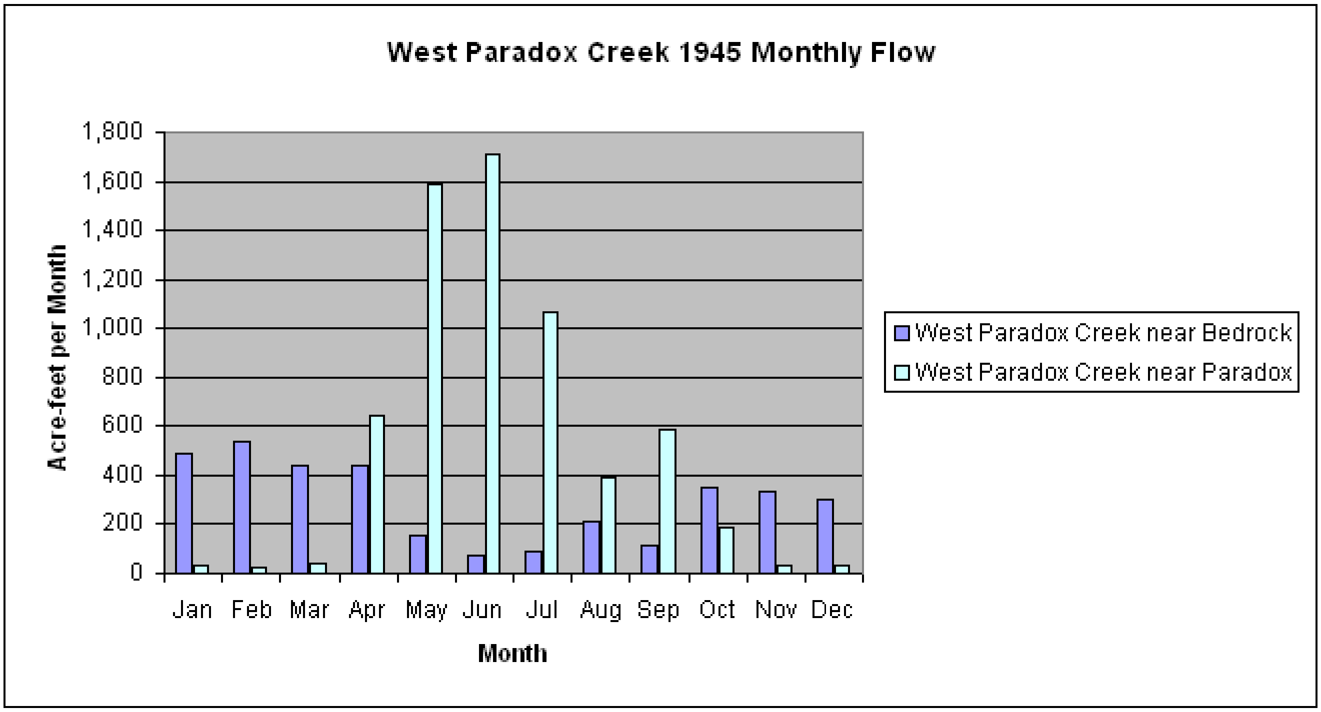


Figure A-4

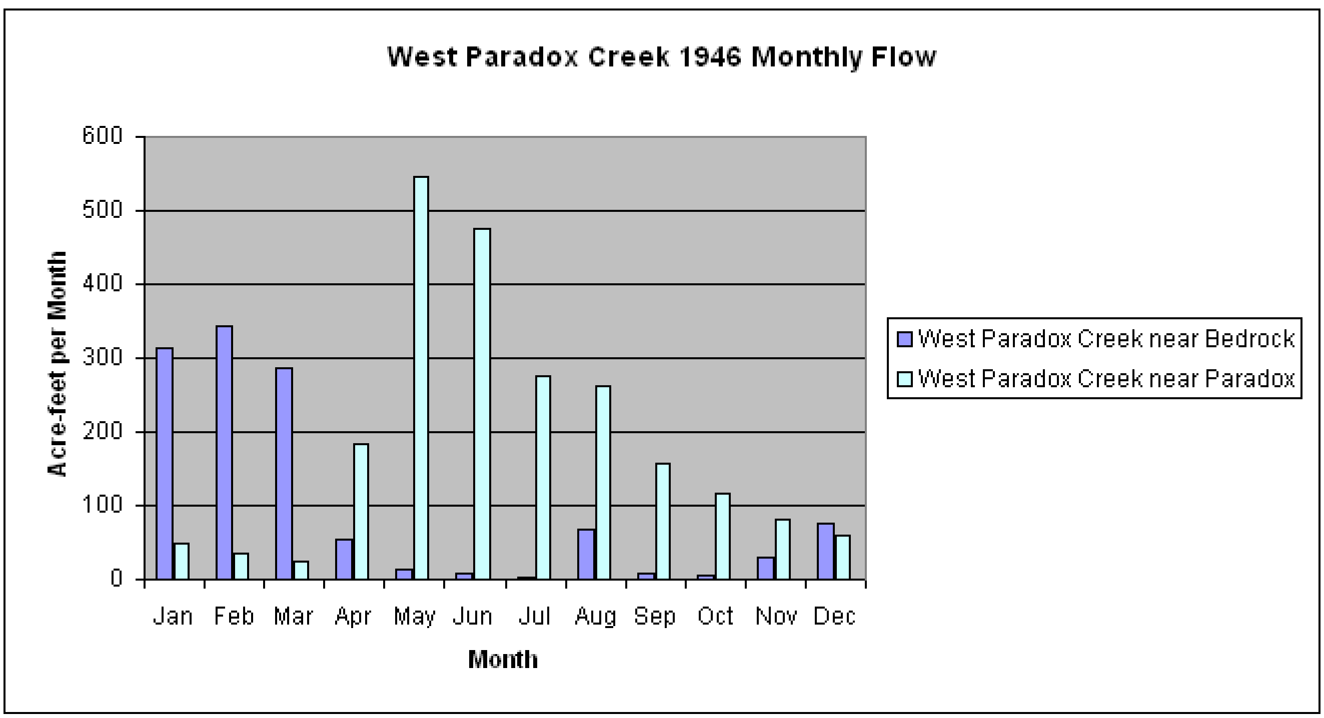


Figure A-5

