APPENDIX B

Drainage Service Options Descriptions

Introduction

The descriptions of drainage treatment and disposal options contained in this appendix are, in most cases, revisions of descriptions prepared for the San Luis Unit Drainage Program (SLUDP) (Reclamation, 1990a). In that study, a preliminary set of 30 options was identified and described in a set of memoranda or white papers. The memoranda provided physical descriptions, rough cost estimates (if available), and evaluation of the options based on four criteria (described in Section 5 of this report): **relationship to other options, effectiveness, efficiency,** and **acceptability**. After a screening process, a set of 12 detailed options descriptions was prepared (Reclamation, 1990b).

The options descriptions in this appendix are primarily restricted to drain water treatment and disposal, as discussed in Section 5. The descriptions generally follow the format of the preliminary options descriptions prepared in 1990, but they make use of more detailed information developed during that study and in subsequent studies. Reclamation focused on two aspects of the options for this re-evaluation:

- Description and design of the option and how these may have changed since the 1990 Options Descriptions were developed.
- Updates to the cost estimates. Cost estimates have been based on current design parameters (if different from the 1990 descriptions), and used Reclamation's current cost estimating criteria.

Assumed Range of Drainage Need

Section 3 of this Report describes the information and assumptions used to project a time trend of drainage volume and quality for purposes of developing Preliminary Alternatives. The projections were presented as a range of volumes to account for uncertainty in source-control effectiveness and water supply. The cost estimates for the options are designed to cover the potential range of volumes and quality.

Drainage Service Options

The following categories and options are included in this appendix.

Drainage Water Treatment, Concentration, and Volume Reduction

- Desalination by reverse osmosis
- Three methods of selenium treatment: anaerobic bacterial; microalgal; and chemical treatment

- Integrated Drainage Management (IDU)
- Three designs of evaporation ponds: solar gradient, traditional, and enhanced

Drainage Water and Solids Disposal

- Ocean Discharge
- San Joaquin Delta Discharge
- Landfills
- Deep Well Injection

Beneficial Uses of Drain Water and Salts

- Commercial Utilization of Salt and Selenium

Desalination: Reverse Osmosis Treatment

Description

Reverse osmosis (RO) is a pressure-driven membrane operation in which water molecules are forced through membrane pores having an effective size between 0.0001 and 0.001 m. Many ionic and molecular solutes in water are larger than the membrane pores and thus are rejected by the membrane. Solute rejection occurs via size exclusion, charge repulsion, and limited diffusion. An RO operation typically rejects 95 to 99 percent of the feedwater solutes. The greater the concentration of solutes in the feedwater, the greater the pressure that must be applied to achieve the solvent-solute separation. An RO system that treats brackish drainage water in the San Joaquin valley would require an operating pressure in the range of 200 to 400 lb/in^2.

Solid material may accumulate on the membrane surface through various mechanisms (membrane fouling), which cause a reduction in the flux rate of water through the membrane and a deterioration of performance. Membrane fouling can be prevented through a variety of pretreatment operations depending on the specific constituents in the feedwater. The potential for membrane fouling is also a function of the percentage of product water that is recovered through RO treatment.

A review of the water quality parameters for typical drainage water in the San Joaquin Valley suggests two potential modes of RO operation and pretreatment:

1. Low-product water recovery: An RO system operating at about 50 percent recovery would require minimal pretreatment to prevent fouling. Pretreatment may consist of filtration, pH adjustment, and antiscalant addition.
2. High-product water recovery: An RO system operating at about 75 percent recovery would require substantial pretreatment to prevent fouling. Pretreatment may consist of lime softening, sedimentation, filtration, pH adjustment, and antiscalant addition.

A determination as to which mode of operation would be the most cost effective for drainage service has not yet been made and requires further study.

The product water recovered by the RO system is of high quality and can be reused as a potable, industrial, or irrigation water supply. The dissolved constituents rejected by the membrane are carried from the RO system in a highly concentrated waste stream (known as concentrate), which requires disposal.

Relationship to Other Options

Desalination using RO generates a concentrated brine stream that requires disposal. The concentrate could be evaporated and the dried salts disposed of in a landfill. Another potential option for disposal of concentrate include deep-well injection or discharge to the ocean.

Effectiveness

Capacity

Given adequate pretreatment, RO technology could be used to treat the entire quantity of drainage water collected in the SLU. The determination of whether RO would be used to treat a portion or all of the drainage water would likely be based on the intended use of the product water, the concentrations of the dissolved constituents that are targeted for removal, the capacity of the concentrate disposal method, and the cost of treatment.

There are three potential constituents of drainage water that could be targeted for removal by RO treatment: total dissolved salts (TDS), selenium, and boron. Both the low- and high- recovery operation modes described previously would be equally effective in reducing the level of TDS and selenium. Removal of boron (to permit agricultural reuse of the product water, for example), however, may require extensive pretreatment in a high-recovery RO operation.

Stage of Development

RO is a proven technology that has been implemented on a large scale throughout the U.S. and the world. Its primary application has been desalination of brackish and sea waters to produce potable drinking water. To a lesser extent, RO has recently been used to desalinate wastewater and irrigation drainage water for reuse. Although this technology is highly developed, research continues in the construction and materials of membranes to improve performance, minimize fouling, and reduce costs.

Required Study

The cost and performance of RO treatment depends on site-specific factors. Pilot studies using actual drainage water are necessary to determine pretreatment requirements and RO operating and performance parameters, which are extrapolated to estimate the costs of a full-scale treatment system. These studies should include a pilot-scale comparison of both high- and low-recovery systems.

An RO pilot study was conducted over a 5-week period during July and August 2000, in the Buena Vista Water Storage District. The pilot was designed and operated in the low recovery mode as described above to obtain data on the feasibility of using RO on a seasonal basis. The study did not produce sufficient data to reach definite conclusions regarding cost and performance. The report indicated that additional study was required (Fisher, Travis J. and Christopher J. Martin, 2000).

Another RO pilot system was put into operation in November 2000, at Panoche Drainage District. That study encountered significant membrane fouling due to shortcomings in the pretreatment. It is unknown whether the Panoche study will yield information that is needed for an analysis of this drainage service option. It is recommended that a separate RO pilot study be initiated to specifically address the needs of this evaluation effort.

Efficiency

Costs

The cost of RO treatment depends on the salinity of the drainage water and the design recovery rate of product water. As the salinity of the drainage water increases, greater hydraulic pressure is required to achieve separation of the product water and the hydraulic pumps consume more electricity. The amount of product water recovered by RO impacts the pretreatment requirements for the drainage water. A preliminary analysis indicates that pretreatment to remove hardness would be required for recoveries greater than 50 percent. Below this threshold, pretreatment of drainage water may consist of antiscalant addition only.

Conceptual-level cost estimates are presented for RO treatment of drainage water having a salinity concentration of 2200 and 7000 mg/L, operating at 50 and 75 percent recovery.

TABLE B-1
Cost of RO Treatment per Acre-foot of Drainage Water

	Salinity Concentration	
Operating Mode	**2200 mg/L**	**7000 mg/L**
50% recovery with antiscalant	$160/acre-ft	$260/acre-ft
75% recovery with softening	$440/acre-ft	$680/acre-ft

These estimates do not include the cost of concentrate disposal. The costs and descriptions of concentrate disposal options are discussed elsewhere in this report. RO treatment of the drainage water would produce a low-salinity product water stream that could be reused for irrigation. The estimated value of this water is $150/acre-ft of product water, which is equivalent to $75/acre-ft of drainage water at 50 percent recovery and $112/acre-ft of drainage water at 75 percent recovery. These product water values are subtracted from the RO treatment costs to yield the estimated net costs of RO treatment shown below:

TABLE B-2
Net Cost of RO Treatment per Acre-foot of Drainage Water[a]

	Salinity Concentration	
Operating Mode	**2200 mg/L**	**7000 mg/L**
50% recovery with antiscalant	$85/acre-ft	$185/acre-ft
75% recovery with softening	$328/acre-ft	$568/acre-ft

[a] Net cost equals RO cost – value of product water.

Sensitivity

The cost of RO treatment is sensitive to the cost of energy and variations in the quality and quantity of drainage water.

Acceptability

Public Acceptance

Public acceptance of RO treatment would probably depend on the method of concentrate disposal and the intended use of the product water. Although treated as a separate option here, concentrate disposal is usually considered an integral component of an RO system design and is often the deciding factor in whether an RO plant is constructed. Reuse of desalinated drainage water would be acceptable for irrigation or industrial purposes; however, reuse as potable water may encounter public opposition.

Institutional Compatibility

RO treatment and reuse of agricultural drainage water is compatible with current water treatment trends. Discharge and disposal of the concentrate stream would require the appropriate regulatory approval.

Environmental Impacts and Other Issues

Potential environmental impacts would all be related to the method of concentrate disposal, which is treated as a separate option here.

References

American Membrane Technology Association and the U.S. Bureau of Reclamation. 2001. *Water Treatment Cost Estimation Program.* Denver, Colorado.

Fisher, Travis J. and Christopher J. Martin. 2000. *Desalination Pilot Report for Buena Vista Water Storage District, Kern County, California.* Boyle Engineering Corporation, Bakersfield, California.

Anaerobic – Bacterial

Description

Anaerobic-bacterial treatment is a drainage water disposal option that consists of treating agricultural drainage water or wastewater by the use of biological reactor and microfiltration. A pilot study is ongoing in the WWD to study removal rates of selenium in drainage water with anaerobic-bacterial treatment.

Anaerobic-bacterial treatment would involve the creation of holding ponds for receiving drainage water. The biological reactor would include upflow fixed-film beds, fluidized beds, and sludge blanket reactors (U.S. Department of the Interior and California Department of Fish and Game 1990).

The pilot study for the removal of selenium from drainage water showed successful reduction of selenium and nitrate.

Relationship to Other Options

Anaerobic-bacterial treatment requires disposal of residual sludge product. Residual solids left after change-out of the biological reactor would need to be disposed of off-site.

Effectiveness

Anaerobic-bacterial treatment appears to be a practical biological treatment option for drainage water. Current studies have shown that a reduction in selenium occurs with the implementation of anaerobic-bacterial technology. Rates of removal of selenium ranged from 85 percent to 90 percent during the 13-year study.

Stage of Development

Anaerobic-bacterial treatment is currently being studied for practical use for the treatment of drainage water. Researchers from EPOC Agricultural Corporation and Binnie California, Inc. are continuing their study at the WWD. This technology can be implemented at this time.

Required Study

Additional studies on other constituents may be necessary to measure the rate of removal in addition to the treatment of selenium and nitrogen in drainage water.

