San Joaquin Valley Drainage Program

TECHNICAL REPORT

SEPTEMBER 1988

AGRICULTURAL DRAINAGE WATER TREATMENT, REUSE, AND DISPOSAL IN THE SAN JOAQUIN VALLEY

PART II
REUSE AND DISPOSAL

The San Joaquin Valley Drainage Program was established in mid-1984 as a cooperative effort of the U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, U.S. Geological Survey, California Department of Fish and Game, and California Department of Water Resources. The purposes of the Program are to investigate the problems associated with the drainage of irrigated agricultural lands in the San Joaquin Valley and to formulate, evaluate, and recommend alternatives for the immediate and long-term management of those problems.

This report is one of several Program technical reports presenting research findings to date and implications on specific topics such as geohydrology of the San Joaquin and Tulare Lake Basins, fish and wildlife resources, public health, agricultural setting, planning methods, and drainage water treatment, reuse, and disposal. The data and information in these reports are being used in formulating and evaluating drainage water management options and preliminary alternative plans, which will be presented in a separate report in late 1988. A draft report outlining latest study results and alternative plans will be completed for public review in the fall of 1989. Final study results and recommended area-specific plans will be presented in the Program's final report in the fall of 1990.

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TECHNICAL REPORT

AGRICULTURAL DRAINAGE WATER TREATMENT, REUSE, AND DISPOSAL IN THE SAN JOAQUIN VALLEY OF CALIFORNIA

PART II: REUSE AND DISPOSAL

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September 1988

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SECTION I

SUMMARY AND CONCLUSIONS

This report presents the preliminary engineering evaluations of in-valley disposal alternatives and reuse possibilities of agricultural subsurface drainage water in the San Joaquin Valley, California. Because these evaluations do not entail considerations of the institutional aspects (e.g., public acceptance), total economics, and environmental impacts, the conclusions must be viewed as preliminary. This report was prepared because preliminary plans must be drafted and decisions must be made on the basis of available information.

Investigations are still ongoing, so to a large degree this report should be viewed as a status report. As studies are completed and more complete information become available they will be reported in a subsequent final technical report.

The salient findings and conclusions of this evaluation are summarized as follows:

Disposal

1. Evaporation ponds are widely used means to dispose of drainage water, especially in the Tulare Lake Basin of the valley. Their effects on wildlife and on ground-water resources and their biological, chemical, and seepage aspects are being examined by the San Joaquin Valley Drainage Program (SJVDP) and others. Because the effective life and long-term operation of evaporation ponds are crucial to the acceptable solution of the drainage problem the SJVDP has arranged funding for UC, Davis researchers

to investigate the long-term efficacy and management of evaporation ponds.

2. Deep-well injection, according to a study by URS of injecting 10 Mgal/d from 42,000 acres of the Westlands Water District, appears feasible by injecting about 5,000 feet deep into a sandstone zone underlying the Kreyenhagen formation. This formation zone is reported to be about 400 feet thick, relatively impermeable, and extensively underlies much of the valley. The total estimated unit cost of injection was reported to be $189/acre-foot using rapid filtration to remove suspended solids to avoid clogging. The pilot deep-well injection project to be conducted by Westlands is essential to confirm that this cost estimate is indeed reliable.
3. Discharge to the San Joaquin River is practiced within the San Joaquin River Basin portion of the valley. It is likely that in 1989 Central Valley Regional Water Quality Control Board (CVRWQCB) regulations will be imposed on drainage discharge to meet water quality objectives. The CVRWQCB will in 1988 consider adoption of water quality objectives recommended by a technical committee commissioned by the SWRCB. The committee concluded (1987) that its recommended water quality objectives can be most effectively met through drainage volume reduction achieved through irrigation management. However, it was contended at the SWRCB hearings that the degree of drainage volume reduction suggested was not realistically achievable. Therefore, to get a

better handle on water quality management costs in the discharge of drainage water to the river, the SJVDP has started a study predicated on irrigation management being a given and the success of drainage volume reduction being a variable. Accordingly, treatment and other disposal measures would be implemented in addition to and not in lieu of drainage volume reduction.

Reuse

Reuse alternatives are not expected to be technically available for the relatively short-term solution, but, nevertheless, agricultural drainage water and even the salts it contains should be viewed, long range, as potential resources rather than as wastes only.

1. Marsh reuse of drainage water was a major component of the IDP recommended plan, but the reported impacts of selenium in drainage water on wildlife at Kesterson Reservoir cast doubt on the feasibility of using drainage water in marshes and wetlands. Certainly, the benefit:cost ratios developed by the IDP would undergo drastic changes in that the cost component would significantly increase due to treatment costs. It has been recommended by the State Water Resources Control Board (SWRCB) that a water quality objective of 2 mg/L, selenium, be adopted for impounded wetlands use such as Grasslands. To attain this level of selenium would require costly treatment.

2. Powerplant cooling reuse was another component of the IDP recommended plan and was expected to yield an annual equivalent

net benefit of $3.31 million. However, the California Energy Commission (CEC) projects a significantly lower demand for thermal generated electricity in the valley than did the IDP. DWR, using CEC projections, estimates a net increase of powerplant cooling water use of 2,000 AF/yr by 2010. Even if there is a drastic turnaround in the demand for powerplant cooling water in the valley, studies indicate that there is a substantial cost in the order of $220/AF to treat valley drainage water for powerplant cooling reuse. Consequently, it is not realistic to expect that the power companies would be willing to buy drainage water.

3. Salt recovery and marketing could have a significant impact on the economic feasibility of in-valley disposal alternatives. However, there appears to be conflicting professional views on the marketability of sodium sulfate, one of the more marketable major salt in drainage water. We have asked USBM to give us an independent evaluation as to what it believes to be the marketing potential for sodium sulfate.

4. Aquacultural reuse has been demonstrated to the extent that there is considerable information that drainage water can be used to culture a wide variety of organisms varying from algae to fish. However, such findings are only part of the answer regarding aquacultural potential. The complete assessment must include an evaluation of marketability of products grown in the water.

5. Solar gradient ponds offer the potential of using the salts in drainage water to produce a high demand product--electrical energy. DWR has done considerable work on solar ponds at Los Banos using a starting brine supply constituted of salts and having a similar composition to drainage water. However, information is not available on the cost to produce solar pond energy using drainage water as a brine source. DWR is considering pursuing further solar pond studies at the Binnie's anaerobic bacterial test site in Mendota. If the solar pond study proceeds, it bears watching.

SECTION II

DISPOSAL

Program management and advisory committees directed that investigative and planning efforts focus on in-valley solutions to the drainage water disposal problems. No studies of out-of-valley disposal of drainage water are planned to be conducted by the program.

In-valley disposal options are evaporation ponds, deep-well injection, and discharge to the San Joaquin River.

I

Evaporation Ponds

Evaporation ponds have been a commonly used means to dispose of saline subsurface agricultural drainage water in the western and southern portions of the San Joaquin Valley. Within the jurisdictional areas of the Central Valley Regional Water Quality Control Board (CVRWQCB) there now are over 20 pond facilities covering about 7,000 acres. Plans have also been developed by potential drainage water dischargers for future disposal to evaporation ponds. The CVRWQCB has received applications for discharge to pond facilities that will cover an additional 10,000 acres. The Board now projects requests for more than 20,000 acres of such ponds to be constructed within the next 5 to 10 years.

Evaporation ponds are viewed by many drainage water dischargers as a viable means for disposal. However, the observations of elevated levels of selenium, boron, and other toxicants in some evaporation ponds in the Tulare Basin and awareness of impacts of selenium on wildlife at Kesterson Reservoir have caused serious concerns as to the potential adverse environmental impacts of evaporation ponds.

There is a clear, imminent need to provide means to dispose of a growing volume of drainage water in the valley. Agriculture in the valley thus faces a need to implement "short-range solutions" to maintain productivity; it cannot afford to wait for the "long-range solutions" alone. Evaporation ponds appear to be a possible short-range alternative that could be in place and operational within a short time. However, ponds must be designed, constructed, and managed to minimize adverse effects on environmental resources.

Problems associated with evaporation ponds are being defined and acceptable design and operation methods are being studied by numerous agencies and interests.

Potential Problems

Basically, the disposal of agricultural drainage water in evaporation ponds can create two serious problems. The first is ground-water pollution and/or contamination, and the second is the wildlife impacts of surface storage. The latter impact, in turn, causes public health concerns in connection with the consumption of contaminated wildlife. At this time, it is difficult to identify all that will need to be done in the design, construction, and operation of evaporation ponds to reliably evaluate ponds as a solution option. Many agencies and interests are investigating various aspects of evaporation ponds. The problems and constraints that face the acceptance of evaporation ponds as a viable alternative are reported below.

Ground-water pollution/contamination. State water quality control requirements significantly affect the siting and construction standards of evaporation ponds, and those requirements, in turn, are largely governed by whether agricultural drainage water is classified a hazardous waste. Section 66699, Division 4 (Environmental Health) of Title 22 of the California Administrative Code, classifies as hazardous any waste containing selenium and/or selenium compounds exceeding a soluble threshold limit concentration (STLC) of 1.0 mg/L. Section 66305(a)(2) classifies a waste as hazardous if it poses a substantial present or potential hazard to human health or the environment.

Section 2521 of Title 23, in turn, specifies that hazardous wastes shall be disposed only at Class I waste management units which comply with applicable provisions of subchapter 15.

Subchapter 15 establishes construction standards calling for double lining, leachate collection and removal systems, and precipitation and drainage control facilities for Class I ponds. The regulations for surface impoundments provide for exemptions to certain requirements, but the standards are basically as shown in table II-1.

These stringent standards cause Class I storage impoundments for hazardous wastes to be very expensive. In its RO desalting study for the SJVDP, CH2M Hill reported estimated costs of $20,000 per acre for Class II and $200,000 per acre for Class I pondage (CH2M Hill, 1986). Evidently, the capital cost of pond construction can be substantially reduced by avoiding Class I pond standards.

The Toxic Pits Cleanup Act (Section 25208-4, Article 9.5, Chapter 6.5 of Division 20 of the Health and Safety Code) will prohibit, after June 30, 1988, hazardous waste ponds located within 1/2 mile upgradient of potential drinking water supplies. It has no provision for exemption of agricultural drainage ponds from this provision after January 1, 1986.