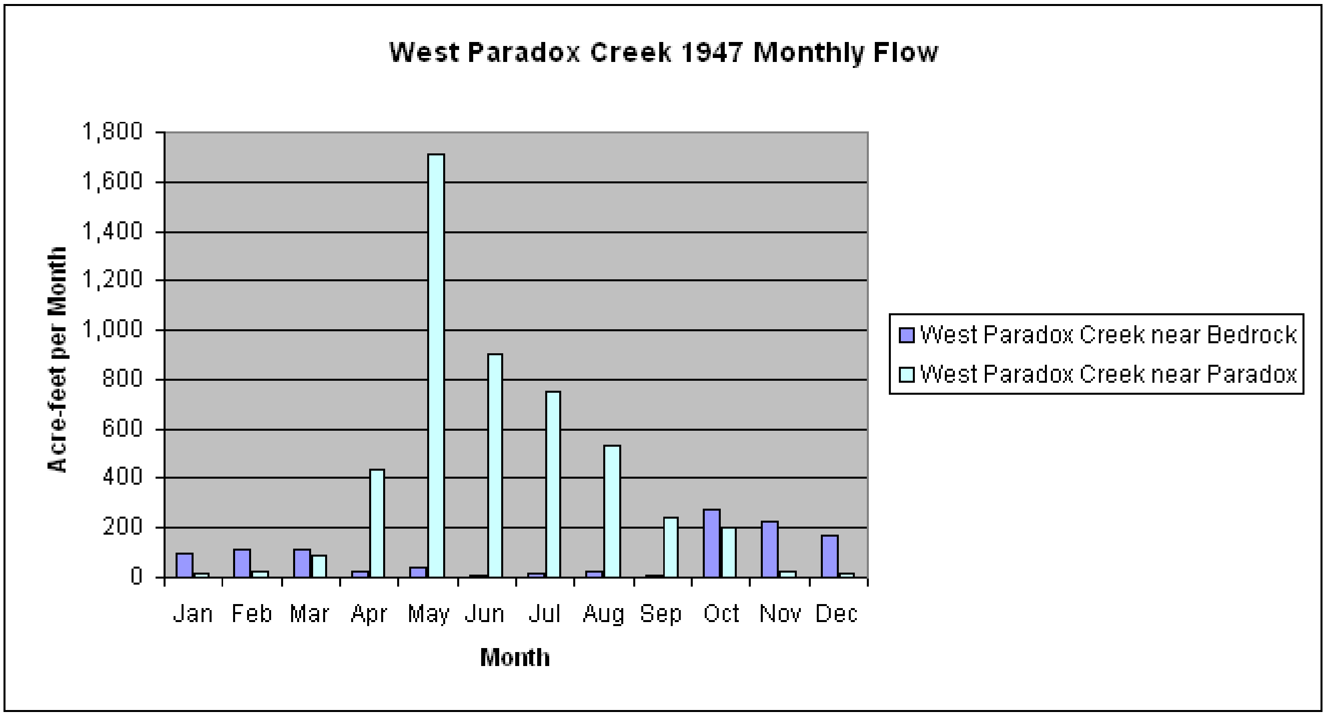


Figure A-6

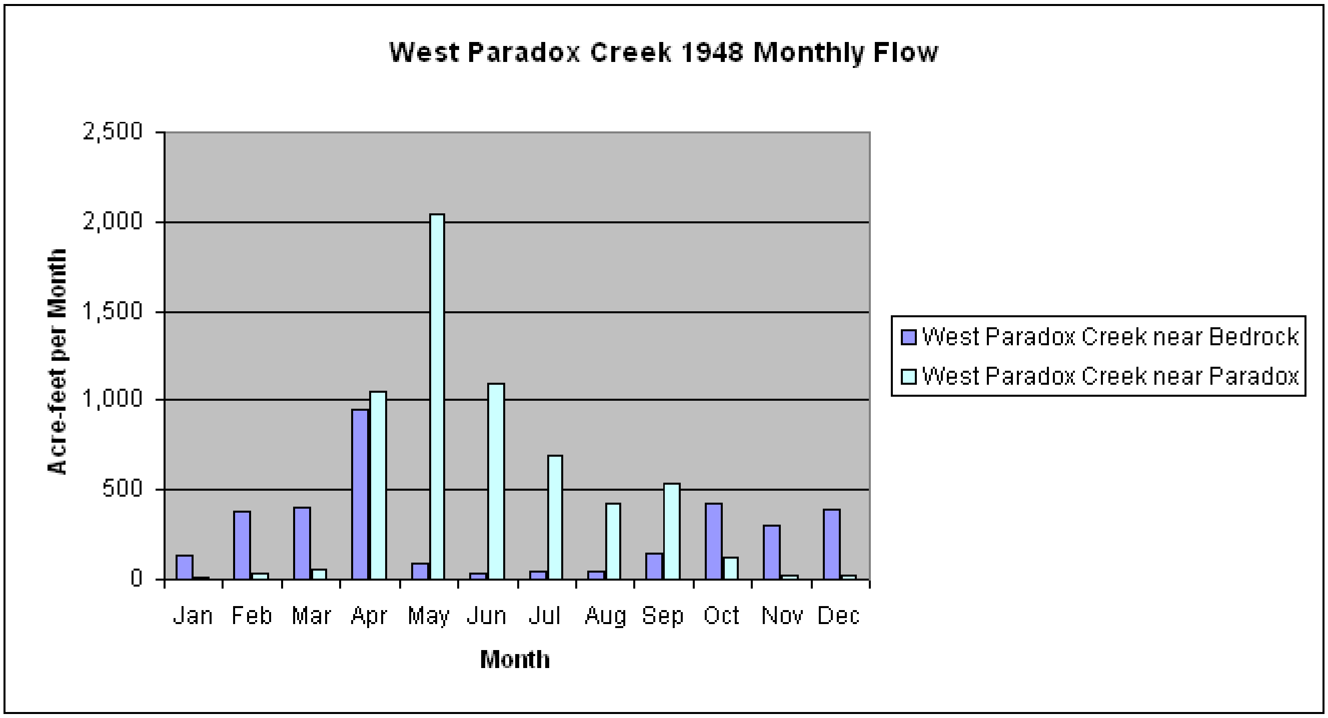


Figure A-7