Efficiency

Cost

Preliminary cost estimates for anaerobic-bacterial treatment in the pilot study at WWD ranged from $145-$244/acre ($2,000 dollars), depending on the size of the treatment ponds and flow rate (Quinn et al. 2000). These estimates assume a flow rate up to 10 MGD (11,200 acre-feet per year). Construction of large-scale biological reactors for anaerobic-biological treatment is costly.

Sensitivity

As with microalgal-bacterial treatment, anaerobic-bacterial treatment system will also require a large tract of land for construction of the treatment system. The site would need to accommodate several biological reactors and their supporting structures. The cost of a treatment system will also depend on the target rates of reduction or removal of contaminants as well as the quality of the drainage water that will flow through the system.

Acceptability

Public Acceptance

Unknown – still in pilot study phase. It is expected that this technology would be acceptable to the public because it can reduce hazardous concentrations of selenate to non-hazardous levels.

Institutional Compatibility

Anaerobic-bacterial treatment is expected to be highly regulated. The Regional Water Quality Control Board (RWQCB) and the U.S. Environmental Protection Agency (EPA) will most likely focus on the contaminant loads in the drainage water as well as the final byproduct of anaerobic-bacterial treatment. The California Department of Water Resources (DWR), as well as participating Drainage Districts, has actively supported studies of anaerobic-bacterial treatment.

Environmental Impacts and Other Issues

Potential environmental impacts of anaerobic-bacterial treatment include the potential for wildlife exposure. A treatment facility is expected to pose less hazard to wildlife than the surrounding drainage channels, evaporation ponds, or drainage-contaminated wetlands (McGahan et al. 2000). Since the contaminants are expected to be sequestered in the residual sediment of the reactors and treatment beds, potential for exposure is minimized.

References

McGahan, J., D. Davis, and M. Alemi. 2000. *Innovative Drainage Management Practices in California*. ASCE Watershed Management 2000 Conference, Fort Collins, CO. June.

Quinn, W.T., T.J. Lundquist, F. Bailey Green, M.A. Zarate, and W.J. Oswald. 2000. Algal-bacterial treatment facility removes selenium from drainage water. *California Agriculture*, 54:6 (50-56).

U.S. Department of the Interior and California Department of Fish and Game. 1990. *San Joaquin Valley Drainage Program*, Draft Final Report. June.

Microalgal – Bacterial

Description

Microalgal-bacterial treatment is a drainage water disposal option that consists of treating agricultural drainage water or wastewater by the promotion of algal growth to effectively remove or reduce the constituents in the drainage water to its more treatable forms. Microalgal-bacterial treatment is currently used in Advanced Integrated Wastewater Pond Systems (AIWPS) technology for the treatment of sewage and industrial waste. A demonstration microalgal-bacterial facility created for the removal of selenium in drainage water operates in the Panoche Drainage District (PDD), on the west side of the San Joaquin Valley. This algal-bacterial selenium removal (ABSR) facility has been in operation since 1997.

The goal of microalgal-bacterial treatment is to grow microalgae on drainage water, using the algal biomass as a carbon source for native bacteria such as Acinetobacter and Psuedomonas. Microalgae are produced from a variety of sources, including commercial sources as well as byproducts of conventional wastewater treatment.

Microalgal-bacterial treatment would involve the creation of treatment ponds for receiving drainage water. AIWPS systems typically consist of a Reduction Pond (RP), High Rate Pond (HRP), and an Algae Settling Pond (ASP). A Dissolved Air Flotation (DAF) Unit and a Sand Filtration (SF) Unit can be added for final harvesting of the residual algae.

The pilot study for the PDD for the removal of selenium from drainage water showed successful reduction of selenate and nitrate into their more non-soluble forms. Rates of removal varied on the types of substrate added to the system.

Relationship to Other Options

Microalgal-bacterial treatment requires disposal of the spent algae product.

Effectiveness

Microalgal-bacterial treatment appears to be a practical, biological treatment option for drainage water. Current studies have shown that a reduction in selenium and nitrate occur with the implementation of microalgal-bacterial technology. Rates of removal of selenium ranged from 45 percent to 80 percent during the cumulative 2-year ABSR study. Seasonal fluctuations were observed in the rates of removal, with relatively higher rates found during warmer weather.

Stage of Development

Microalgal-bacterial treatment is currently being studied for widespread application for the treatment of drainage water. Researchers from U.C. Berkeley and Lawrence Berkeley Laboratory are continuing their ABSR study at the Panoche Drainage District (PDD). This technology can be implemented at this time.

Required Study

Additional studies on other constituents may be necessary to measure the rate of removal in addition to the treatment of selenium and nitrogen in drainage water.

Efficiency

Cost

Preliminary cost estimates for microalgal-bacterial treatment in the PDD Study range from $104-272/acre-foot (2000 dollars), depending on the size of the treatment ponds and flow rate (Quinn et al. 2000). These estimates assume a flow rate up to 10 million of gallons per day (MGD) (11,200 acre-feet per year).

Sensitivity

A microalgal-bacterial treatment system will require a large tract of land for construction of the reduction ponds, high rate ponds, and supporting structures. The cost of a treatment system will also depend on the target rates of reduction or removal of contaminants as well as the quality of the drainage water that will flow through the system.

Acceptability

Public Acceptance

The level of public acceptance is unknown as findings are still in pilot study phase. It is expected that this technology would be acceptable to the public because it can reduce hazardous concentrations of selenate to non-hazardous levels.

Institutional Compatibility

Microalgal-bacterial treatment is expected to be highly regulated. The Regional Water Quality Control Board (RWQCB) and the U.S. Environmental Protection Agency will most likely focus on the contaminant loads in the drainage water as well as the final byproduct of microalgal-bacterial treatment. Reclamation as well as participating Drainage Districts have actively supported studies of microalgal-bacterial treatment.

Environmental Impacts and Other Issues

Potential environmental impacts of microalgal-bacterial treatment include the potential for wildlife exposure. An ABSR facility is expected to pose less hazard to wildlife than the surrounding drainage channels, evaporation ponds, or drainage-contaminated wetlands (Quinn et al. 2000). Since the contaminants are expected to be sequestered in the deep sediments of the RPs, potential for exposure is minimized. However, exposure to contaminants in the final effluent is currently under evaluation in current studies by Quinn et al. (2000).

References

McGahan, J., Davis, D. and M. Alemi. 2000. *Innovative Drainage Management Practices in California*. ASCE Watershed Management 2000 Conference, Fort Collins, CO. June.

Quinn, W.T., Lundquist, T.J., Bailey Green, F., Zarate, M.A. and W.J. Oswald. 2000. *Algal-bacterial treatment facility removes selenium from drainage water*. California Agriculture, 54:6 (50-56).

Selenium Removal: Chemical Treatment

Description

Selenium is present in some drainage waters at levels that exceed regulatory limits for discharge to surface waters and impoundments. In drainage water, selenium occurs primarily in the form of dissolved selenate (SeO_4^{2-}) and selenite (SeO_3^{2-}), which are the species that pose a risk to the environment. Several treatment technologies have been developed which convert selenate to other forms of selenium that are not considered hazardous to the environment.

In 1986, Murphy (1988) discovered that ferrous hydroxide [$Fe(OH)_2$] removes both selenate and selenite from solution. This occurs by way of an oxidation-reduction reaction followed by co-precipitation. During the reaction, soluble selenate is reduced to insoluble elemental selenium while soluble ferrous hydroxide is oxidized to insoluble iron oxides. This reaction may be represented as:

$$Se^{VI}O_4^{2-} + 6Fe(OH)_2 \rightarrow Se^0 + 3Fe_2O_3 + 2OH^- + 5H_20$$

The elemental selenium adheres to the surface of the iron oxide flocs that form and settle to the bottom of the solution. The reaction is pH dependent and requires the addition of lime or sodium hydroxide to maintain a pH of about 9.

A series of field and laboratory tests conducted during 1987 - 1988 using drainage water from Mendota, California found that several constituents in the water inhibited the selenate reduction reaction (Moody and Murphy, 1989). Dissolved oxygen (O_2) and nitrate (NO_3^-) in drainage water are competitors to selenate for reduction by ferrous hydroxide. Bicarbonate (HCO_3^-) interferes by reacting with ferrous hydroxide to precipitate as ferrous carbonate. Oxygen, nitrate, and bicarbonate should be removed from the drainage water in a pretreatment step prior to the reduction of selenate with ferrous hydroxide.

Biological denitrification is a technology that can be used to consume the dissolved oxygen and nitrate in the drainage water. Bicarbonate is rapidly removed by raising the pH above 9 where the carbonate species predominates and precipitates out of solution as calcium carbonate. This is accomplished by the addition of lime.

Relationship to Other Options

Chemical treatment is not a complete drainage disposal option; it still requires disposal of the product water. Chemical treatment does, however, enhance the viability of other reuse and disposal options that require selenium removal to meet regulatory discharge requirements for surface waters and impoundments. Additionally, chemical treatment generates a non-hazardous solid waste that requires disposal in a landfill.

Effectiveness

Capacity

Chemical treatment effectively removes selenium from drainage water. Preliminary field and laboratory studies indicate that this technology has the capacity to reduce the selenium concentration in drainage water to levels that are in the range of regulatory discharge requirements. Removal of other potentially harmful trace metals has also been demonstrated through co-precipitation with iron oxides (Merrill et al., 1987; Okamoto and Okamoto, 1977; Okuda et al., 1975).

Stage of Development

The reduction of selenate in deionized water by ferrous hydroxide was discovered in Reclamation's Denver laboratory in 1986. A pilot test was conducted using drainage water near Mendota, California, in 1987. The pilot test revealed that other dissolved constituents in the drainage water inhibit reduction and removal of selenium (Moody et al., 1987). The field test achieved 90 percent removal of selenium within 1 hour and 95 percent removal within 4 hours in the presence of the yet unknown inhibiting constituents.

Additional laboratory experiments were performed in Denver in 1988 to identify the competing and interfering solutes in the selenium reduction reaction. These experiments found that dissolved nitrate, oxygen, and bicarbonate interfered with the reduction of selenium in drainage water. The results were published in a paper that also described pretreatment operations that can be used to remove the interfering solutes prior to chemical treatment for selenium removal (Moody and Murphy, 1989).

No additional work has been done since 1989 to develop this technology or evaluate the performance and cost of a treatment process in the field.

Required Study

Field studies are required to evaluate the performance and cost of a combined treatment process that removes both selenium and the other interfering solutes. This was not done in the previous studies. Additional studies are required to optimize the potential pretreatment operations that are necessary to effectively remove the selenium. The testing of a combined treatment process should also include an evaluation of the sludge characteristics and the potential to recycle the sludge to reduce the cost of disposal. The iron oxide sludge could be redissolved with acid in a recycle mode without affecting precipitated elemental selenium.