Table II-1. Construction standards for waste management units*

Type of waste management unit	Clay liner(1)	Synthetic liner	Leachate collection and removal system	Subsurface Barriers: Cutoff walls	Subsurface Barriers: Grout curtains
Class I					
Surface Impoundment	Double liner (2) $\leq 1x10^{-7}$ cm/sec		Required blanket type	$\leq 1x10^{-7}$ cm/sec (4)	$\leq 1x10^{-7}$ cm/sec
Class II					
Surface Impoundment	Double or single required (3), $\leq 1x10^{-6}$ cm/sec	Not required	Required with double liner blanket type	$\leq 1x10^{-6}$ cm/sec (5)	$\leq 1x10^{-6}$ cm/sec

1 All permeabilities specified in this table are maximum allowable permeabilities.
2 Outer liner shall be a clay liner; inner liner may be a synthetic liner instead of a clay liner if inspected according to Subsection 2548(f) of this article.
3 Single liner shall be a clay liner and removed or replaced as described in Section 2542 of this article. Double liner systems shall have either an outer clay liner or shall be underlain by a substantial thickness of natural geologic materials with a permeability of 1×10^{-6} cm/sec or less to act as an outer liner.
4 Cutoff walls required where there is potential for lateral movement of fluid, including waste and leachate.
5 Cutoff walls required where there is potential for lateral movement of fluid, including waste or leachate, and the permeability of natural geologic materials is used for waste containment.

*From Article 4, Title 23, of the California Water Code.

Note: Authority cited: Section 1053, Water Code. Reference: Sections 13172 and 13360, Water Code.

This, in effect, may make Titles 22 and 23 hazardous waste requirements and exemptions inapplicable for agricultural drainage ponds in most of the valley. The SWRCB is reported to be drafting legislation that may allow exemption of certain ponds from this prohibition under certain conditions. The hazardous waste regulatory aspects of evaporation ponds need to be followed closely in the coming months.

Research scientists at University of California, Riverside, have been studying microbial methylation of selenium. They believe that it may be possible to use certain fungal strains to volatilize selenium in saline water, and it may therefore be possible to volatilize and reduce the selenium level in evaporation ponds and keep them in conformance with the Toxic Pits Act. Consequently, the SJVDP has negotiated an agreement with UC Riverside to conduct further research in microbial methylation to reduce selenium levels in evaporation ponds.

The researchers have recently orally reported promising laboratory test results wherein the addition of certain organic material has significantly accelerated the volatization of selenium in water columns. Additional information from the researchers will be reported in a later, followup technical report.

Wildlife Protection. The need to protect wildlife will significantly affect the design, construction, and maintenance and, therefore, the cost of evaporation ponds. In this regard, it is appropriate to review the recommendations of the San Joaquin River Basin Technical Committee, which was assembled pursuant to the SWRCB's WQ Order 85-1 to propose: (1) water quality objectives for the San Joaquin River, (2) effluent limitations for agricultural drainage discharges in the basin, and (3) methods to regulate these discharges (SWRCB, 1987).

The committee reported that selenium in impounded waters could accumulate in the diet of waterfowl; e.g., benthos, between 500 to 1,000 times. It thus concluded that the water quality criterion for impounded waters could range from approximately 1-2 ug/L total selenium and possibly lower, and that the unofficial USFWS guideline of 2.0 ug/L selenium in impounded waters applied to marsh habitat such as waterfowl management areas appears to be reasonable at least until additional data become available. It should be noted that these values are for freshwater systems. There is some question as to whether they are applicable to saline evaporation ponds. DWR, the RWQCB, and other agencies sampling programs are developing site specific information which will shed more light on appropriate limits for evaporation ponds. The SWRCB staff has indicated selenium levels for normal water impoundments are not intended for evaporation ponds; evaporation ponds may be permitted to operate with different limits than those for normal impounded waters.

If a 2 ug/L selenium criterion is applied to evaporation ponds, they would not be expected to be economically feasible. Selenium treatment cost studies indicate that costs increase by about 100 percent or more to meet a 2 ug/L standard as opposed to a 5 ug/L standard (Western Consortium for the Health Professions, Inc., 1986).

An alternative to selenium treatment may be to construct and operate evaporation ponds such that they do not threaten wildlife. This is being attempted by the imposition of construction design standards and operation requirements, which both, also increase cost.

Other Considerations

In fully evaluating evaporation ponds as a component of the drainage water management alternatives, there are two other important considerations--the substantial allocation of lands for evaporation disposal and the deferred problem of accumulated salt disposal.

Land requirements. Brown and Caldwell, in its disposal screening study for the SJVDP, reported that the Soil Conservation Service (SCS) estimates that in the SCS's sequential four-cell pond design, 0.265 acre of pond surface would be required to contain each acre-foot of drainage water produced per year (Brown and Caldwell, 1987). Allowing an additional 21 percent of land area for levees, buffer zones, etc., SCS is reported to estimate about 0.32 acre of land requirement per acre-foot of drainage water to be disposed. The impact of this significant allocation of land can, of course, be minimized by using the less productive lands having shallow, low permeability soils.

Disposal of accumulated salts. The eventual need for disposal of accumulated salts has been a long-recognized problem with evaporation ponds. Clearly, salt disposal needs within the drainage problem area of the valley are significant. For each acre-foot of 1,000 mg/L TDS drainage water evaporated, about 1.36 tons of salt would accumulate. If 6,000 mg/L is assumed as the valleywide average TDS of drainage water, salt accumulation would exceed 8 tons per acre-foot of drainage water. Obviously, the rate of salt accumulation and, therefore, the frequency of disposal depends largely on the salinity of the drainage water. Brown and Caldwell reports that SCS estimates salt disposal would be required every 50 years (Brown and Caldwell, 1987). CVRWQCB staff, on the other hand, orally reports observations of over a foot of salt accumulation in 10-year-old ponds.

Two options for accumulated salt disposal are mineral and salt recovery and in-valley disposal.

A study of in-valley disposal of salts will soon start initially with a cooperative agreement wherein UC, Davis will investigate questions such as: What volumes of salt might we expect, what kind of salts will accumulate and in what order will they precipitate, what hazardous constituents and at what levels will those constituents occur, etc.?

Evaporation Pond Siting in the Valley

Brown and Caldwell, in its disposal areas screening study for the SJVDP, identified potential evaporation pond areas in the San Joaquin using the following screening criteria:

1. Land Use. Exclusion of urban, industrial, and military use areas.
2. Topography. Exclusion of terrain steeper than 10 percent because of difficulty and cost of evaporation pond construction.
3. Soils and Geology. Exclusion of areas having permeable soils in near-surface formations.
4. Wetlands. Exclusion of areas mapped and identified as wetlands by the Department of Fish and Game (DFG).
5. Rare and Endangered Species Habitat. Exclusion of areas designated as rare, threatened, and endangered species habitat by U.S. Fish and Wildlife Service (USFWS) and DFG. Where this criterion resulted in almost total exclusion of subareas, Brown and Caldwell allowed for habitat distribution.
6. Geologic Hazards. Exclusion of areas near known faults.

7. Flood-Plain Zones. Exclusion of areas in the 100-year flood plain of streams or lakes. Actually, a major exception was made for playas or dry lake beds.

Using these criteria, Brown and Caldwell identified potential areas in the valley for the construction of evaporation ponds.

DWR is in its second year of a 2-year study program to evaluate the impacts of evaporation ponds and to develop guidelines for the construction and operation of acceptable ponds. In this program, DWR is working closely with DFG, USFWS, the Central Valley RWQCB, UC, Davis, USGS, SCS, SWRCB, SJVDP, and various drainage districts.

The San Joaquin District of DWR has initiated a study to determine the costs to construct and operate evaporation ponds according to presently available guidelines.

II

Deep-Well Injection

Deep-well injection is a long used technology in the San Joaquin valley by the oil and gas industry for the disposal of oil field brines into deep underground formations. On a much more limited basis, five reported known sites have been used for deep-well injection of toxic or hazardous wastes. The application of this technology for the disposal of agricultural drainage water was examined by the URS Corporation (URS) under a contract with the U.S. Bureau of Reclamation (USBR), administered under the SJVDP (URS, 1986). This chapter reports on the URS study for the USBR and on the currently available information from the ongoing prototype pilot injection project URS is conducting for Westlands Water District (Westlands).

Study for the USBR

The contract with URS called for the consultant to conduct an appraisal level study of deep-well injection of drainage water flowing in the San Luis Drain prior to the plugging of drains in Westlands. The study basically entailed a definition of the institutional or regulatory constraints and a determination of the facilities required to inject 5 and 10 Mgal/d of drainage water and the estimate of costs both to construct and operate those facilities.

Institutional Constraints

Deep-well injection will be rigidly controlled by an exacting permit process of the Underground Injection Control (UIC) Program of EPA. Injection of hazardous wastes has in recent years been receiving considerable attention of Federal, State, and local regulators because of failures of some injection efforts. However, in its review of laws and regulations and its contacts with regulatory agencies, URS concluded that drainage water in the San Luis Drain is not a hazardous waste. Consequently, it expected that it would be permissible to inject drainage waters through triple-cased wells into highly saline formations lying below all usable ground water and below the areally extensive, thick, continuous, and impermeable Kreyenhagen Formation, which bottoms out about 5,000 feet below the San Joaquin Valley floor near Check 41 of the San Luis Drain.

If waters to be injected are deemed hazardous under Federal and State definitions, several provisions of the Resources Conservation and Recovery Act (RCRA) will apply. Waters having selenium concentrations of 1 mg/L or more would be classified as hazardous wastes. The UIC program specifies which of the RCRA regulations are applicable to deep-well injection of hazardous wastes.

Three State agencies, the Department of Health Services (DOHS), State Water Resources Control Board (SWRCB), and the Division of Oil and Gas (DOG) of the Department of Conservation, have authority over the construction and operation of injection wells.

DOHS has permitting authority over above-ground facilities and activities that are coincident with the operation of injection facilities for hazardous wastes (Health and Safety Code Sections 25150 and 25159). Since the enactment of AB 2058 (Connelly) in 1985, DOHS has assumed further authority over injection wells for toxic substances but it has no permitting authority over nonhazardous waste facilities.

The SWRCB has wide-ranging authority over water quality control. The Regional Water Quality Control Boards have permitting authority over waste discharges that affect the quality of waters of the State (California Water Code sec. 13260).

DOG has authority over all Class II wells under the UIC program and has permitting authority over <u>any</u> well which could possibly penetrate oil- or gas-bearing strata. It is also involved in specifying blowout prevention measures.