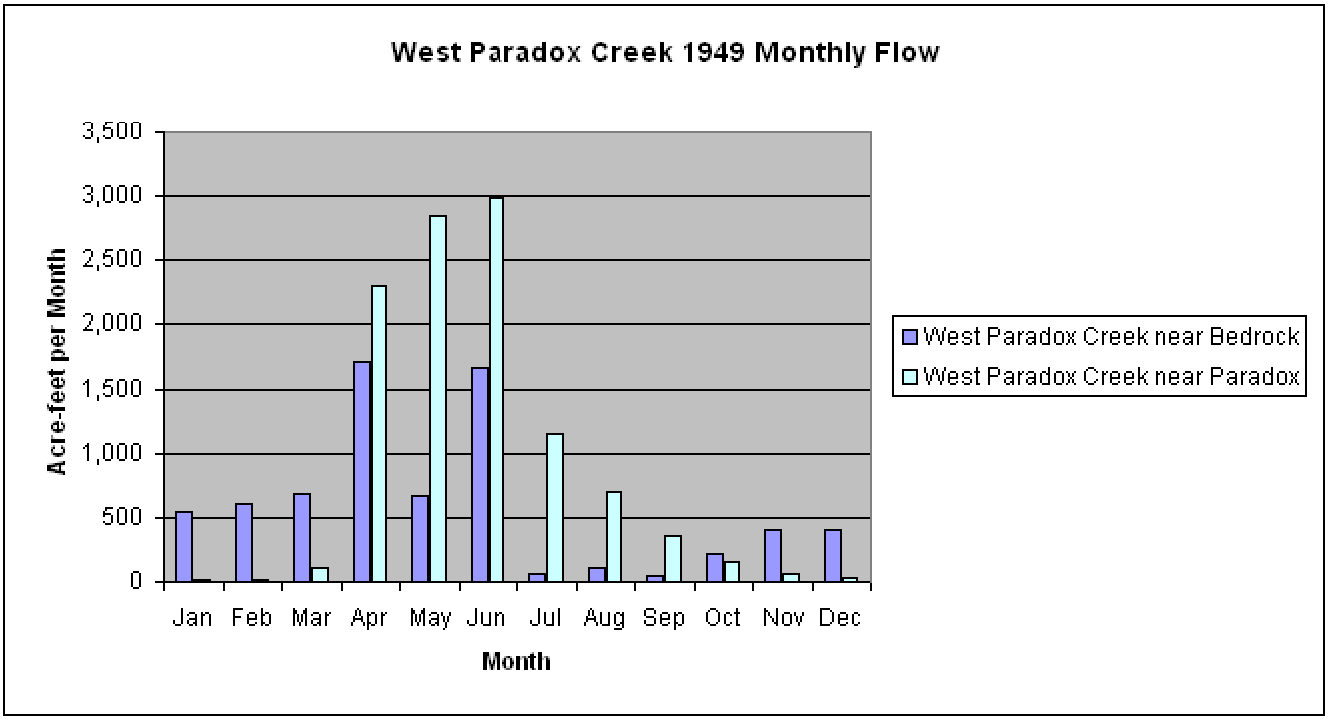


Figure A-8

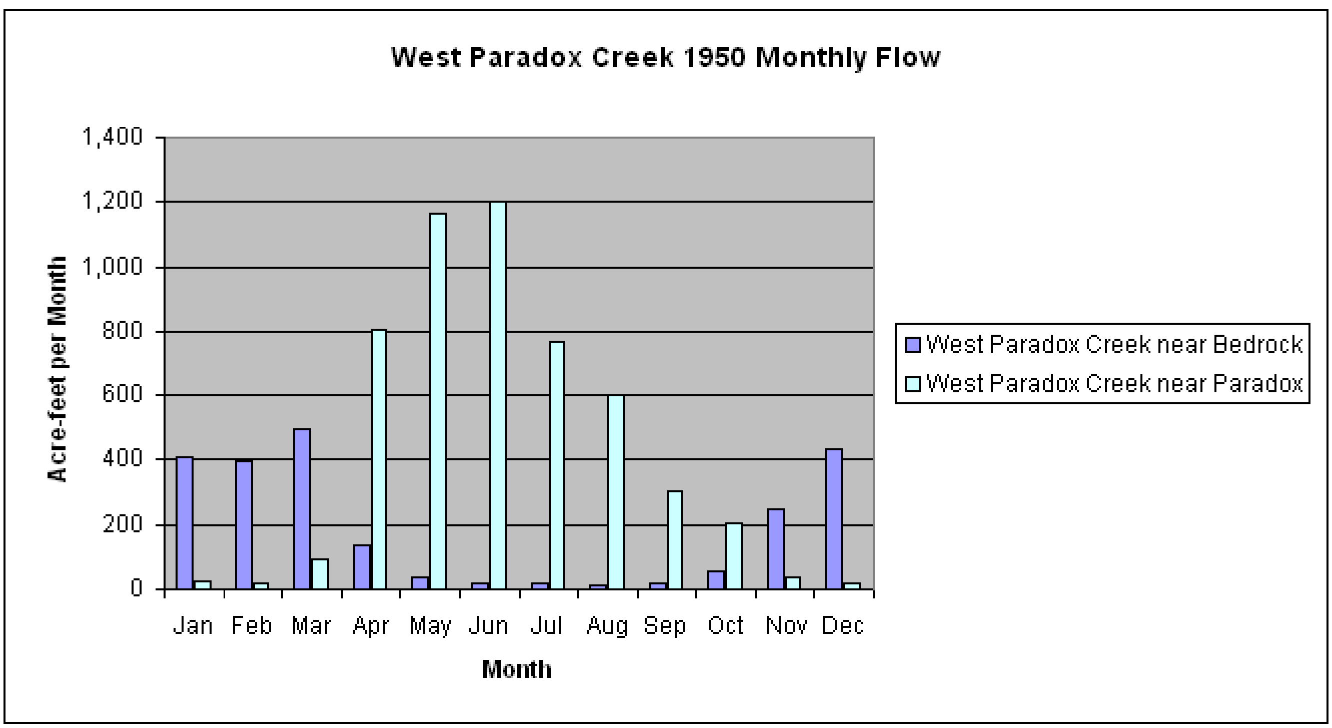
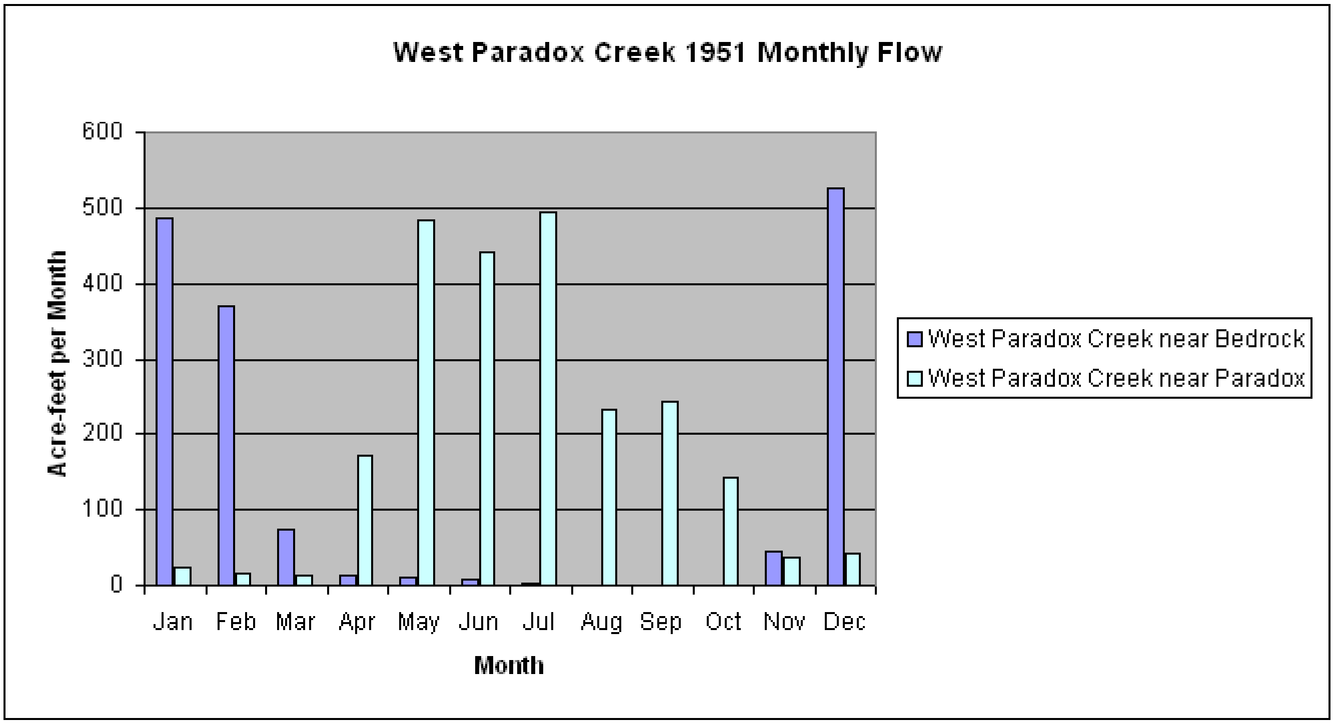


Figure A-9


West Paradox Creek 1951 Monthly Flow
Acre-feet per Month
0
100
200
300
400
500
600
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
West Paradox Creek near Bedrock
West Paradox Creek near Paradox