Efficiency

Costs

Cost estimates for a 50-mgd water treatment plant to remove selenium to a level below 5 μg/L were prepared from laboratory and field data (Moody and Murphy, 1989). These costs were updated to current year dollars using the Construction Cost Index published by *Engineering News Record*. The cost of selenium removal is estimated as $270 per acre-ft of drainage water in year 2001 dollars. This estimate includes the cost of pretreatment operations to remove the constituents that compete or interfere with the selenium reduction reaction. This estimate does not include the cost of disposal for the iron oxide sludge that contains the reduced elemental selenium.

There is considerable uncertainty in this estimate because some of the cost components were based on performance parameters that have not been verified in the field. In general, cost estimates for water treatment require pilot-scale field data to verify performance and chemical quantities.

Sensitivity

The cost and efficiency of chemical treatment are sensitive to variations in the levels of selenium and other constituents in the drainage water.

Acceptability

Public Acceptance

Public acceptance is unknown, but it is expected that this technology would be acceptable to the public because it can reduce hazardous concentrations of selenate to non-hazardous levels.

Institutional Compatibility

It is expected that the chemical treatment process and landfill disposal of iron oxide sludge would meet with regulatory approval.

Environmental Impacts and Other Issues

Chemical treatment produces an iron oxide sludge whose characteristics and quantity have not been adequately determined in a field setting. It is expected that the sludge would have a minimal impact to the environment by disposal in a landfill.

References

Merrill, D.T., M.T. Manzione, D.S. Parker, J.J. Petersen, W. Chow, and A.O. Hobbs. 1987. "Field Evaluation of Arsenic and Selenium Removal by Iron Coprecipitation," *Environmental Progress*, 6(2): 82-90.

Moody, Charles D., Andrew P. Murphy, Bryan G. Ralston, and Robert A. Hulsey. 1987. "Bureau of Reclamation Experimental Results for Removing Selenate from Agricultural Drainage Waters," Toxic Substances in *Agricultural Water Supply and Drainage – Searching for Solutions*. Papers from the 1987 National Meeting, Las Vegas, Nevada, December 2-4, 1987; U.S. Committee on Irrigation and Drainage, Denver.

Moody, Charles D. and Andrew P. Murphy, 1989. "Selenium Removal with Ferrous Hydroxide: Identification of Competing and Interfering Solutes," *Toxic Substances in Agricultural Water Supply and Drainage – An Environmental Perspective.* Papers from the Second Pan-American Regional Conference of the International Commission on Irrigation and Drainage, Ottawa, Canada, June 8-9, 1989; U.S. Committee on Irrigation and Drainage, Denver.

Murphy, Andrew P. 1988. "Removal of Selenate from Water by Chemical Reduction." *Ind. Eng. Chem. Res.*, Vol. 27, pp. 187-191.

Okamoto, S., and S.I. Okamoto, 1977. "Coprecipitation of Divalent Metal Ions in Solution by Formation of Ferrous Hydroxide Gel," *Yogyo Kyoakaishi*, 85(10): 518-522.

Okuda, T., I. Sugano, and T. Tsuji, 1975. "Removal of Heavy Metals from Wastewater by Ferrite Co-Precipitation," *Filtration and Separation*. 472-477.

Integrated Drainage Management

The term "integrated drainage management" is used in this report to describe methods for managing agricultural drainage through reapplication of tile drain water to a sequence of increasingly salt-tolerant crops. The number of steps comprising the reuse sequence is variable as are the crops to which the drainage water is applied at each stage of the sequence.

As defined in this memo, integrated drainage management refers to treatment of agricultural drainage water through reuse by crops or trees. The disposition of residual drainage effluent from the final stage in the sequence of agricultural processes is not addressed here but is addressed in discussions of land fills, solar ponds, reverse osmosis and other techniques for treatment of waste streams of the type generated by integrated drainage management.

Description

General

Integrated drainage management encompasses other terms that describe more narrowly specified approaches to reuse of agricultural drainage. One such term is agroforestry. Agroforestry has been defined by the San Joaquin Valley Drainage Program (SJVDP) report *A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley* (SJVDP, September 1990) as "the practice of growing certain types of trees with drainage water. The trees act to dispose of applied drainage and shallow groundwater through foliar evaporation and at that time produce a marketable commodity" (p. 179). Because research into agroforestry has broadened to include salt-tolerant crops and halophytes beyond the eucalyptus trees and atriplex originally proposed, the concepts explored by agroforestry research are now more broadly applied in integrated drainage management.

Another common term is "Integrated on-Farm Drainage Management" (IFDM) (WRCD, October 1999). A distinction between IFDM and integrated drainage management is that IFDM is limited to the farm scale and includes a final disposal method for the salts.

Drainage water reuse is a third commonly used term. The final report of the Drainage Reuse Technical Committee (SJVDIP, February 1999) defines drainage water reuse as, "the use of drainage water for beneficial purposes." The report focuses on reuse for irrigation because the majority of research and technical information relates to this subject. Strategies of drainage water reuse that have been proposed include:

- Sequential Reuse—a sequence of fields with the tile drain water from each field used on the next; thus, drainage water with increasing salinity is used on crops with increasing salt tolerance
- Blending—tile drainwater is blended with better quality water
- Cyclic Reuse—tile drainwater and good quality water are used in cycles on a field depending on the salt tolerance of the crop grown

- Combinations—some blending may occur on one of the fields in a sequential reuse program

Although each of these methods is a potential component of an integrated drainage management strategy, sequential reuse is fundamental to the concept of integrated drainage management. Sequential reuse can be defined as a tile drainwater treatment option that uses certain crops (trees, salt tolerant forages, or halophytes) that grow in relatively high salinity conditions to concentrate applied tile drainwater within the root zone. Although some of these crops may have the ability to uptake or fix selenium or other salts from applied drainwater, research to-date has shown these amounts to be negligible in terms of the total salt balance.

Traditional Configurations

Existing integrated drainage management systems have three or four stages designed to come to equilibrium at differing salinities for each of the crops begin grown so that the equilibrium salinity is appropriate to the salt tolerance of the particular crop. As noted above, the concentrated brine collected from the final stage is unsuitable for further treatment by agricultural processes and must be treated and disposed of by other techniques.

Integrated drainage management can be implemented at different scales. Different stages of the treatment process can be contained within a single farm, as is the case at Red Rock Ranch (WRCD, October 1999) and Rainbow Ranch (Andrews, 2001). Alternatively, different stages of treatment could be sited at different locations so that the overall program assumes a district or regional scale.

The system being implemented at Red Rock Ranch (WRCD, October 1999) and a similar system more recently installed at Rainbow Ranch (Andrews, 2001) first use irrigation water in a low-saline zone covering about 75 percent of the area growing vegetables and other salt-sensitive crops. Tile drainwater from this area is blended with tailwater (irrigation water in the case of Rainbow Ranch) and used to irrigate salt-tolerant commercial crops such as cotton, sugar beets and other grasses on a “low-saline” zone occupying about 20 percent of the area. The drainwater from this zone is used on very salt-tolerant grasses or halophytes in the “moderate-saline” zone. This drainwater is used on halophytes in the “high-saline” zone (the Rainbow Ranch system only has the first three stages). The concentrated brine collected form the “high-saline” zone then requires disposal.

A potential advantage of integrated drainage management is that it uses drainage water to produce marketable crops. For example, the cotton grown in the “low-saline” zone at Rainbow Ranch was reported to have produced high yields. Research is ongoing to determine the suitability of various salt-tolerant forages that could be grown in the “moderate-saline” zone. These forages could be used to make up the existing shortfall of forages on the west side of Valley. Continuing research is examining the potential of halophytes, such as Salicornia, to concentrate brine in the “high-saline” zone and to produce marketable products. Some researchers and farmers feel that the brine discharged as tile drainage from the “high-saline” zone can be disposed of safely on farm with a netted solar evaporator resulting in crystallized salt. Another option would be to collect the brine for further treatment and disposal by non-agricultural processes at regional centers.

Alternative Configurations

At this point both Red Rock Ranch and Rainbow Ranch offer useful models for evaluation of the costs and performance of integrated drainage management strategies.

Both of these sites were conceived as self-contained facilities for treatment and disposal of drainage wastes. However, given the magnitude of the drainage issues facing the San Luis Unit, other configurations for integrated drainage management should be evaluated. Two fundamental considerations in formulating alternative treatment configurations are:

- Lands that are best suited to commercial production of salt-sensitive crops may not be contiguous to lands that are best suited to production of salt-tolerant crops or halophytes.
- Regulatory compliance with regard to treatment and disposal of discharge from the integrated drainage management process is proving to be complex at on-farm facilities such as both Red Rock Ranch and Rainbow Ranch. Regulatory requirements for integrated drainage management are discussed later in this document.

A possible response to the first consideration is that there may be advantages to identifying sites that are particularly well-suited to management of salt-tolerant crops or halophytes because of factors such as soil and groundwater conditions. Therefore, alternatives could be evaluated where the first one or two stages of the integrated drainage management sequence would be normal farming operations carried out on land best suited to commercial agriculture. Drainage discharged from these lands would be conveyed in canals or pipelines to regional facilities specializing in production of salt tolerant crops.

One possible distinction between the on-farm and the regional approach may be that management at the farm level would be likely to devote the best soils to production of commercial crops and the poorest soils to production of less profitable salt-tolerant crops. By contrast, a regional management approach might favor production of salt-tolerant crops on good soils because of the better water and salt management characteristics of these soils.

A regional approach to the final stages of an integrated drainage management program might also be useful from a regulatory standpoint. Rather than having a large number of on-farm facilities generating waste streams that may require regulatory compliance, a regional approach would result in a smaller number of sites requiring compliance. In addition, because these sites would specialize in management of reused drainage water, they may have both the management emphasis and the scale to enable them to respond to environmental issues more effectively than farm managers whose first priority is operation of a commercially viable farm.

Design and Operational Considerations

Integrated drainage management combined with the collection of concentrated brine is most feasible on land with subsurface drainage that enhances the ability to collect deep percolation. Based on existing prototype systems, 75-80 percent of the irrigated area slated to receive drainage service would remain suitable for salt-sensitive crops. The remaining 20 to 25 percent would be moderate- and high-saline zones for sequential reuse. Alternatively, land could be developed outside of the irrigated area for sequential reuse. Theoretically, these areas could be reclaimed for salt-sensitive crops in the future if desired.

Only the land area required limits the potential for integrated drainage management. For example, if Salicornia uses 2.5 acre-feet of water per acre per year (Benes, et al, 1999), then 40,000 acres of Salicornia would be needed to treat 100,000 acre-feet of drainwater.

Effectiveness

Stage of Development

Some practitioners feel that integrated drainage management is ready to be more widely implemented. They acknowledge that research and testing remain to be done, however, they view this continued testing as being parallel to continuing research on an agricultural commodity.