At the local level, Fresno County requires land use permits from the Planning Department for facilities construction and a well permit from the Department of Health. Merced County, however, prohibits deep-well injection.

Evidently, there are numerous regulatory hurdles to attain deep-well injections approval, but there are also potential liabilities that should be considered. Leakage from pipes and/or confining zones bear liability risks. EPA will require certain financial responsibilities be maintained, but there are also other complex, uncertain liability issues such as those that relate to adjoining property rights.

With regard to the question of induced seismicity, URS is confident that the risk is relatively slight. It reported that:

> "After a study of the relevant data, it appears that the possibility of induced seismic activity, even at low levels, by deep-well injection below the Kreyenhagen confining layer is extremely remote at the anticipated injection pressures. Induced seismicity is also very unlikely at possible higher pressures allowed under fracture gradient analysis. Not only is the projected formation pressure buildup in the injection zone apparently far too low to cause seismicity, but the sub-Kreyenhagen Formations should tend to deform plastically rather than with brittle seismic faulting."

<u>Geohydrologic Setting</u>

According to URS, geologic conditions in many parts of the San Joaquin Valley are largely unknown where older rocks are covered by younger Pleistocene and recent sediments. Knowledge of deep geologic conditions in most of the valley depends on drilling data. Consequently, URS's interpretation of subsurface geologic conditions is based largely on extrapolations between areas where data are available.

Fresh ground water throughout much of the valley comprises an important resource that must be protected. These freshwater units are underlain by increasingly saline water-bearing zones with water having salinity up to or exceeding seawater concentrations. URS concluded that deep permeable units underlying the Tertiary age Kreyenhagen Shale are the most suitable for receiving injected drainage water. Formations below the Kreyenhagen Shale are isolated from overlying freshwater-bearing sediments by thick sequences of low permeability shales of the Kreyenhagen Formation. These formations, such as the Tertiary Domengine Sandstone and Gatchell Sandstone, consist of many hundreds or thousands of feet of clean, permeable sandstone containing highly saline water.

The Kreyenhagen Shale is an extensive layer of marine clay overlying a thick section of coarse grained deposits and is one of the most uniform beds throughout the San Joaquin Valley. It acts as a hydraulic confining layer and is continuous throughout most of the San Joaquin Valley, all of the Delta area, and about one-half of the Sacramento Valley. Towards the eastern side of the San Joaquin Valley, the Kreyenhagen Formation intertongues with and is replaced by undifferentiated continental beds of the Walker Formation. In the vicinity of Check 41, the preferred injection site for the Westlands area, the top of the injection horizon is estimated to be about 5,300 feet deep and about 1,000 feet thick.

Injection Facilities

Class I wells are generally used to inject hazardous or nonhazardous wastes that are not considered part of oil field operations. The construction of a Class I well requires drilling a hole to a depth that meets UIC requirements and below the lowermost formation that contains (within a quarter of a mile) a well used for drinking water and into a formation capable of receiving the wastes. Porous, saline water-bearing sandstones confined above and below by relatively impermeable rock strata are considered the most desirable receiving formations.

A prototype injection well is depicted in figure II-1. An outside casing is placed throughout the length of the well hole where it passes through freshwater zones. A second steel casing is installed within the outer casing through the length of the well down through the confining layer, and the space between the casing is filled with cement. This provides barriers to prevent waste migration into any freshwater zones that may be penetrated. A third pipe, the injection tubing, is installed within the second casing. It is sealed to the second casing at the top and bottom. The annular cavity between the second and third casing is filled with a noncorrosive fluid which is kept under constant pressure. This pressure is continually monitored to detect leakage when wastewater is pumped under pressure through the injection tubing.

Well size selection depends largely on cost which, in turn, is a function of capital construction costs and operating costs. These costs are offsetting in that the smaller the diameter of the well, the lower the capital costs and the higher the operating costs will be, and vice versa. The higher operating cost of the smaller diameter wells is due mainly to the higher head losses in pressurizing the wells and the accompanying higher annual energy cost to overcome the head loss.

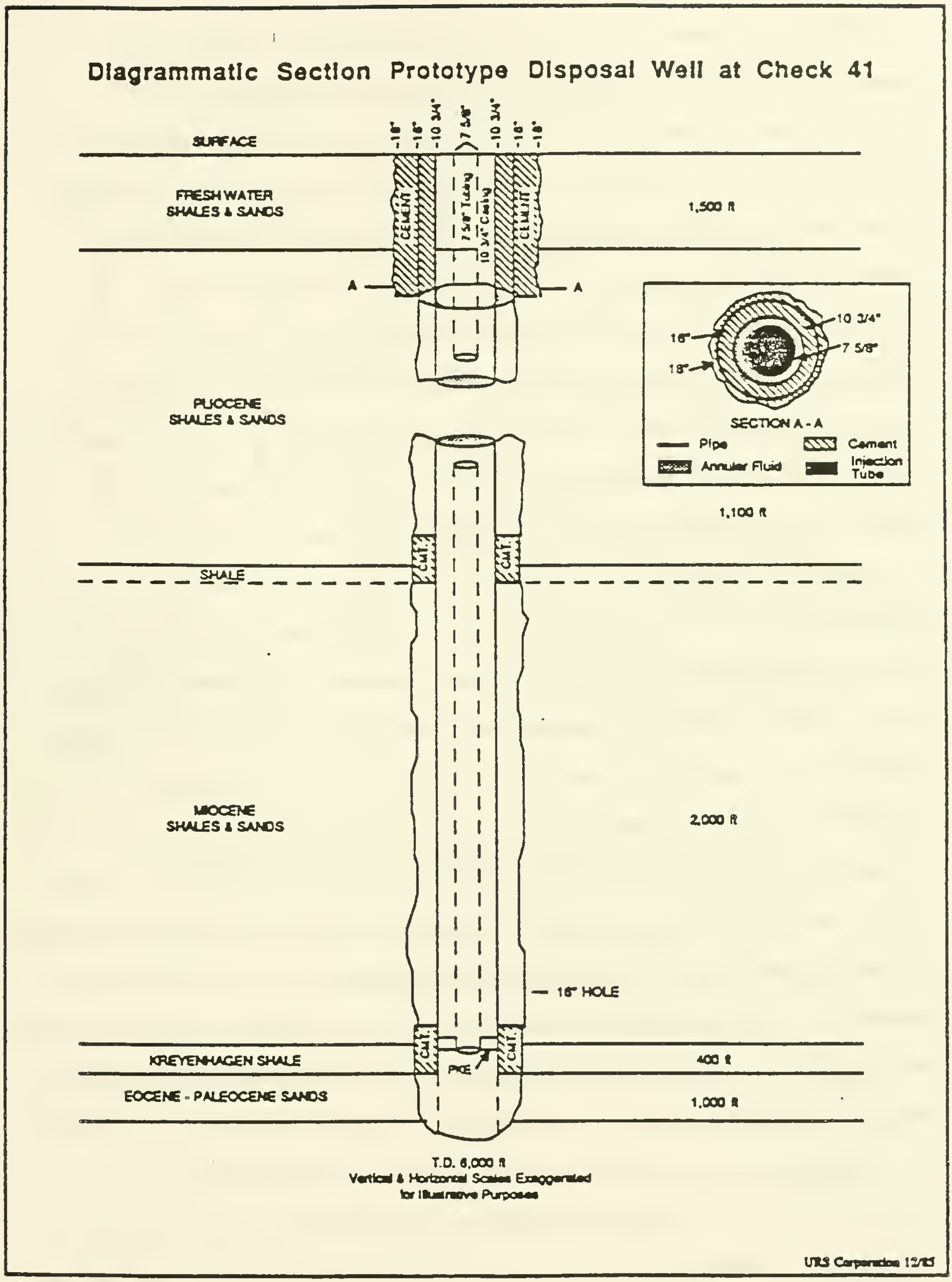


FIGURE II-1. DIAGRAMMATIC SECTION PROTOTYPE DISPOSAL WELL AT CHECK 41

Figure II-2 shows a plot of the annual costs for various well diameters based on a 6-percent interest rate and injection of 7,000 gal/min (10 Mgal/d) for three different amortization periods (10, 20, and 30 years). The annual costs include both the amortized capital costs and the annual operating costs. On the basis of this graph, URS recommended a well diameter of 7-5/8 inches. URS added, however, that the actual well sizing would be selected after pilot tests determine transmissivity and permeability and pump tests indicate an appropriate flow rate for each well. The well size would be selected to accommodate the design flow and be optimized between well construction cost and energy cost to pump against friction head losses.

The service life of the injection well or, in this case the amortization period, was governed largely by the aquifer pressure buildup. The life expectancy of injection wells was commonly observed to extend to about 35 years. However, because the pressure buildup in the receiving formation is a function of both the volume injected and the rate of injection, time is a limiting factor if pressure buildup and its accompanying higher annual operating costs are to be minimized. Lacking data on the injection zone, URS deemed it should conservatively recommend 25 years as the service life until pilot studies confirm or refute the assumption. Moreover, URS estimated that the increment of cost for the total injection system to inject 10 Mgal/d would amount to only $5 per acre-foot more for a 25-year service life as compared to a 30-year life.