Other researchers are concerned that an equilibrium salt balance has not been achieved and may not be achieved for many years. Although progress has been made in the development of integrated drainage management, little data greater than 5 years old is available from areas in the SLU that have been irrigated using tile drain water. Thus, little definitive information exists about the condition of soils resulting from long-term irrigation using drainwater or concentrated brine. One result of testing over the last 10 years is a shift in the role of Eucalyptus trees to "drainage water interceptors" due to their poor performance (SJVDIP, 1999).

Required Study

To more effectively analyze integrated drainage management, further study is required in the following areas:

- Consumptive use of drainwater by candidate crops over a range of salt tolerances
- The potential for selenium introduction into the food chain
- Potential yield under drainwater irrigation
- Long-term sustainability of sequential reuse systems
- Market analysis of salt-tolerant crops
- Long-term impact of application of saline water on soil salinity and use of management practices (such as blending with higher quality water) to manage soil salinity

Efficiency

System Costs

Costs have been reported for the integrated drainage management pilot project at Red Rock Ranch (WRCD, October 1999). Excluding the costs for the low-saline zone and for the solar evaporator, the capital costs for tile drains and irrigation system installation amount to an annual capital cost of around $80 per acre-foot of drainage water used by the facility. The cost of land is not included in this total. Assuming cotton (acala variety) is grown on the low-saline zone, using U.C. Cooperative Extension (1999) costs of production and returns and assuming 1) no reduction in cotton yields, and 2) no returns on the salt-tolerant forages and halophytes, the annual operating costs amount to about $70 per acre-foot. This leads to a total cost of about $150 per acre-foot of drainage water. Costs have not been developed for the alternative configurations discussed.

Sensitivity

Costs of integrated drainage management would be most sensitive to the water use and growth rates (production) of the crops grown and the market value of those crops. These factors could determine the treatment capacity of integrated drainage management reuse and the potential benefit from crop production. Only limited definitive data are available on the yield, water use, nitrogen requirements, etc., of proposed salt-tolerant crops or the potential market for forages or Salicornia.

The cost of integrated drainage management is also sensitive to the cost and availability of genetically screened seeds. Currently there is not an established source in the western United States for large quantities of appropriate seeds.

Acceptability

Public Acceptance

Integrated drainage management has tended to receive favorable public reaction because of the promise of a simple, natural solution to a complex problem. Negative comments tend to focus on treatment and disposal of discharges from the final stage of integrated drainage management facilities.

Institutional Compatibility

Integrated drainage management involves the collection and application of agricultural drainwaters which have been linked to environmental problems, such as at Kesterson Reservoir and at evaporation ponds in the Tulare Basin.

The primary regulations that come into play with respect to integrated drainage management are 1) the California Environmental Quality Act (CEQA); 2) the Porter-Cologne Act; and 3) Title 27.

These regulations do not apply to use of drainage water applied to agricultural crops but they do govern treatment and discharge of concentrated effluent generated as an end product of integrated drainage management. Primary considerations in application of environmental regulations are:

- Volume and constituent concentrations of the waste discharge stream
- Location of the discharge
- Local groundwater conditions
- Assimilative capacity of local surface waters for waste discharge

Title 27 requirements for disposal of designated wastes include provisions for liners, leachate collection systems and monitoring wells that impose costs that are difficult for on-farm facilities to absorb. However, it may be that disposal of Title 27 designated wastes will prove to be economically feasible if disposal sites handle wastes generated on a regional scale.

Marketing of crops grown under integrated drainage management might be regulated by the U.S. Department of Agriculture or the California Department of Food and Agriculture if they are intended for use as cattle feed or a feed supplement, as are salt tolerant forages.

Environmental Impacts and Other Issues

The environmental impacts of integrated drainage management would be difficult to quantify as these types of projects are implemented. Some of the potential impacts include the following:

- Concentration of salts and other constituents in and below the root zone of integrated drainage management sites. Long-term impacts might include localized groundwater degradation.
- Introduction of selenium into the food chain by creating a wildlife habitat that is abundant in selenium.

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Salinity-Gradient Solar Ponds

Description

Salinity-gradient solar ponds are a variation of evaporation ponds that are specially engineered and operated to capture and store a portion of the solar energy that radiates through the surface of the pond. Their purpose is to generate energy during the course of the natural evaporation of water at the surface. A typical salinity-gradient solar pond is composed of three distinct regions (Hull et al, 1989):

- Surface zone: The surface zone is a homogeneous layer of relatively fresh water that is transparent to visible light and allows solar energy to radiate to the bottom of the pond.
- Intermediate gradient zone: The nonconvective gradient zone constitutes a thermally insulating layer whose salinity, temperature, and density increase with depth.
- Bottom zone: The bottom zone is a homogenous, concentrated salt solution where salts precipitate and accumulate at the bottom of pond.

The solar energy is converted to heat and stored in the bottom zone creating brine temperatures between 50 to 90°C. The heat escapes upward from the bottom zone slowly because the overlying gradient zone is nonconvective and the thermal conductivity of water is low. Heated brine is pumped from this zone through a heat exchanger and then returned to the bottom of the pond. The heat exchanger permits extraction of heat energy for a variety of potential uses, including process heating, space heating, desalination, and electricity generation (Lu et al., 2001).

Relationship to Other Options

Salinity-gradient energy ponds do not provide complete drainage service because the salts that accumulate at the bottom of the pond require disposal at the end of the project life. The salts would most likely be excavated and hauled to a landfill for disposal.

Effectiveness

Capacity

The capacity of salinity-gradient solar ponds to treat drainage water is nearly identical to that of evaporation ponds. In terms of drainage service, both technologies provide a means for substantially reducing the volume of drainage through natural, solar evaporation. All drainage water could potentially be evaporated using either of these options. Regulatory limits on the concentrations of dissolved constituents within the ponds, however, could limit the ability to implement these technologies on a portion of the drainage water.

Stage of Development

Salinity-gradient solar ponds were developed in Israel in the 1950s and primarily focused on electricity generation using a Rankine-cycle engine. Beginning in 1979, the solar pond at En Boqeq was the first pond to generate commercial electricity and supplied a peak output of 150 kW at a resort area. A 60-acre salinity-gradient solar pond supplied heat to operate a 5-MW power station at Bet Ha Arava between 1984-1994.

A variety of experimental and demonstration ponds were constructed at numerous locations across the U.S. beginning in the 1970s. Two 0.5-acre, salinity-gradient solar ponds were constructed at Los Banos, California, in 1983. The ponds were operated between 1986 to 1989 using a salt mixture of similar composition to agricultural drainage water in the San Joaquin valley (Engdahl, 1987).

Salinity-gradient solar ponds have not achieved commercial success in the U.S. because the cost of the energy produced has not been competitive with other sources of energy.

Required Study

The results of the Los Banos project indicate that agricultural drainage water can be used to construct and operate a salinity-gradient solar pond. Studies are required to evaluate potential uses of the heat produced and the overall economics of this technology in the San Joaquin Valley. Additional information is needed to determine whether the benefit of the energy produced by salinity-gradient solar ponds is greater than the additional cost.

Efficiency

Costs

Cost estimates were developed based on a technical memorandum that describes the feasibility and costs of SGSPs in the San Joaquin Valley (Lu et al., 2001). The total annualized construction and O&M costs of a SGSP are about 10 times greater than the total costs of an equivalent-size evaporation pond. SGSPs, however, produce energy whose value can offset some or all of the additional cost to build and operate them.

Conceptual-level estimates of the costs and benefits of a SGSP facility in the San Joaquin Valley are presented in the following table. These following assumptions were used to prepare these estimates:

- The bottom zone of the pond would be constructed at no cost using dried salt or concentrated brine from existing evaporation ponds. A preliminary analysis indicates that a SGSP would not be economically viable if salt must be purchased or dried using an enhanced evaporation system. Assuming that evaporation ponds are implemented for SLU drainage service, it may take 5 years or more to produce enough brine to establish a SGSP.
- The costs to construct and operate evaporation ponds that are part of the SGSP facility are not included. Operation and maintenance of the salinity gradient requires influent and effluent streams. The effluent stream would be discharged to an evaporation pond. The costs associated with evaporation ponds are found elsewhere in this report.
- Construction and operation of a SGSP may require a geomembrane liner and bird netting on the surface. Estimates are provided for ponds with and without liners and netting.
- Operation of the SGSP would evaporate 4 acre-ft of drainage water per acre of surface area through natural evaporation. Salts in the drainage water would precipitate and accumulate at the bottom of the pond.

- Costs for site closure or final disposal of salts that accumulate in the bottom of the pond are not included.
- Calculation of benefits assumes an energy value of $1/therm and $0.135/kW·hr, and is based on the quantity of heat energy that would be available for use for three different applications: process heat (i.e., crop drying), a thermal desalination plant, and the production of electricity using an organic Rankine-cycle engine.
- Cost analysis is based on a 50-year project life at 6 percent interest.

TABLE B-3
Estimated Costs and Benefits for a Salt Gradient Solar Pond

	Cost/ac-ft	Benefit/ac-ft
Total annualized costs without liner and netting	$4,700	
Total annualized costs with liner and netting	$6,100	
Annual benefit of energy for process heat		$9,800
Annual benefit of energy for desalination		$7,800
Annual benefit of energy for electricity production		$2,500

A comparison of the costs and benefits indicates that construction and operation of a SGSP facility could generate a net profit depending on whether a liner and netting are required and how the heat energy is used. Although SGSP technology is considered a proven technology there have been few applications and they has not achieved commercial success. Therefore, there is considerable uncertainty with regard to the estimated costs and benefits. Construction and operation of a demonstration SGSP facility in the San Joaquin Valley would be required to obtain reliable cost and benefit information.

Acceptability

Public Acceptance

The application of this technology in the San Joaquin Valley may be somewhat more acceptable to the public than traditional evaporation ponds, because it provides a renewable source of energy.

Institutional Compatibility

Regulatory acceptance would focus on the potential for groundwater degradation and exposure of wildlife to selenium.

Environmental Impacts and Other Issues

Salinity-gradient solar ponds could potentially impact groundwater quality and wildlife.

References

Engdahl, Donald D., 1987. *Technical Information Record on the Salt-Gradient Solar Pond System at the Los Banos Demonstration Desalting Facility*, Department of Water Resources, State of California.

Hull, John R., Carl E. Nielsen, and Peter Golding, 1989*. Salinity-Gradient Solar Ponds, CRC Press, Inc*. Boca Raton, Florida.

Lu, Huanmin, John C. Walton, Harry Remmers, and Scott Irvine, 2001 (in progress). Conceptual Application and Feasibility of Salinity-Gradient Solar Pond Technology in the San Joaquin Valley, California.

Evaporation Ponds

Description

Evaporation ponds are man-made impoundments of water that utilize the sun's energy to evaporate water. Their purpose is to reduce the volume of waste streams that require disposal. As the water evaporates, the remaining solution becomes more concentrated until saturation occurs. Upon saturation, salts precipitate and settle to the bottom where they accumulate over time until the ponds are closed. Upon site closure, the accumulated salts are either buried in place or excavated and hauled to a landfill.

Evaporation ponds are frequently designed and constructed to provide sequential evaporation such that impounded water flows through a series of ponds, each one having higher salinity than the previous one. Berms are constructed around the perimeter of the ponds to contain the impounded water to provide freeboard for wave action and surges, and to allow for vehicular access. Clay or synthetic liners are sometimes required to minimize seepage of the impounded water into the underlying groundwater. A variety of measures are sometimes implemented to minimize wildlife exposure to the ponds. These measures include: fencing, surface netting, and carbide cannons. Construction and operation of evaporation ponds in the Valley are regulated by the State through the Central Valley Regional Water Quality Control Board (CVRWQCB).

The efficiency of evaporation ponds depends primarily on local weather conditions. The climatic factors that influence the rate of evaporation include: exposure to sunlight, air temperature, water temperature, wind speed, and relative humidity. The hot, arid climate of the Valley provides conditions that are quite favorable for the efficient operation of evaporation ponds.

Relationship to Other Options

Evaporation ponds may or may not require additional disposal of salts. If the ponds are constructed and permitted as a permanent disposal facility, the salts would be buried in place at the conclusion of the project and the ponds would constitute a complete disposal option. If the salts have to be excavated and removed from the site, then the ponds would constitute a volume reduction option that must be combined with an off-site landfill to provide complete drainage service. Evaporation ponds could also be used for partial evaporation of the drainage water with final disposal by deep-well injection or discharge to the ocean.

Effectiveness

Capacity

The Soil Conservation Service estimated that 0.265 acres of pond surface are required to evaporate one acre-foot of drainage water in the Hanford-Lemoore area (Brown and Caldwell, 1987). With an additional 10 percent of land area for access roads and levees the total land requirement was estimated at 0.3 acres per acre-foot of drainage water.

Potential locations for evaporation ponds within the San Joaquin Valley were evaluated with respect to various criteria (land use, topography, groundwater hydrology, floodplains, and environmental constraints) to determine their capacity for evaporation of drainage water and salt disposal (Brown and Caldwell, 1987). The study concluded that there is sufficient capacity to provide for complete evaporation of Valley drainage waters. Conversely, the study also concluded that the locations suitable for evaporation would not be suitable as a permanent repository for the dried salts.

Stage of Development

Evaporation ponds are an established, well developed technology to reduce the volume of waste streams. During the period 1972 - 1985, 28 large evaporation ponds were constructed in the San Joaquin Valley to evaporate drainage water. These ponds covered a total area of about 7100 acres, mostly in the vicinity of Tulare Lake Basin. Of the 28 ponds, only 10 remain active covering an area of about 4900 acres. The remainder were either voluntarily deactivated due to high costs of regulatory compliance, or closed by order of the CVRWQCB due to toxic levels of selenium in the impounded waters (Technical Committee on Evaporation Ponds, 1999).

Required Study

An evaluation of evaporation ponds as a volume reduction and disposal option for drainage water requires an assessment of regulatory compliance requirements for groundwater and wildlife protection and evaporation performance in the San Joaquin Valley. The experience gained from the operation of current and previous evaporation ponds should provide significant information on environmental impacts, rate of evaporation, and precipitation of salts. If this information is readily available, then no additional studies are required.

Efficiency

Costs

Conceptual-level cost estimates for the construction and operation of evaporation ponds in the San Joaquin Valley are presented in the table on the next page. The estimates were developed from current unit costs and vendor quotes and follows the approach used in the detailed option descriptions in a previous evaluation of evaporation ponds (SLUDP, 1990). The analysis of cost data assumes a 50-year project life, 6 percent interest, and an annual evaporation rate of 4 ft/yr. Cost estimates were developed for an evaporation pond facility that would encompass 1280 acres (approximately 1130 acres of pond surface).

The facility would be divided into twelve 100-acre ponds with flow control devices between ponds. Water would be pumped from the collector system into the first pond from which it would flow into pond 2 and then to pond 3 and so on through the system, increasing in salinity in the process. The construction costs shown in the table include land acquisition, including the purchase of compensatory land on a 1:1 basis, earthwork, fencing, geomembrane liner, and bird netting. It is assumed that liner and netting would be required on a quarter of the facility (i.e., ponds 10 – 12) where the brine becomes very concentrated. The O&M costs include maintenance, pumping power, and monitoring. This conceptual cost estimate does not include any additional costs associated with salt disposal or site closure. It should also be noted that this estimate could increase if treatment for selenium removal is required.

TABLE B-4
Estimated Costs for Evaporation Pond Treatment (based on a 1280 acre facility)

Cost Component	Annualized Cost	Cost/Acre-Ft
Capital Costs		
Land, facility	$203,000	
Land, compensatory	$122,000	
Earthwork	$100,000	
Geomembrane liner	$624,000	
Fencing	$29,000	
Bird netting	$474,000	
Subtotal	$1,552,000	
Contingency (30%)	$466,000	
Engineering/administration	$605,000	
Total Capital Costs	**$2,623,000**	**$580**
O&M Costs		
Maintenance	$100,000	
Monitoring	$100,000	
Total O&M Costs	**$200,000**	**$50**
Total Annualized Costs	**$2,823,000**	**$630**

Sensitivity

The costs of evaporation ponds are sensitive to potential environmental impacts. As the potential for adverse impacts increases, the costs for protective measures and/or mitigation also increases.

Acceptability

Public Acceptance

It is expected that the public may accept limited expansion of evaporation ponds within the San Joaquin Valley, assuming regulatory compliance and permits are obtained. Large-scale expansion would generate significant concerns.

Institutional Compatibility

To be added.

Environmental Impacts and Other Issues

Evaporation ponds can potentially degrade underlying groundwater and harm exposed wildlife. Regulators control these potential impacts by imposing constraints on the construction and operation of the ponds.

References

Brown and Caldwell, Consulting Engineers, 1987. *Screening Potential Alternative Geographic Disposal Areas*. Prepared for the San Joaquin Valley Drainage Implementation Program. Sacramento, California.

Technical Committee on Evaporation Ponds, 1999. *Evaporation Ponds – Final Report*. Prepared for the San Joaquin Valley Drainage Implementation Program. Sacramento, California.

Enhanced Evaporation Systems

Description

Enhanced Evaporation Systems (EESs) are mechanical devices that are installed at evaporation ponds to augment the quantity of water that evaporates by natural means. Natural evaporation in a pond occurs only at the interface between the water and air. The quantity of water that evaporates is, therefore, directly proportional to the surface area of the pond. The rate of evaporation is also dependent on climatic factors such as temperature, wind speed, and humidity. An EES increases the quantity of water that evaporates by both increasing the surface area of water that is exposed to the air and imparting a wind effect about the air-water interface. This is accomplished simply by forming small water droplets that are sprayed through the air.

EES's are sold in a variety of configurations but their designs share a commonality in creating water droplets that are sprayed into the air. The combined surface area of the droplets provides for a much greater rate of evaporation as compared to that which occurs at the pond surface. The commercially available EES's that are most applicable to the elimination of waste streams are:

- Suspended shower system: Shower lines consisting of pipes with nozzles are suspended 60 to 150 feet above ground between structural towers. Water is pumped through the pipes and nozzles and it evaporates during its descent to the ground.
- Turbo-spray system: A turbo-spray system is similar to a snowmaking machine. An electrically driven blower propels water droplets up to 100 feet above the ground. Droplets are formed by pumping water through nozzles that are mounted at the end of a cylindrical tube. The blower ejects air through the cylinder, which carries the droplets as they evaporate during their trajectory.

The mining industry relies on EESs throughout the world to reduce the volume of their waste streams. The benefit of enhanced evaporation is to reduce the area of ponds required for natural evaporation as well as the potential environmental impacts associated with the ponds.

Relationship to Other Options

Enhanced evaporation serves as a volume reduction step for drainage water and requires an additional disposal option for the residual salts. EES's are always used in conjunction with evaporation ponds, which serve to capture most of the residual salt and spray that drift from the nozzles to the ground. The salts that accumulate in the evaporation ponds either remain buried in place or are excavated and hauled to a landfill.

Effectiveness

Capacity

EES's can potentially be used in conjunction with evaporation ponds to treat all of the drainage water in the San Joaquin Valley. Residual salt and spray from an EES that falls into an underlying evaporation pond causes the pond to become increasingly concentrated with dissolved and suspended salts. This material gradually accumulates as scale on the surfaces of pumps, pipes, valves, and nozzles causing a reduction in flow through the EES. Scale formation, therefore, probably limits the capacity of EES's to completely evaporate the drainage water. The final evaporation stage of the drainage water would likely be carried out in the evaporation pond.

Stage of Development

EES technology has been developed and achieved commercial success only within the past 20 years. As the technology matures it is expected that evaporation performance will improve and that capital and operating expenses will decline.

Required Study

The performance of EES's is strongly dependent on site-specific weather conditions and the composition dissolved constituents in the water. A pilot-scale field study of enhanced evaporation of drainage water is required to develop cost and performance data in the San Joaquin Valley.

Efficiency

Costs

As described earlier, EES's are used in conjunction with evaporation ponds to enhance the rate of evaporation. They are installed and operated within the impoundment to minimize potential drift of residual salt and spray outside of the evaporation facility.

A conceptual cost estimate to furnish, install, and operate an EES in the San Joaquin Valley was developed using the following assumptions:

- Individual evaporator units cost $20,000 each.
- Feedwater rate to the evaporator unit is 66 gpm; average evaporator efficiency is 67 percent net evaporation (i.e., 44 gpm evaporates). Evaporator unit would operate only when conditions are favorable for evaporation (i.e., evaporator would be running about 70 percent of the time).
- Bearing service would be required every 5 years at a cost of $500/unit, motor replacement would be required every 10 years at a cost of $3500/unit, and entire evaporator unit is replaced every 20 years.
- Project life is assumed to be 50 years and the discount rate is assumed to be 6 percent.
- Contingencies are estimated as 30 percent of total equipment costs. Engineering and project management are an additional 30 percent of these costs.
- Cost of power is current retail rate: 7.5¢/kW-hr.

The estimated cost of using EES technology to evaporate drainage water is $480/acre-ft. This does not include any costs associated with constructing, operating, and maintaining the evaporation ponds where EES would be used. The primary cost component of an EES is the electric power consumed by pumps and turbines to form the water droplets and propel them through the air. The economic viability of EES for the evaporation of drainage water would likely depend only on the cost of power to run the system. The above estimate conservatively assumes the current retail cost of electric power from PG&E. There is a possibility that power could be obtained for this project at a substantially lower cost. The current price of "project power" that is generated by Reclamation facilities and made available for federal projects is about 1.5 ¢/kW-hr. If this "project power" were made available for a federal EES project to provide drainage service to the San Joaquin Valley, the cost for evaporation could be reduced to about $200/acre-ft of evaporated drainage water.