The layout of the injection wells is determined largely from a minimum separation requirement and cost considerations. Adequate well separation is needed to minimize pressure buildup by avoiding overlapping

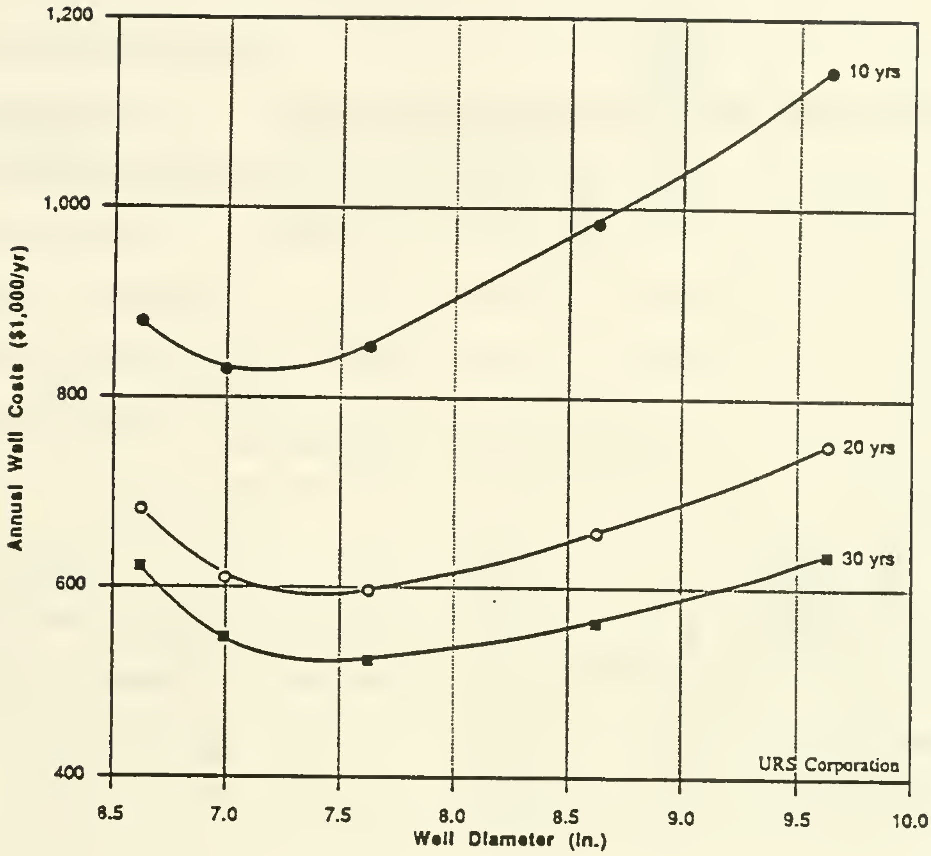
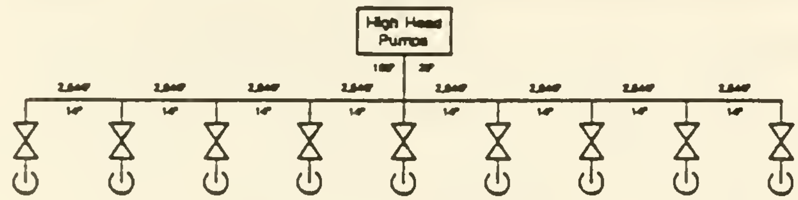


FIGURE II-2. Well Diameter Versus Annual Costs (6% Interest; 7,000 g/m).

injection influences of adjoining wells. URS assumed a half-mile horizontal separation as necessary in the injection zone, and developed four well layout schemes--linear-vertical, linear-directional, star pattern, and a closed loop-vertical. Layouts for all except the closed loop-vertical scheme are depicted in figure II-3. The linear-directional and star pattern schemes entail slant drilling of wells to attain the half-mile separation at the injecting horizon.

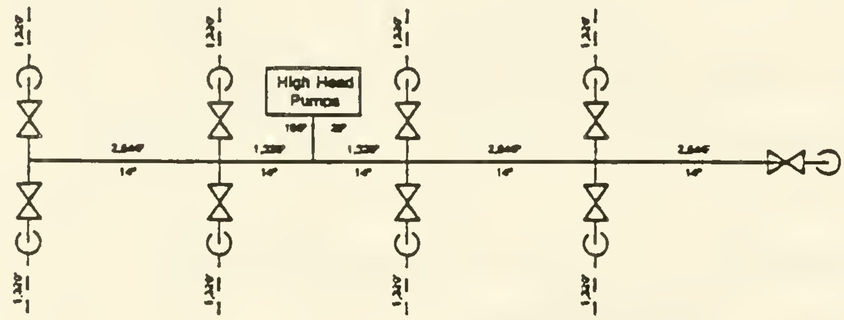
Deep Well Injection Linear - Vertical Siting Plan



Well Construction

Type	Number	Length/ea	Total Length
Vertical	9	6,000'	54,000'

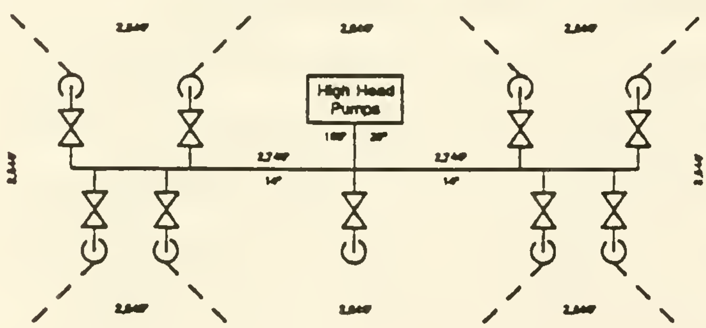
Deep Well Injection Linear - Directional Siting Plan



Well Construction

Type	Number	Length/ea	Total Length
Vertical	1	6,000'	6,000'
Directional	8	6,400'	51,200'
Total	9	---	57,200'

Deep Well Injection Star Pattern Siting Plan



Well Construction

Type	Number	Length/ea	Total Length
Vertical	1	6,000'	6,000'
Star	8	6,700'	53,600'
Total	9	---	59,600'

FIGURE II-3
PLAN VIEWS OF WELL TYPES

Appurtenant Facilities

In addition to the injection wells, the principal facilities are the pretreatment and the conveyance facilities.

The purpose for pretreating the drainage water prior to injection is to minimize clogging or fouling of the well. Clogging of the well or the receiving formation could result from one or a combination of the following reasons:

- Blinding of the injection face from the accumulation of particulate matter;
- Clogging of the injection face or formation due to chemical precipitation, e.g., calcium sulfate (gypsum); and/or
- Clogging of the well or formation with slime and/or nitrogen gas bubbles from the biological denitrification of nutrient-rich drainage water.

URS investigated four treatment options with regard to physical blinding by particulate matter:

1. Injection following chlorination only with no solids separation,
2. Pretreatment by sedimentation in a flocculating clarifier system,
3. Pretreatment by rapid filtration through a single media bed, and
4. Microscreens.

It is possible that the treatment for removal of particulate matter may not be necessary. One possibility is that drainage water taken directly from the farm drains may have very low suspended solids and be directly injectable.

It is even possible that water from the San Luis Drain may have low suspended solids concentration that would not lead to blinding problems. URS analyzed samples from three operating injection sites in California for total suspended solids (SS); TDS; and fats, oil, and grease (O&G). The results compared as follows:

Constituent (mg/L)	SS	TDS	O&G
Check 41, San Luis Drain	11	9,820	N/A
Sample A	13	2,872	35.5
Sample B	15	12,363	64.7
Sample C	17	33,959	50.0

URS reported that the assessment of the problem of chemical precipitation requires careful evaluation of the ambient quality of the water in the injection zones, the quality of the injectate, and the possible chemical reactions. The quality of water in the sub-Kreyenhagen injection zone is not well known, but limited oil field data indicate that the water would have salinity similar to seawater, i.e., 35,000 mg/L, TDS. URS surmises that the chemical quality of the deep formation water near Check 41 would have a TDS concentration of 40,000-50,000 mg/L and be primarily sodium chloride in character with low sulfate levels. It concluded that mixtures of drainage water and formation water could cause chemical precipitation and formation clogging due to calcite (calcium carbonate) or gypsum (calcium sulfate) formation. Its scaling calculations indicated that (1) the drainage water is unstable with respect to calcite formation, (2) the formation waters are stable, and (3) mixtures are marginally stable with respect to calcite or gypsum precipitation.

However, in its evaluation of treatment needs, URS assumed that the receiving formation and the ambient conditions within the formations would not cause chemical precipitation. Accordingly, chemical pretreatment to prevent such reactions was not included in its cost estimates.

Biological activity and resultant fouling of the injection horizon appear to be more serious concerns. URS considers it prudent for all injectate to be chlorinated to reduce any biological activity. Biological fouling can occur as microbial activity causes a buildup of slime across the pipe and injection face and in the receiving formation or cause the formation of nitrogen bubbles.

URS was directed in its study to examine a collector drain option, an alternative in which drainage water is intercepted and collected in the field drains and injected before its discharge into the San Luis Drain. Such an option may be feasible inasmuch as the level of suspended solids was expected to be low in the field drains. Also, it was expected that if the nutrient-rich drainage water was not exposed to sunlight and the algae productive environment of the San Luis Drain, organic suspended solids production would be minimized.

Because the farm collector drains are spread out along 14 miles of the San Luis Drain, gravity conveyances to collect flows to common wells were determined conceptually. The estimated total capital cost of such a system was estimated to be $12,307,000, while the annual O&M cost was $797,000.

Well Maintenance

In addition to the preceding treatment methods, there are maintenance practices or corrective measures to keep the injection wells operating efficiently with minimum head loss. The addition of detergents or strong acids to dissolve and free pipe scale and chemical precipitants is reported to be a common maintenance practice. Particulate blinding can be corrected by jet washing of the injection face or back pumping of the injection well. Biological fouling has been successfully reduced with the addition of strong chlorine solutions.

The cost for restoring injection well capacities is reported to be relatively inexpensive, except in rare cases when well construction material has deteriorated with age, generally after about 35 years, when major rework or reconstruction is required. URS assumed in its cost estimates that with reasonable preventative measures, including chlorine disinfection and suspended solids removal, well reconditioning would be required every 5 years. It was further assumed that the wells would require rework about every 2 years if suspended solids were not removed.

Well reworking costs are reported to range from about $3,000 to $12,000. URS assumed a cost of $10,000 to rework wells of the type contemplated and included that cost as a specific maintenance item. Well or equipment replacement was also included in the cost estimates as a percentage of the initial capital cost.

Cost Summary

The capital cost of construction of the four injection well layout alternatives were estimated as follows:

Alternative	Capital cost[a]
(a) Linear-Vertical	$ 7,928,000
(b) Linear-Directional	$ 7,658,000
(c) Star Pattern	$ 7,525,000
(d) Closed Loop	$ 8,283,000

[a] Based on nine injection wells of 1,000 gal/min capacity at Check 41 which are required for 10 million gallons per day (Mgal/d) design flow.

It is significant to note that the cost of deep wells generally fluctuates with the oil well development industry, i.e., increased oil demand creates increased demand for oil drilling (deep wells) services which, in turn, increase construction cost. At the time deep well construction costs were quoted to URS, the oil industry was at an ebb and costs were accordingly low. The cost of a 7-5/8-inch injection tube well with a 10-3/4-inch intermediate casing and a 16-inch surface casing was estimated at $88/foot of length regardless of vertical or slant drilling. For the pretreatment alternatives the capital and O&M costs were estimated as follows:

Alternative	Capital[a] cost	O&M[b] (per year)
(a) No Solids Separation	$2,648,000	$ 960,000
(b) Sedimentation	7,192,000	1,438,000
(c) Rapid Filtration	4,953,000	1,048,000
(d) Microscreens	6,111,000	1,136,000

[a] Based on 10 Mgal/d design flow.
[b] Based upon 6 percent interest, $.075/KWh, 25-year life and 11,200 acre-feet per year (AF/yr) feed.