An EES would be used only if the cost/acre-ft is lower than the cost/acre-ft in a natural evaporation pond facility. A review of the cost components and estimates for evaporation ponds indicates that EES would be more expensive than evaporation ponds that do not require geomembrane liner or bird netting. The estimates also indicate that an EES could provide substantial cost savings when lined and netted evaporation ponds are required. In this instance, the cost of operating an EES would by offset by the savings in reduced area of land, netting, and liner for the evaporation pond.

Sensitivity

The cost of operating EES's is sensitive to the local cost of electrical energy needed to power the equipment.

Acceptability

Public Acceptance

EES's produce a visible mist of water droplets that can drift with the air currents up to a mile away. A large number of EES units alter the humidity and temperature of the air within their zone of influence. For these reasons, EES units should be operated at a far enough distance from human activity that their effects are not noticed. Public acceptance will be a function of this distance.

Institutional Compatibility

Regulatory agencies are primarily concerned with the drift of the spray that is produced by EES's. Regulatory acceptance is usually conditional on shutting down EES operation when the local wind speed reaches a specified value.

Environmental Impacts and Other Issues

Water droplets produced by EES's evaporate in the atmosphere leaving behind salt particles that eventually drift to the ground surface. The fate of these salt particles determines the potential environmental impacts. Using evaporation ponds to collect and store the residual spray and salt minimizes these impacts.

Ocean Discharge

Description

Ocean discharge is an agricultural drainwater disposal option that disposes the drain water, including dissolved salts and trace constituents, into the Pacific Ocean.

Mixing the drainage water with ocean water will reduce the concentrations of contaminants. A properly designed outfall, with a diffuser, works with the water densities, currents, and flow movements in the ocean to provide the necessary mixing mechanism. Untreated drainage water will rise from the diffuser because it has a lower density than ocean water. Concentrated drain water will drop through the water column if its density is greater than that of ocean water.

There are many possible configurations for an ocean discharge outfall (Brown and Caldwell, 1987). Types of systems range from long, deep-water, multi-port diffusers that convey large volumes of untreated drainage water; to very deep open-end pipes that discharge low volumes of very concentrated treatment brine.

Major elements of an ocean disposal system include collection, conveyance, pumping, power generation, and outfall components. The collection and conveyance components include the existing section of the San Luis Drain.

An outfall would be required to direct the discharge to the appropriate location and depth in the ocean to mix the drainwater with seawater to acceptable concentration levels. These components are major facilities requiring a significant capital expenditure. The costs estimated below include the cost of the outfall and diffuser.

Relationship to Other Options

Ocean discharge of untreated drainage water can be implemented independently of other options. It is possible, however, that the most economically feasible or institutionally viable implementation would combine ocean discharge with one of the following:

- Source control
- Drainage water treatment
- San Joaquin River discharge

Effectiveness

Capacity

Several locations along the central California coast are potential ocean disposal sites. The Brown and Caldwell (1987) report identified nine potential untreated drainage water sites and eight concentrated brine disposal sites in San Mateo, Santa Cruz, Monterey, and San Luis Obispo Counties. They screened these sites assuming highly concentrated treatment brine would be disposed in ocean waters at least 600 meters deep and that drainage water could be discharged in ocean waters at least 60 meters deep. Locations that would not be acceptable as ocean discharge points are those such as Monterey Bay with an Area of Special Biological Significance and those with significant engineering or technical constraints.

Technically, the ocean discharge option could handle all the flow anticipated from the SLU.

Stage of Development

Ocean discharge is an available technology. Domestic wastewater is presently discharged in the Pacific Ocean at Santa Cruz, Capitola, Watsonville, Fort Ord, southern Monterey Bay at Carmel, and Morro Bay. Heated cooling water from electrical power production facilities is discharged at Moss Landing in Monterey Bay and at Morro Bay. Ocean discharge has been used for domestic wastewater and electrical power generation cooling water.

Required Study

More study is required to clarify the feasibility of the ocean discharge option; the effects of the discharge on the ocean environment, especially in areas of biological significance; and mixing and diffusion rates of drainwater discharges in seawater.

Efficiency

Costs

Reclamation developed appraisal level costs for this system. The total construction cost of the potential ocean discharge system is $2,470 per ac-ft per year. The annual costs of operation, maintenance, recovery, and energy total $150 per ac-ft per year per year. Some of the key components and variables affecting the costs of these options are:

- Transmission systems
- Outfall and diffuser configuration
- Operation and maintenance
- Service life
- Location of components and distance to outfalls
- Discharge solution contaminant concentrations
- Oceanographic conditions

Reclamation designed the system based on a steady flow of 450 cfs. Costs were then proportion as to the flow rate. This process should provide enough accuracy for this level of design providing the flow rates do not get too small.

The cost estimators used a power cost of 75 mils.

Sensitivity

The cost of an outfall system would be most sensitive to the final concentration of the discharge water, either untreated drainage water or concentrated brine, discharge location and depth.

Acceptability

Public Acceptance

It is expected that coastal communities and other groups will strongly protest the concept of ocean discharge of agricultural drainage water.

Institutional Compatibility

A large portion of the Pacific Ocean, stretching from Marin County to south of Big Sur, is currently designated as a protected marine sanctuary, the Monterey Bay National Marine Sanctuary. New outfalls for drainage discharge would not be permitted. Discharge of drainage water into other areas of the Pacific Ocean would need to meet requirements of the California Ocean Plan. A NPDES permit would be required from the RWQCB. Other agencies with regulatory authority include the California Coastal Commission, the Corps of Engineers, and the U.S. Coast Guard.

Environmental Impacts and Other Issues

Salts and trace elements found in drainage water could degrade the quality of the receiving water and endanger the marine ecosystem. Future investigators must thoroughly study this, if this alternative is brought forward. A well designed diffuser can reduce such problems.

References

Brown and Caldwell, 1987. *Screening Potential Geographic Disposal Areas*. Prepared for the San Joaquin Valley Drainage Program under contract with the U. S. Bureau of Reclamation. April 1987.

San Joaquin Valley Drainage Program. (SJVDP), 1987b. Summary of Minutes of the Policy and Management Committee Meeting. August 17, 1987.

San Joaquin Delta Discharge

Description

San Joaquin Delta discharge option disposes drainage water, including dissolved salts and trace constituents from agricultural drainage, into the San Joaquin Delta.

Mixing the drainage water with Delta water reduces the concentrations of contaminants to acceptable levels. The outfall would include a 10:1 diffuser and works with the river and tidal currents to provide the necessary mixing mechanism.

Major features of a Delta discharge system would be a canal or pipeline for conveying drainage water from the San Luis Unit (SLU) to the Delta, regulating storage to control the timing of discharges, and a diffuser to control concentrations of contaminants in Delta waters. The IDP presented a conceptual plan for a valley-wide Delta discharge system in 1979. It included a lined drainage canal beginning near Bakersfield, running northwesterly along the valley trough to a discharge point at the confluence of the Sacramento and San Joaquin Rivers near Chipps Island, approximately 4 miles west of Pittsburg. Wetland marshes together with special regulating reservoirs would store summer drainage water flows for discharge to Delta waters during periods of high river flow, primarily in winter and early spring months. The SLU would serve by approximately 17,000 acres of wetlands and ponds in the Mendota area. This plan was developed prior to findings of selenium toxicity at Kesterson Reservoir in 1984.

This design extends the existing drain and disposes the drainwater south of Chipps Island. It uses the previously designs and quantities to bring the costs up to present day.

Relationship to Other Options

San Joaquin Delta discharge would require, at minimum, some drainwater treatment to reduce the level of selenium to less than 50 ppb and a 10:1 dilution at the outfall. However, as described above, combining Delta discharge with controlled drainage or treatment might enhance disposal opportunities.

Effectiveness

Capacity

The 1979 IDP planned discharge site near Chipps Island was strategically selected to achieve maximum mixing and dilution of drainage water with Delta outflow water. At that time, the disposal capacity was judged to be adequate to handle the ultimate drainage water flow of the majority of the San Joaquin Valley, estimated to be 668,000 acre-feet annually by 2085, with a salt load of 3.9 million tons (IDP, 1979). This conclusion was based on detailed numerical modeling, including verification with the U.S. Army Corps of Engineers physical model in Sausalito. Chipps Island was selected as the easternmost and therefore most economical discharge point that would ensure protection of Delta waters against adverse impacts.

These studies would need to be updated with respect to selenium and other potentially toxic trace constituents and the proximity of the outfall to newly constructed features in the river. It is considered likely that the capacity of Delta discharge would be able to handle drainage water flows from the SLU if not the entire valley.

Stage of Development

Delta discharge is an available technology.

Required Study

Study is required in the following areas to better understand the opportunities and constraints relative to Delta discharge:

- Determination of the Delta's assimilative capacity considering applicable water quality objectives and criteria, with respect to all constituents of concern
- Identification of potential treatment needs to meet water quality objective
- Operation studies to determine required regulation reservoir storage capacity, if any, to minimize water quality impacts
- Related studies of controlled drainage to determine potential for in field storage
- Mapping needs to be done to locating new features in the area that may affect the outfall or that the outfall may affect. Hydrologic studies of the area of outfall need to be updated.

Efficiency

Costs

As part of its study, the IDP prepared cost estimates for four Delta discharge locations. Annual equivalent costs for the Chipps island option were the highest at $33.4 million dollars, including capital, operation, maintenance, replacement, and power costs. These costs for the Chipps Island discharge are assumed to be indexed to 1979. Estimators have updated these costs for 2001 cost levels. The construction cost currently for this option is $2,870 per ac-ft with annual costs of $150 per year per ac-ft. These costs do not include potential treatment costs or incremental costs that could be incurred for alternatives to surface storage facilities.

The cost estimators used a power cost of 75 mils.

Sensitivity

The costs described above are most sensitive to potential treatment requirements to satisfy water quality considerations. They are also sensitive to any change in location of the outfall.

Acceptability

Public Acceptance

Environmental organizations and Bay Area interests are strongly opposed to Delta discharge.

Institutional Compatibility

Delta water quality improvement is one of the main objectives of the CALFED Bay-Delta Program. Substantial restrictions and/or mitigations may be necessary for Delta discharge to be compatible with the CALFED water quality improvement program and to satisfy discharge permitting requirements.

Environmental Impacts and Other Issues

Degradation of Delta water quality is the most important potential impact of Delta discharge. Concerns have been raised about bioaccumulation of selenium and other constituents in the aquatic biota. These and other concerns would need to be addressed through the discharge permitting process with the RWQCB.

The IDP plan included provisions for interceptor drains to be installed downslope from and parallel to the drainage canal to intercept seepage in order to avoid degrading groundwater.

References

San Joaquin Valley Interagency Drainage Program. *Agricultural Drainage and Salt Management in the San Joaquin Valley*. June 1979.

San Luis Unit Drainage Program Preliminary Alternative Workshop. Bureau of Reclamation. 1990.

Supporting Information Supplement to San Luis Unit Drainage Program Preliminary Alternative Workshop. Bureau of Reclamation. 1990.

Special Report on Drainage and Water Service and Draft Supplement the Final Environmental Statement, San Luis Unit, Central Valley Project, California, June 15, 1984.

Land Disposal of Residuals

Description

Landfilling could be used to dispose of solids extracted from SLU drainwater. Landfilling involves placing highly concentrated salts and trace constituents in a disposal site regulated to accept such materials. The salts and trace constituents are extracted from drainwater by a treatment option such as evaporation ponds or thermal evaporation. The type of landfill required depends on the characteristics of the solids extracted. Either existing or newly constructed landfills could be used for solids disposal.

California regulations divide solid wastes into categories that determine the class of landfill in which a solid waste can be deposited (i.e., Class I, II, or III, with Class I being for hazardous wastes). Evaporation ponds or thermal treatment units are assumed to be located near Mendota. A detailed description of the landfill option was prepared for the SLUDP (Reclamation, 1990b), which addressed the quantity and quality of the drainage solids produced.

The primary constituents of concern in the SLU drainwater are arsenic, molybdenum, and selenium. Because these constituents are in the group of “wastes that must be managed as hazardous wastes” and based on the estimated concentrations of these constituents, the solids extracted from SLU drainwater will be required to be disposed of in a Class I or II landfill.

However, if concentrations of these constituents and any trace organics (such as may result from agricultural chemicals) fall below the acceptance levels for a Class III landfill, a substantial disposal cost savings could be anticipated.

Waste acceptance criteria were collected for seven existing Class I and II landfills estimated to be within the study area applied to the SLUDP study.

Existing Landfill Capacity

Information from the SLUDP has been updated as shown below. Table B-5 includes the sites presented in the SLUDP report as well as two additional sites within the study area.

The suitability of this waste for disposal as a Class II or I waste will need to be determined following laboratory testing of the actual waste. Additionally, as previously stated, there is the possibility that the waste may be within the waste acceptance criteria of several Class III sites within the study area. This possibility should be evaluated further.

TABLE B-5
Existing Landfill Capacities
(Updated from 1990 study)

Landfill	Class	County	Distance From Mendota (mi.)	Permitted Maximum Daily Tonnage	Approximate Average Daily Tonnage Currently Received	Site Disposal Capacity (million yd^3)
Kettleman	I	Kings	55	N/A		
Safety-Kleen (Buttonwillow), Inc.	I	Kern	105	4,050	N/A	14.3[a]
Buena Vista	II	Amador	110	450	170	0[b] currently 5 (pending)
Altamont	II	Contra Costa	110			
Keller Canyon	II	Contra Costa	110	4,500	3,000	17
McKittrick	II	Kern	105			
Forward	II	San Joaquin	95	N/A	N/A	2.1

[a]Capacity from published CIWMB data (CIWMB, 2000).
[b] 5 million cy capacity to be available upon completion of new module in approximately 1 year. Currently there is no capacity for out-of-county waste.
N/A Not Available

Chemical Waste Management—Kettleman Hills Site

The Chemical Waste Management—Kettleman Hills facility (CWM-KH) is one of the largest Class I landfill facilities in California and one of two sites in the vicinity of the study area that can accept both designated and hazardous wastes except those of radioactive content. This site is located on 211 acres, 4 miles southwest of Kettleman City off of Highway 41.

According to the environmental manager for CWM-KH, as of January 1, 1990, the landfill site had a remaining air space capacity of 1.1 million cubic yards. Another 3.5 million cubic yards was projected to become available at a new landfill site in 1991; an additional 3.0 million cubic yards was to become available in 1992 through a reconfiguration of the existing landfill. The projected lifespan and loading rates associated with these expansions were considered proprietary information (Personal Communication, 1990c).

The financing, design and construction, operations plan, permits, and environmental review have been completed for the proposed additional landfill at the CWM-KH site. However, the State Department of Health Services is regulating the actual amount of on-line landfill capacity. Kings County hazardous waste production in the year 2000 is estimated to be approximately 8,600 tons (Kings County Planning Agency and McLaren Environmental Engineering Inc., 1989). This facility continues to import hazardous wastes from other counties in the state. However, no estimate has been made quantifying the amount of hazardous waste that will be imported in the year 2000.

Safety-Kleen—Buttonwillow Site

Safety-Kleen Inc. owns and operates a Class I landfill in the western portion of Kern County approximately 105 miles south of the study area. This 320-acre facility is approximately 8 miles west of the town of Buttonwillow off of Lokem Road.

In discussions with the site operator, it was felt that the waste generated from this project would be acceptable at this site (Juan Campos, 2001a).

This landfill has a new cell opening in December 2001 (Juan Campos, 2001a). The total site available capacity was not available, but the permitted daily maximum is 4,500 tons per day (Jaun Campos, 2001b). A report generated by the California Integrated Waste Management Board (CIWMB, 2001) estimates that the site received approximately 50,000 tons in the last quarter of 2000, equating to approximately 500 tons per day. Using these figures, the site could have the potential to receive approximately 4,000 tons per day of waste from this project.

Disposal fees were estimated to be in the range of 26.50 to 30.00 per ton (Juan Campos, 2001b).

Waste Management—McKittrick Site

The McKittrick site is a Class II surface impoundment and landfill facility that accepts both drilling muds, soils with petroleum deposits, and designated liquids and solids. This waste disposal site is approximately 45 miles west of Bakersfield in Kern County at the intersection of Highways 58 and 33 near the town of McKittrick. This facility is approximately 105 miles southeast of Mendota.

In 1972 the site initially accepted only drilling muds; contaminated soils have been disposed of at this site since 1989. This landfill facility has an existing waste intake of 400 cubic yards/day or approximately 104,000 cubic yards/year. In 1990 this site began retrofitting to expand existing capacity to approximately 400,000 cubic yards with an associated projected lifespan of approximately 4 years (Personal Communication, 1990e).

Allied Waste—Forward Landfill

Forward, Inc. owns and operates a Class II landfill approximately 2 miles south of Stockton on Austin Road in San Joaquin County. This facility is approximately 95 miles north of Mendota and accepts soils with petroleum deposits and designated solid wastes. The Class II landfill currently has a remaining capacity of approximately 4 million cubic yards, but will have a permit revision to bring this total up to 40 million cubic yards within a few months (they bought the site next door). They are currently permitted to take a maximum of 6,680 tons per day, and this total will go up to 8,880 tons per day with the permit revision. They typically receive about 4,000 tons per day currently (Butch Stefani, Jr., 2001).

The disposal fee for Forward Landfill was estimated to be a maximum of $20 per ton, with the fee decreasing with larger tonnage totals received (Joe Griffin, 2001a).

Allied Waste—Keller Canyon Landfill

Keller Canyon is an approximately 1,400 acre Class II landfill located in southeastern Contra Costa County, approximately 110 miles northwest of Mendota, in the Altamont Hills. The site currently has about 17 million cubic yards or capacity remaining. They are permitted to receive 4,500 tons per day. Although they have recently been receiving their permitted maximum daily tonnage, more typically they receive approximately 3,000 tons per day (Joe Griffin, 2001b). The disposal fee for Keller Landfill was estimated to be a maximum of $20 per ton, with the fee decreasing with larger tonnage totals received (Joe Griffin, 2001b).

Amador County—Buena Vista Site

Phase II of the five-phase Buena Vista waste facility project consists of a Class II landfill, a portion of which is currently accepting designated solid wastes generated within Amador County, or from out-of-county sources on a case by case basis, as long as these sources are not contributing significant waste quantities. This site is approximately 110 miles north of Mendota near the town of Ione in western Amador County.

The site is operated by a private waste company that will presume more of the administration for the site in 2002. At this time, the operator will begin construction of a 5 million cubic yard expansion (2 other smaller expansion areas remain). The site is currently permitted to receive 450 tons per day with current receipts estimated at 170 tons per day. The tipping fee is highly variable, and a specific fee for this material was not provided (Dennis Grady, 2001).

Existing Disposal Site Availability Summary

The closest disposal facility to the proposed project area would be the Kettleman Hills site, approximately 55 miles southeast of Mendota. The remaining facilities are approximately 100 miles northwest and southeast of Mendota. Primary access to these facilities is along Interstate 5.

Table B-5 summarizes the existing disposal capacities for each facility. These figures are only projections subject to modification.

Potential volumes of solid wastes generated by the project range from between 9,700 and 921,200 cubic yards per year, depending on the weight, density, and volume of the solids (see Table 1).

In reviewing the disposal site information shown in Table B-5, there appears to be sufficient aggregate capacity to accept the waste from this project. However, the following considerations will need to be addressed:

- Each site is permitted and/or equipped to accept a certain level of daily capacity; therefore, the amount of additional waste each site could accepts from this project on a daily basis will vary and will require coordination with the facility operators.
- Most of the disposal sites offer considerable disposal fee discounts for large quantities of waste disposed. This issue will need to be addressed with the disposal sites when the precise quantities and characteristics of the wastes are known. It would be wise to consider negotiating fees and delivery tonnages with site(s) expected to be used.
- The disposal requirements for the waste generated from this project could vary significantly. The disposal could range from a Class I facility (very expensive) to having the material used as a daily and interim cover material at a Class II or III project (could

be relatively inexpensive to free to dispose). To determine the appropriate disposal methods, it is imperative that chemical concentration data be obtained and reviewed as soon as feasible. This information will also need to be shared with the Class II (and possibly Class III) site operators to determine where the waste can be accepted. Generally, each site has different chemical acceptance criteria.

Development of a New, Site Specific Disposal Site

Siting of a new Class I or II landfill specific for these wastes was also reviewed in the SLUDP study. The siting criteria and other regulatory considerations were presented in the study report. In general, these considerations remain valid except that the addition of new regulatory requirements (RCRA Subtitle D) and the complexity of the permitting process will likely make permitting a Class I or II facility even more difficult and the process more lengthy than in 1990. Some advantages of developing a site-specific landfill are:

- The facility could be designed specifically to handle the waste generated by this project, rendering it a mono-fill. Permitting and design could be simplified for a mono-fill.
- Capacity and daily tonnage limit concerns would not exist.
- The transfer/haul cost component of this cost option would be significantly less than if the waste is hauled to an existing facility.
- CERCLA risk could be lower in that the wastes from this project would not be co-disposed with other wastes that could cause more varied contamination if there is a failure of the lining system or breach of the liner at another facility.