The total unit cost of injection (cost per acre-foot) for the various alternatives herein described using the star pattern of injection at Check 41 were estimated as follows:

San Luis Drain Option*	Annual cost per acre-foot Capital	O&M	Total
(a) No Solids Separation	78	86	164
(b) Sedimentation	113	128	241
(c) Rapid Filtration	96	93	189
(d) Microscreens	105	108	213

* For 10 Mgal/d, 6 percent interest, $0.075/kWh power cost, and 25-year service life, at Check 41.

The above costs, as noted, were predicated on an interest rate of 6 percent and energy cost of $0.075 per kWh. Because of the uncertainty of these cost-affecting factors in the future, URS was requested to conduct a sensitivity analysis to determine the effects of interest rate and energy cost changes on the cost of alternatives. Figure II-4 depicts the results of the sensitivity analysis.

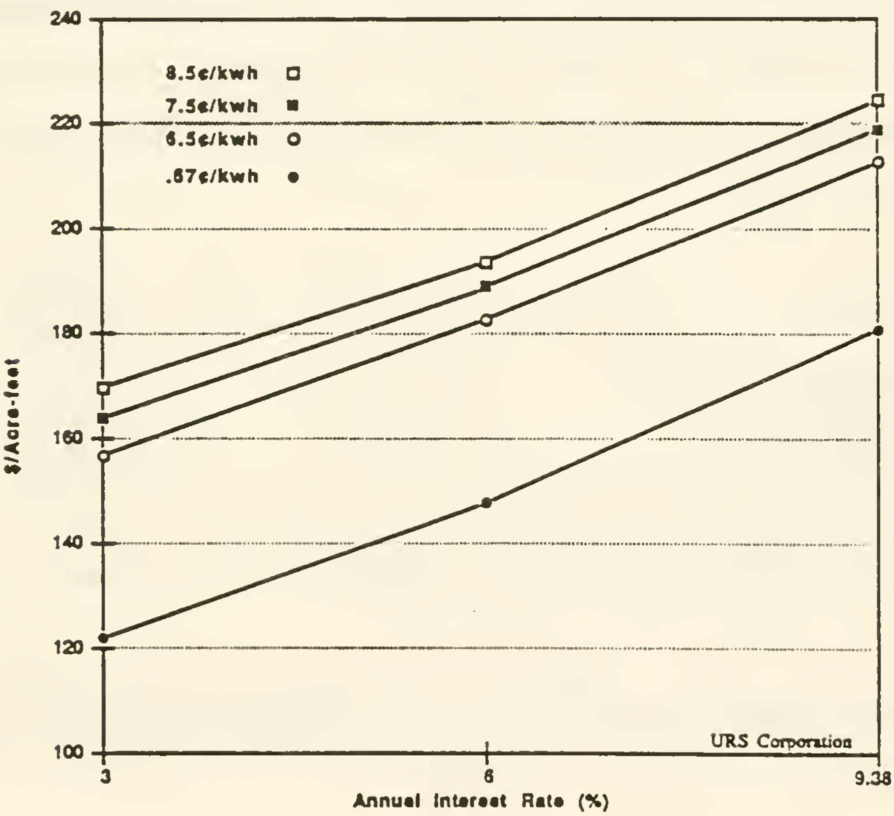


FIGURE II-4. Sensitivity Analysis for Check 41 Option

The URS report includes the reservation that: "This report does not conclude that deep-well injection is technically feasible or institutionally acceptable. Technical feasibility can only be proved by pilot testing. Institutional acceptability can only be determined by proceeding with the permitting process and environmental review."

URS proposed that a pilot test program should be designed to produce data in four major areas:

° Injection-well design

° Pumping system design

° Pretreatment system design

° Maintenance requirements

Injection-well design requires information on the depth of formations, the piezometric surface, thickness of the injection and confining formations, and the quality of the deep receiving water and soil and the injectate. The information will be used, for example, to determine well casing sizes, construction materials, well hole diameter, need for well screen, and well field configuration.

The pumping system design requires data on the storage capacity, transmissivity/permeability, and porosity of the receiving formation. Such information is needed to determine pressure buildup which affects the economical design of a pumping system compatible with the injection-well design.

Pretreatment system design also requires information on the effective permeability of the receiving formation in addition to the quality of the injectate, particle size distribution of suspended solids in the injectate, and the quality and character of receiving water and formation to determine the potential for chemical reaction and clogging.

Maintenance requirement for the deep-well injection of agricultural drainage water without actual experience can only be surmised from other deep-well injection experience, mainly those in oil field injection. Maintenance and/or well restoration requirements for full scale drainage water injection operations can be more reliably predicted from pilot injection efforts.

III

Discharge to the San Joaquin River*

About 77,000 acres of irrigated agricultural land in the San Joaquin River Basin have subsurface drainage systems that eventually discharge to the San Joaquin River. About 48,000 acres of these lands are upstream of the Merced River. Discharge of drainage water to the San Joaquin River is an important part of the overall valley drainage problem. Therefore, a Technical Committee composed of State Board and Central Valley Regional Water Quality Control Board staff was formed to propose: (1) water quality objectives for the San Joaquin River, (2) effluent limits for agricultural drainage discharge in the basin, and (3) methods to regulate those discharges. Because the Committee's proposals will bear significantly on the structural measures that would be used in any scheme to discharge to the river, the Committee's work to date is discussed here.

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*Material in this section is drawn largely from the SWRCB Order No. W.Q. 85-1 Technical Committee's final report: "Regulation of Agricultural Drainage to the San Joaquin River," August 1987.

Background

Beneficial uses of State waters are those uses which are to be protected against water quality degradation. The identification of these uses in the San Joaquin River is a key step in its water quality control planning. The Committee's recommended beneficial uses are shown in figure II-5.*

To protect these beneficial uses, the Committee identified 26 consituents in agricultural drainage water that would be of potential concern. Using screening criteria developed by the Committee, these were narrowed down to 11 constitutents: boron, molybdenum, salinity, selenium, cadmium, chromium, copper, manganese, mercury, nickel, and zinc. These were further narrowed down to four primary constitutents of concern; boron, molybdenum, salinity, and selenium. The Committee dealt mainly with these four constitutents.

The concentrations of these constituents are variable in the river, the sloughs and drainage canals that discharge into the river, and the eastside tributaries (figures II-6 through II-9). The concentrations are highest in the sloughs and canals, generally diminish moving downstream in the river, and are lowest in the eastside tributaries. This variability of quality has an important impact on the locations where water quality objectives are established, and therefore, on the management of agricultural drainage discharges to the river.

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*DFG has challenged the Board's recommended deletions of certain beneficial uses in the San Joaquin River. DFG has also challenged the 10 ppb (monthly mean) and 26 ppb (instantaneous maximum) selenium objectives in Mud and Salt Sloughs.