Disadvantages include:

- Costs to develop, operate, and pay for closure/postclosure maintenance of this site can be projected, but are not as definable as quoted disposal fees. Depending on a variety of parameters, the disposal costs for a new mono-fill could actually be higher (disposal portion).
- Permitting a new facility can be a lengthy process with considerable public involvement. Many facilities fail in the permit stages and are never built. If public opposition is expected or the regulatory requirements become onerous, the costs to permit a new site can become prohibitive. It can also be difficult to site a new facility if provisions for such a facility are not included in the appropriate County Siting Element of its Waste Management Plan.
- It may be difficult to site a facility that will meet all of the siting criteria. A major consideration in development of a site-specific mono-fill is the citing criteria that would apply. The SLUDP study discussed at length some of the siting criteria and concerns in place at the time. In addition, RCRA Subtitle D became effective on October 9, 1993 These regulations include siting criteria for municipal landfills (Class III) are now contained in California Code of Regulations, Title 14, and applied also to Class II landfills. The Subtitle D siting criteria further restrict the areas that will be suitable for new landfill construction.

Acceptability

Public Acceptance

Landfills are widely used and accepted methods for disposal of wastes.

Institutional Compatibility

All existing landfills described in this memorandum are already permitted and operational. New landfills would have to satisfy all permitting requirements as described above.

References

California Integrated Waste Management Board, 2000 Landfill Tonnage Report, web-based publication, published in 2001 (CIWMB, 2001).

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Deep Well Injection

Description

Deep well injection is a drainwater disposal option that consists of discharging or injecting drainwater into geologic receiving formations that do not contain fresh water at depths ranging from 5,000 to over 8,000 feet below the land surface. The viability of deep well injection as a drainage disposal option is unproven, however, deep well injection is routinely used in oil fields in the Central Valley of California to dispose of salt water brine that is a byproduct of oil and gas production. Deep well injection would involve the drilling of an injection well or multiple wells to the desired depth in a receiving formation and the injection of drainwater under pressure into the receiving formation. The drainwater may require treatment prior to injection in order to prevent plugging of the receiving formation.

WWD conducted a pilot project to test the feasibility of deep well injection as a drainwater disposal method in western Fresno County in 1990. The test well was drilled to a depth of 8,100 feet and an injection test conducted in the Martinez Sandstone at a depth of approximately 7,500 feet indicated a limited capacity for injection of drainwater at the pilot well test site.

Distribution piping and appropriate controls would be required to convey drainwater to injection well sites. If implemented on a wide scale, an injection well field could consist of as may as 10 wells, each spaced 1 to 2 miles apart depending on the subsurface characteristics of the receiving formation.

Relationship to Other Options

Deep well injection may require pretreatment to prepare the drainwater for injection. Pretreatment would likely include filtration through a 6-micron filter and chlorination to reduce microbial activity plugging. In addition, temperature adjustment may be required to avoid air entrainment.

The capacity of available receiving formations may be such that injection rate and safe storage volume of each injection well would be smaller than the projected drainwater flows, therefore deep well injection may only be feasible in conjunction with a treatment method such as evaporation in order to concentrate the drainwater.

Effectiveness

Deep well injection is only practical if an appropriate geologic formation is present to receive the drainwater. An appropriate receiving formation must have adequate storage and permeability characteristics and must confine the injected drainwater to avoid degradation of overlying freshwater aquifers. WWD identified the Martinez Sandstone as a potential receiving formation for injected drainwater. A pilot injection test conducted in the Martinez Sandstone indicated the permeability of the formation was significantly less than expected. Data from the pilot test indicated that the overlying Temblor-Zilch formation at a depth of approximately 5,000 to 6,300 feet below ground surface might have greater permeability than the Martinez Sandstone. No injection tests were conducted in the Temblor-Zilch formation. The capacity of the pilot injection well was approximately 150,000 gallons per day (USBR, 1990). An injection well field of ten wells, each with a capacity of 150,000 gallons per day would have an annual capacity of 1,680 acre-feet per year.

Within the SLU, already clear the most logical location of deep injection wells is where drainwater has accumulated and where the depth to the base of useable fresh water aquifers is shallowest. The areas in the vicinity of the towns of Mendota and Five Points fit these general criteria.

Stage of Development

In California, deep well injection has been used for more than 50 years for the subsurface disposal of oil field brines. During 2000, the Division of Oil and Gas reported that about 46,000 acre-feet of brine waters were disposed of by deep well injection in California oil fields. In addition, about 146,000 acre-feet of water was injected for water flooding, steam flooding, and cyclic steam petroleum recovery operations statewide. In Fresno County, approximately 950 acre-feet of brine waters were disposed of by deep well injection, while approximately 7500 acre-feet of water was injected for petroleum recovery operations in 2000 (CDOG, 2000). Oil field practices in California and across the United States have established deep-well injection as a viable method for disposal of industrial wastes.

Required Study

The technical feasibility of deep well injection as a drainage disposal option is unproven. The injection rate is highly dependent on site specific subsurface conditions in the receiving formation. Additional pilot testing of candidate receiving formations would be required to develop deep well injection as a viable disposal option.

Efficiency

Cost

Preliminary cost estimates for deep well injection of drainwater in the San Luis Unit range from $242-356/acre-foot **(2001 dollars)**, depending on the method of pre-treatment (URS, 1986). These estimates assume an injection rate of 10 MGD (11,200 acre-feet per year), 6 percent interest rate, 25 year service life, and $0.075 kWh power cost.

The pilot test well drilled by WWD in 1990 cost approximately $1 million to construct (USBR, 1990).

Sensitivity

Deep well injection cost data is extremely sensitive to the injection capacity of the target receiving formation. The subsurface characteristics of the receiving formation affect the construction and operation costs of an injection well. The ultimate cost of an injection well will also depend on the quality of the injected drainwater and the treatment processes used in conjunction with injection.

Acceptability

Public Acceptance

Deep well injection of oil field brine by the oil industry for waste disposal and petroleum recovery is widely accepted by the public in California. Development of deep well injection into shallower target receiving formations would likely meet negative public comment due to the potential for degrading water quality in overlying fresh water aquifers.

Institutional Compatibility

Deep well injection is highly regulated. Fresno County closely supervised construction of the pilot well in WWD under a conditional land use permit, the State Air Pollution Control District, the RWQCB, and the U.S. EPA. Because deep well injection has the potential for degrading useful groundwater aquifers the level of regulatory participation is expected to remain high.

Environmental Impacts and Other Issues

Potential environmental impacts of deep well injection include the potential degradation of useful groundwater aquifers, and alteration of deep geologic formations by increasing subsurface fluid pressures in the vicinity of the injection wells and potentially inducing subsurface fracturing and seismicity.

References

California Dept. of Conservation, Division of Oil, Gas and Geothermal Resources, (2000), Annual Report of the State Oil and Gas Supervisor, Injection Tables.

U.S. Bureau of Reclamation (1990), San Luis Unit Drainage Program, Preliminary Alternatives Workshop Supporting Information, U.S. Department of Interior, Bureau of Reclamation, Mid-Pacific Region, January 29-30, 1990.

URS Corporation (1986), Deep-Well Injection of Agricultural Drain Waters, An Appraisal Level Study with Application to Kesterson Reservoir Problems, Prepared for the San Joaquin Valley Drainage Program, October 1986.

Commercial Utilization of Salt and Selenium

Description

There are a number of potential commercial opportunities to utilize the salts as well as selenium contained in irrigation drainage water of the Valley. The Salt Utilization Technical Committee of the SJVDIP has identified a number of potential commercial uses. Potential uses for sodium sulfate (and other salts) include the production of: soap and detergent, glass, tile and glazing materials, construction blocks, road stabilization materials, textile dyes, and salt flats for testing and racing high-speed vehicles. In addition, some potential exists for the generation of heat and electricity from solar ponds.

Utilization of selenium harvested from irrigation drainage water may have a market potential as a nutritional supplement in livestock feed as well as in the human nutrition and health field. Selenium deficiencies in livestock have been linked to white muscle disease, retained placentas, and infertility in cattle. In addition, some medical studies have found selenium to be of benefit in preventing some types of cancer, as well as heart disease.

Relationship to Other Options

Utilization of salts and selenium accumulated from irrigation drainage of the SLU is a drainage management action, rather than a drainage service action, as defined by the SLU Drainage Feature Re-evaluation Function Analysis Study, August 2001. In other words, while the activities necessary to collect, harvest, and utilize salt and selenium may help control the quantity and quality of water requiring drainage service, they do not provide drainage, in or to, a selected area. This option would need to be combined with treatment options to separate constituents, and with disposal or reuse options for remaining water and unused by-products.

Effectiveness

Two primary advantages emerge from commercial utilization of salts and selenium obtained from drainage of the SLU. First, the processes used to separate and recover the salts and selenium typically reduce the amount of water requiring drainage service, thereby reducing the capital investment and operating costs of providing drainage service. Second, any revenues generated from the sale of products or by-products resulting from the recovery process will offset the cost of separation and recovery (at least to some extent).

Stage of Development

All of the potential opportunities for utilizing salt or selenium from irrigation drainage are in a very preliminary stage of development. In most cases, a determination of whether the technology used to separate and recover salts and selenium can be implemented on a scale large enough to be economically viable still needs to be made.

Required Study

In almost all cases, determining whether salts or selenium can be separated and recovered on an economically feasible basis will require additional local or site-specific research, development, and testing. Standard methods of collecting salt samples need to be established to measure the variability in composition of salt produced from San Joaquin Valley irrigation drainage as well as to compare the effectiveness of different methods of separating and collecting salt and selenium. In addition, most of the uses listed above require additional research to determine the economic feasibility of large-scale applications from a marketing perspective as well as a technological one.

Efficiency

Cost

Cost estimates of separating, collecting, and harvesting salt and selenium from irrigation drainage on a commercial basis was not readily available for inclusion in this memo.

Acceptability

Public Acceptance

The public has expressed interest in the concept of commercial utilization. Acceptability of commercial salt products from drain water is unknown. Reuse of treated water for non-potable uses is well-accepted.

References

California Department of Water Resources. San Joaquin Valley Drainage Implementation Program, Salt Utilization Technical Committee, (1999), *Final Report: Utilization of Salt and Selenium Harvested from Agricultural Drainage Water*.

Finley, John W., Cindy D. Davis. 2001. *Selenium (Se) from High-Selenium Broccoli is utilized Differently than Selenite, Selenate and Selenomethionine, but is more effective in Inhibiting Colon Carcinogenesis*. BioFactors 14, no. 1-4 (2001): 191-196.

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