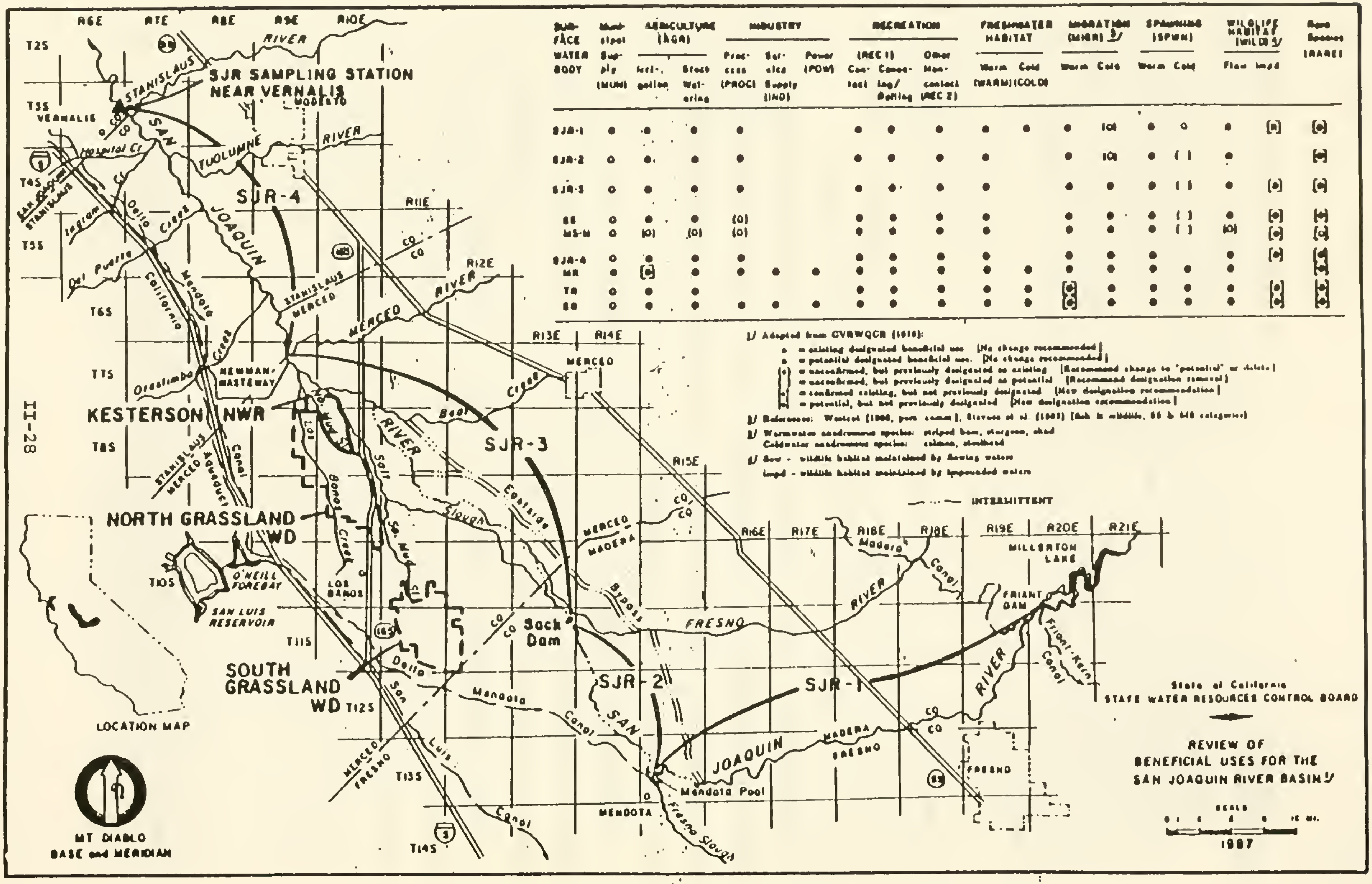

FIGURE II-5. BENEFICIAL USES FOR THE SAN JOAQUIN RIVER

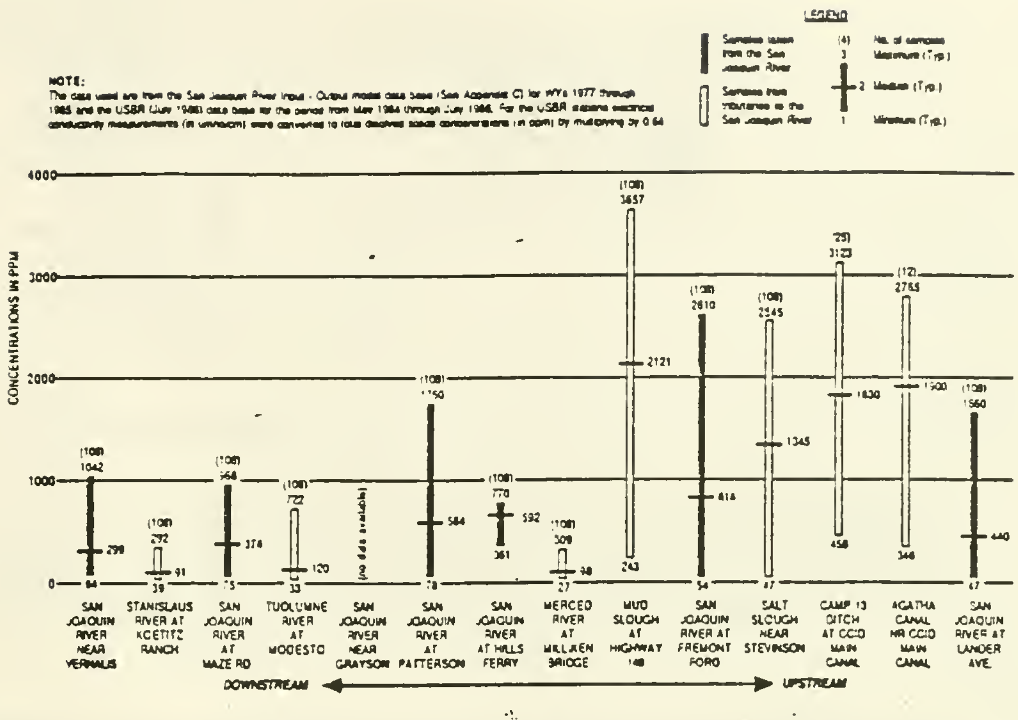

FIGURE II-6. SELECTED SAN JOAQUIN RIVER BASIN TDS CONCENTRATIONS

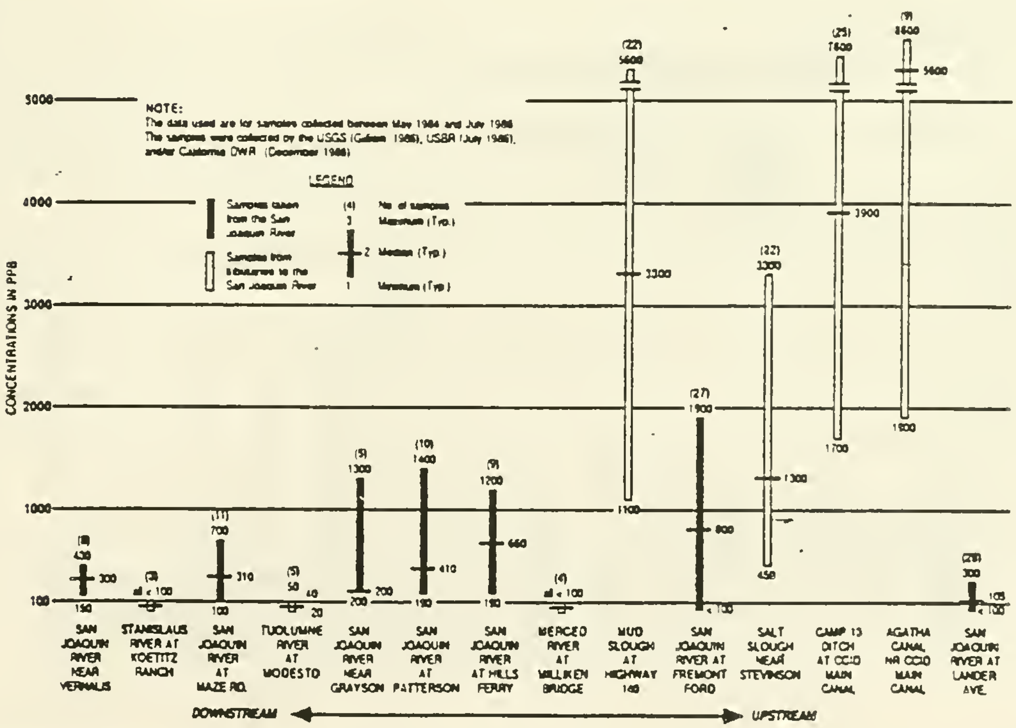

FIGURE II-7. SELECTED SAN JOAQUIN RIVER BASIN BORON CONCENTRATIONS

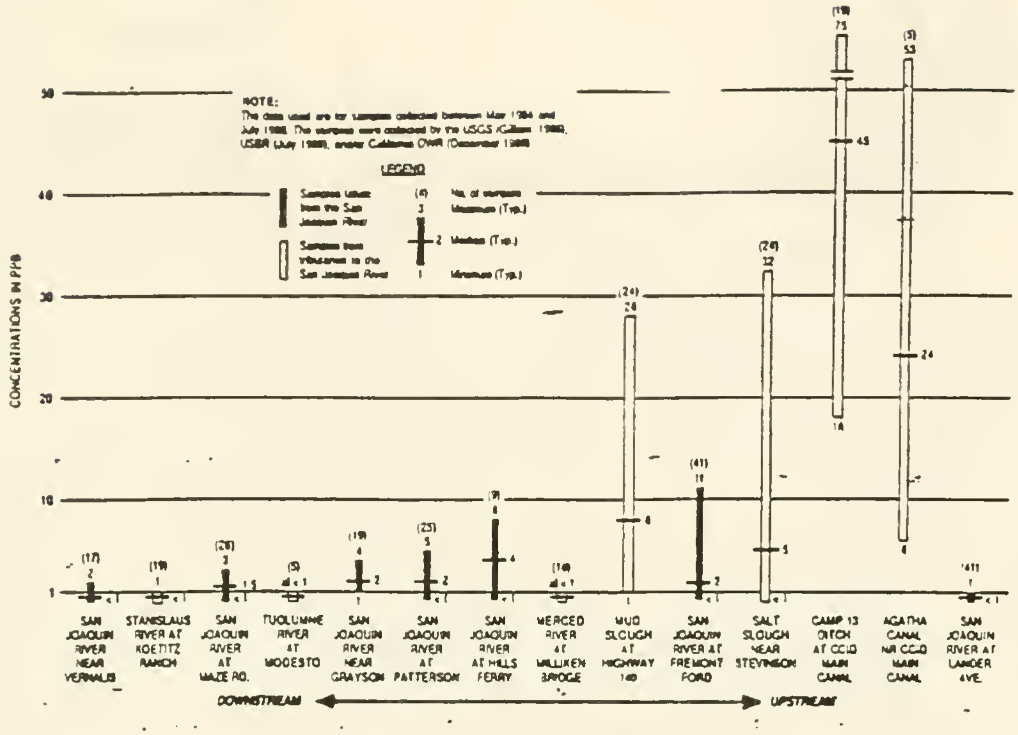

FIGURE II-8. SELECTED SAN JOAQUIN RIVER BASIN SELENIUM CONCENTRATIONS

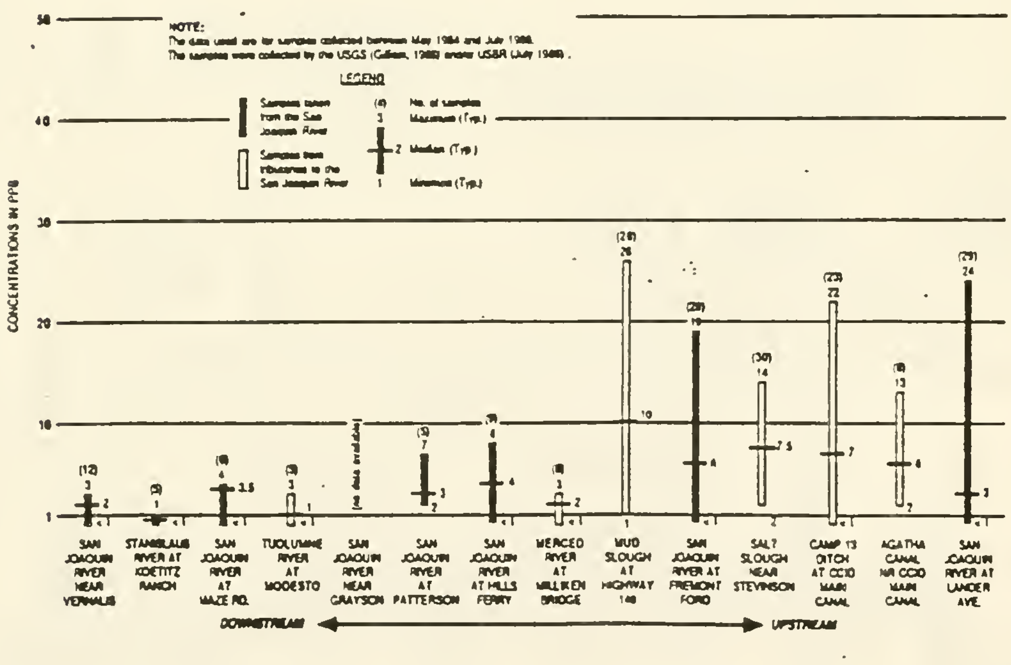

FIGURE II-9. SELECTED SAN JOAQUIN RIVER BASIN MOLYBDENUM CONCENTRATIONS

Water Quality Objectives

According to the California Water Code, water quality objectives, are "the limits on levels of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses of water and the prevention of nuisance within a specific area." The Porter-Cologne Act mandates the Regional Boards "to attain the highest water quality which is reasonable, considering all demands being made and to be made on those waters and the total values involved, beneficial and detrimental, economic and social, tangible and intangible." On the basis of its investigation, the Committee has recommended objectives for selenium, salinity, boron, and molybdenum to the Central Valley Regional Board.

Selenium objectives are listed in table II-2. In the case of selenium, the Committee estimated waste load limitations to achieve the interim and long-term selenium objective at Hills Ferry and to reduce selenium loading to downstream areas (table II-3).

Salinity concerns are greatest in the upper reaches of the river that receive subsurface drainage. These concerns were recognized in the Central Valley Board's 1975 Basin Plan, which declared the reach of the river from about Landers Avenue to below Vernalis, a water quality limited segment for salinity. Such a segment is defined as "a segment where water quality will not meet applicable water quality objectives even if municipal and industrial discharges provide required 1977 Federal levels of treatment."

The Committee's water quality objectives for salinity that were recommended to the Regional Board are shown in table II-2.

Boron is reported to be extremely high in the subsurface drainage flows produced in the basin and is diluted in the river by surface return

TABLE II-2. Recommended water quality objectives for the San Joaquin River Basin[a]

Location	Constituent	Maximum mean mothly level	Instantaneous maximum	Compliance date
Interim Objectives				
San Joaquin River at Hills Ferry and downstream	Selenium	5 ppb	26 ppb	October 1991
Grassland WD, San Luis NWR, and Los Banos SWA	Selenium	2 ppb (can be provided via a substitute supply[b])		October 1989
Long-Term Objectives				
San Joaquin River at Hills Ferry and downstream	Selenium	To be determined based on site-specific data		To be determined
	EC	1.0 mmho/cm		
	Boron	700 ppb	5,800 ppb	
	Molybdenum	10 ppb	440 ppb	
Salt & Mud Sloughs & San Joaquin River Lander Ave. to Hills Ferry	Selenium	10 ppb	26 ppb	To be determined
Salt Slough and San Joaquin River Lander Ave. to Hills Ferry	EC	3.0 mmhos/cm		To be determined
	Boron	2,000 ppb	5,800 ppb	
	Molybdenum	10 ppb	440 ppb	
Grassland WD, San Luis NWR, and Los Banos SWA	Selenium	To be determined based on site-specific data (can be provided via a substitute supply[b])		To be determined

[a] Source: Table V-1, SWRCB, 1987.

[b] If a substitute supply of 2 ppb or better is provided, the quantity of this supply should be in a volume equal to the lesser of either (1) the quantity of water historically (mid-1970's) diverted by these waterfowl areas or (2) the actual flow in the canals available to these areas.

Table II-3. Effluent limitations maximum monthly load of selenium discharged by all entities in the DSA[a]

	To Achieve Interim Objective of 5 ppb at Hills Ferry		To Achieve Long-Term Objective of 2 ppb at Hills Ferry	
	Dry & Crit.[b] Water Years ---	Normal[b] & Above Water Years	Dry & Crit.[b] Water Years ---	Normal[b] & Above Water Years
	Selenium (lbs)	Selenium (lbs)	Selenium (lbs)	Selenium (lbs)
Oct	300	350	250	350
Nov	600	750	150	550
Dec	800	850	200	600
Jan	600	750	150	600
Feb	400	700	0	400
Mar	700	1,200	100	450
Apr	600	800	100	200
May	500	800	150	200
Jun	400	600	100	200
Jul	350	450	100	100
Aug	400	500	100	150
Sep	300	300	100	200

[a] Source: Table VIII-2, SWRCB, 1987.

[b] Water year definitions are those as shown in Figure II-5 of the Technical Committee's report. Water year type is determined via the median year projected runoff from DWR Bulletin 120 beginning in February. The May Bulletin 120 establishes the year type for that water year. For the purpose of compliance with these limitations, the previous year's water year classification shall apply to the months October through January.

and east side tributary flows. Median boron levels between mid-1984 to mid-1986 in Agatha Canal, Camp 13 Ditch, Mud Slough, and Salt Slough were 5,600 ug/L, 3,900 ug/L, 3,300 ug/L, and 1,300 ug/L, respectively. Recommended water quality objectives for both boron and molybdenum are shown in table II-2.

Agricultural Drainage Management

When the Central Valley Regional Board amends its Basin Plan, it will include a Program of Implementation to achieve the water quality objectives. The Program of Implementation must contain a description of the nature of actions to achieve the objectives, including recommendations for appropriate action by involved entities, as well as a schedule for the action to be taken.

The Committee recognized that the achievement of its recommended objectives would require time to implement and should be phased in over time. The reasons it cited for staged implementation include: (1) the costs involved; (2) the significant changes that need to be made in drainage disposal and management practices; (3) the need to verify water treatment feasibility on a larger scale; and (4) the need to conduct site specific biological studies to confirm the efficacy and need for the water quality criteria for selenium and other elements of concern.

Irrigation management was viewed by the Committee as a very important component of water quality management in the river. It reported that water conservation can reduce the load of elements, such as selenium, that are discharged to surface waters. Similarly, for salinity, the Committee expected a significant decrease of salt load discharges to the river through water conservation.

The Committee concluded that drainage flow reduction is the least expensive alternative to meet water quality objectives and also provides other significant advantages over treatment to remove selenium:

- Reduction of other constituent loads in drainage water.
- Decrease in treatment costs due to volume reduction if treatment is required in the future.
- Agricultural production benefits arising from the more efficient use of water.
- Availability of scarce water for other uses in the basin resulting from more efficient water use.
- Drainage flow reduction technologies are proven and readily available.
- Lesser capital outlay to implement drainage flow reduction.

On-farm management drainage reduction practices are discussed in greater depth in another SJVDP technical report.

Treatment of drainage water was also investigated by the Committee. The cost estimates are summarized in table II-4. These estimates were based on four groups of treatment processes:

1. Treat tile drainage only for selenium.
2. Treat tile drainage only for selenium and remove TDS using evaporation ponds.
3. Treat tile drainage only for selenium and remove TDS using reverse osmosis.
4. Treat combined tile plus surface drainage for selenium and remove TDS using evaporation ponds.

Assumptions in developing the estimates included:

1. Sludge generated in the selenium removal process will be dried and transported to a Class I landfill.

Table II-4. Drainage treatment costs ($/AF/yr)[a]

Treatment System	Treatment Plant Capacity AF/MO (mgal/d)				
	93.3 (1)	933 (10)	2,800 (30)	4,667 (50)	7,467 (80)
Treat Tile Drainage Only					
Se removal with ion exchange	237	169	154	151	---
Se removal without ion exchange	145	105	93	90	---
Se removal, evaporation pond, no effluent: low estimate	277	234	217	215	---
high estimate	461	416	401	396	
Ion exchange, reverse osmosis, 85 percent of effluent available for use, 15 percent of effluent treated for Se removal and disposed in evaporation ponds: low estimate	476	375	329	319	---
high estimate	521	400	357	347	---
Treat combined tile plus surface drainage (add coagulation to remove suspended solids)					
Se removal without ion exchange	---	133	120	---	102
Se removal evaporation pond (low estimate)	---	261	240	---	222

Note: Capital costs discounted at 4 percent over 20 years.

Source: Neethling (1986)

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[a] From table VII-2, SWRCB Order No. 85-1 Technical Committee's Final Report, "Regulation of Agricultural drainage to the San Joaquin River," August 1987.

2. The combined surface and tile water is considered to be turbid, requires coagulation, flocculation, and sedimentation as primary treatment; this is not required when the tile drainwater is treated alone.
3. Selenium removal is always employed before discharge of drainwater to an evaporation pond in order to limit the needs for a Class I (double-lined) evaporation pond. Accordingly, in the evaporation ponds considered here, only a small section (4 percent) is double-lined. Because of uncertainty concerning the cost of a Class I pond (estimates range from $85,000/acre to $200,000/acre), two estimates are used for the costs of the overall evaporation pond facility: $6,100/acre (low) and $15,000/acre (high).

It was concluded from these estimates that:

1. At high capacity levels the change in the costs per acre-foot of water treated becomes small.
2. It costs approximately $61 to $92/AF extra to reduce the selenium concentration from 10 to 20 ug/L (using biological treatment and filtration) down to 2 to 5 ug/L (using ion exchange).
3. The cost of coagulation and suspended solids removal (required when tailwater is part of the inflow to the selenium removal facility) is $27-$28/AF.
4. The cost of removing salt from drainwater by reverse osmosis is very sensitive to the cost of constructing the disposal pond. At the lower disposal pond cost, salt removal increases costs by

$229 to $321/AF. At the higher toxic pond cost, salt removal increases the cost by $257 to $376/AF.

The Committee focused largely on the detailed evaluation of the costs of meeting selenium objectives although it recognized that other constituents are also of concern. A reason it cited for not dealing in depth with the salinity problem was that the SJVDP would be investigating other methods of disposal.

Structural Facilities in Water Quality Management

The Technical Committee reports that irrigation management and concomitant drainage volume reduction are the key to meeting the recommended water quality objectives. However, at the SWRCB hearings on the Committee's report, achievable drainage volume reduction was a major issue of contention. It was strongly argued by farming interests that the levels of drainage volume reductions suggested by the Committee were not realistically achievable. Consequently, the SJVDP has initiated a study on how structural measures such as treatment and in-valley disposal schemes (i.e., deep-well injection and evaporation ponds) could be incorporated with drainage reduction efforts and what those structural measures might cost.

The basic approach of this study is as follows:

1. Implementation of irrigation management practices and drainage volumes is a given; it is less expensive than structural options. The actual level of drainage reduction achieved is a variable.
2. Structural measures would therefore be implemented in addition to and not in lieu of irrigation management.

REFERENCES (DISPOSAL)

Brown and Caldwell Consulting Engineers (1987) "San Joaquin Valley Drainage Program, Screening Alternative Geographic Disposal Areas."

CH2M Hill (1986), "Reverse Osmosis Desalting of the San Luis Drain Conceptual Level Study."

CVRWQCB, Central Valley Region (1985), "Waste Discharge Requirements for Westlands District; William and Nell F. Crossland; Emma Gilio; Ray R. Scott, Jr.; Lester G. Swancutt; Nella D. Minnite; Vista L. Minnite; and Southern Pacific Land Company, Fresno County," CVRWQCB Order No. 85-205.

EPA (1985), "40 CFR Part 141 - National Primary Drinking Water Regulations; Synthetic Organic Chemicals, Inorganic Chemicals and Micro-Organisms; Proposed Rule," National Register of November 13, 1985.

SWRCB, August 1987. Regulation of Agricultural Drainage to the San Joaquin River. Final report of SWRCB Order No. W.Q. 85-1 Technical Committee.

URS Corporation, October 1986. Deep-Well Injection of Agricultural Drain Waters. An appraisal level study with application to Kesterson Reservoir problems.

SECTION III

REUSE

Reclamation and reuse of drainage water is consistent with Federal and State water management policies, which strive to maximize use of existing water supplies and reuse of water. Therefore, the prospects for reclamation and reuse of agricultural drainage water must be explored and included in the solution of the agricultural drainage problems. Drainage water should not be viewed exclusively as wastewater but also as a potential resource.

It was claimed by the Interagency Drainage Program (IDP) that the major difference between the IDP and the earlier drainage planning efforts is the IDP emphasis on drainage water reuse (IDP, 1979). The opportunities and potentials for reclamation and reuse were identified in the IDP as follows:

- Marsh reuse
- Powerplant cooling reuse
- Agricultural reuse
- Water reclamation-desalting
- Aquacultural reuse
- Ocean salinity repulsion
- Salt reclamation

The SJVDP, to date, has reexamined some of these reuse potentials as well as others. This section presents information to aid in the evaluation of the potentials for reuse in marshes, powerplant cooling, aquaculture, ocean salinity repulsion, salt recovery, and nonconvective gradient solar ponds. Water reclamation desalting is discussed in part one, the treatment technology technical report.

I

Marsh Reuse*

It was concluded in the IDP that drainage water is acceptable for use in marshes, and it was accordingly viewed ". . . a valleywide drainage program offers one of the rare opportunities to recover some of the wetland habitat the San Joaquin Valley has lost." However, since the emergence of ecological problems at Kesterson Reservoir and other reported areas in the valley, the reuse of drainage water for marshes and wetlands is uncertain. It can be assumed that such reuse would not be permissible without treatment for the removal of toxicants.

The difficult question is: What are the acceptable levels, if any, of toxicants to permit this reuse? The answer to this question, of course, establishes the design criteria for drainage water treatment, which, in turn, establishes the costs and determines feasibility. As an example of what might possibly be expected, the Technical Committee recommended in its water quality objectives for the San Joaquin River Basin a selenium level of 2 ug/L for Grasslands (SWRCB, 1987).

Costs

In the IDP, three marsh management approaches were identified, and the Type III marsh was recommended "where and when relatively good

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*Additional details are discussed in greater depth in a SJVDP technical report on fish and wildlife.

quality (low TDS) water is available. These marshes would be flooded from fall to the middle of winter for migrating waterfowl. During the remainder of the year, the marshes are drained and food plants for waterfowl would be grown. Otherwise, Type II marshes having water continuously flowing through would be used. Type I marshes, wherein the only outflow is evaporation and percolation, were not recommended because the impounded drainage water would eventually become so saline that marsh plants could not survive.

When regulatory controls are imposed on agricultural drainage water discharges to the San Joaquin River, salinity could be a limiting constituent. If such is the case, drainage water after marsh reuse may need to be disposed elsewhere such as evaporation ponds. In the case of the IDP, discharge to the western Delta was contemplated, so salinity was not expected to be a prohibiting factor because the receiving water would be more saline than the discharge water.

The IDP's estimated undiscounted (dollar value at the time of the future expenditures) capital costs (in millions) of the marshes and other features of the Recommended Plan, including interest during construction amounted to:

Disposal System	
Drain	$ 422.7
Pumping Plants	16.9
Regulation Reservoirs	31.7
Marshes and Storage Ponds	
Marshes	361.2
Storage Ponds 154.8	
Collector Drains	273.3
Total	$1,260.6

The cost of the marshes and storage ponds totaled $516 million, which amounts to about 41 percent of the total cost of the IDP Recommended Plan. The $516 million estimate reflects costs in 1979 when the estimate was made. In the 8 years since that 1979 estimate, construction costs have increased by about 33 percent, so the present cost of the marshes and storage ponds could conceivably be about $686 million if the IDP estimates are accurate.

The marsh reuse related costs today would be higher because of both escalating construction costs and the cost of toxicant treatment to accommodate marsh reuse.

II

Powerplant Cooling Reuse

The IDP also had an optimistic outlook toward the prospects of the reuse of drainage water for powerplant cooling. Therefore, a short study was undertaken by the SJVDP to take an updated look at thermal electricity demand projections and accompanying powerplant cooling-water demand projection as well a the current state of powerplant cooling technology. The results of this study are reported in a technical information record report (SJVDP, 1986).

Both the California Legislature and the State Water Resources Control Board (SWRCB) have enunciated State policies in support of water reuse. The Wastewater Reuse Law of 1974 declares that wastewater will be reused to the maximum extent to conserve available water resources (California Water Code). The SWRCB encourages wastewater use for powerplant cooling and declares that the use of fresh inland water supplies will be approved by the Board only when it is demonstrated that the use of other water supply sources or other methods of cooling would be environmentally undesirable or economically unsound (SWRCB, 1975).

The IDP Outlook

The IDP included drainage water reuse for powerplant cooling as an important element of its recommended plan. It reported that Pacific Gas and Electric Company had estimated that six new thermal powerplants would be needed in central California by 2010. In the IDP, it was assumed that three of these six powerplants would be built in the San Joaquin Valley and would use drainage water for cooling. However, powerplant cooling reuse was not considered a "built-in" element of the IDP, since powerplant development was not considered to be within the realm of normal government activity"; such reuse would be continually evaluated, promoted, and integrated into the IDP. As such, there was no project cost per se for powerplant facilities, but $3.31 million of annual equivalent net benefit of a total benefit of $92.9 million was attributed to powerplant cooling reuse.

Energy Demand Outlook

The California Energy Commission (CEC) has statewide energy planning responsibilities but limited regulatory authority. The Warren-Alquist Act directs the CEC to provide an integrated assessment of the need for new energy resource additions (PRC Section 25309 b). This requires the CEC to determine a level of demand that balances:

1. Requirements of State and service area growth and development,

2. Protection of health and safety,

3. Preservation of environmental quality,

4. Maintenance of a sound economy, and

5. Conservation of energy and resources.

To achieve this balance, the CEC has adopted three explicit policies: (1) favor projects that keep down ratepayer costs; (2) support development of a resource-balanced electricity generation system that implicitly constrains utility usage of oil- and gas-fired generation; and (3) pursue numerical goals for preferred electrical energy resource additions.

Because of the CEC's implicit role in California's energy planning, this review of thermal electricity demand was based on CEC projections. The CEC prepares biennial reports on statewide electricity needs including detailed analyses based on 12-year planning horizons of the California electricity supply system as required by Public Resources (PRC) Code Sections 25305 and 25308. The CEC's biennial report of May 1985 was the reference source for this study (CEC, 1985).

The CEC's electricity demand expectations up to 1996 may be summarized in its statement that:

"Simply stated, the message of this report is that: (1) there is an abundance of supply projects currently proposed by many sponsors; (2) these projects substantially exceed total need; and (3) many more baseload projects could increase electricity rates since they do not match the load duration curve of the utility. Therefore, economic and environmental burdens may be imposed through the premature construction and operation of unneeded facilities. The demand conformance/need policy addresses this concern.

The CEC report further adds that, "The basic fact that needs to be addressed in the evolution of siting policy is that until the mid-1990's the large private utilities are not proposing to build powerplants."

Cooling Water Demand

These projections for energy demands are reflected in low present demands in the San Joaquin Valley for powerplant cooling water. The California Department of Water Resources (DWR) periodically updates the California Water Plan, which, among other things, projects future water demands. DWR, also relying on CEC electrical need projections, forecasts a net increase of powerplant cooling water use of only 2,000 acre-feet per year by the year 2010 in the San Joaquin Valley (DWR, 1983) (see table III-1). Powerplant cooling water demand was not reported in DWR Bulletin 160-87, the 1987 update of the forementioned report.

Table III-1. Water use for powerplant cooling in the San Joaquin Valley by hydrologic areas and by decades to year 2010 (in acre-feet)

Year	San Joaquin	Tulare Lake
1980	15,000	- 3,000
1990	20,000	-
2000	20,000	-
2010	20,000	-
Net change 1980 to 2010	+5,000	-3,000

Source: DWR Bulletin 160-83, table 48.

Costs

The 12-year planning horizon projection of the potential demand for drainage water for powerplant cooling is not optimistic, but if there is a turnaround in demand, the question remains as to the realistic costs and benefits of using agricultural drainage water for powerplant cooling. In exploring this question, the experiences of two studies on the technical feasibility of using saline water for cooling powerplants with evaporative cooling systems were reviewed.

In 1978, a study of drainage water treatment for powerplant cooling was jointly sponsored by the city of Los Angeles, Department of Water and Power; Pacific Gas and Electric Company; Southern California Edison Company; Electric Power Research Institute; and California Department of Water Resources. DWR and the University of California (UC), Seawater Conversion Laboratory conducted a preliminary evaluation of the technical feasibility of using drainage water for cooling powerplants that use evaporative recirculating cooling systems (DWR and UC, 1978).

Preliminary cost estimates were made as part of the study, but additional studies such as prototype plant operation were reported as being necessary to more precisely determine the treatment cost of a full-scale powerplant.

The 3-year test program included about a year of field testing from January 1977 to late February 1978 at a wastewater treatment facility operated by DWR near Firebaugh. The feedwater supply was from a tiled drainage system (Alamitos) serving about 400 acres of farmland near the test site. Table III-2 shows the chemical quality of the feedwater.

The study was based on a base plant designed to treat 11.5 million gallons per day of water as makeup water for a 1,000-MW powerplant. The testing was on a treatment process to enable softening pretreatment by ion-exchange resin and regeneration of the resin using concentrated cooling tower blowdown without new chemicals.

Table III-2. Alamitos tile drainage water chemical analysis of low- and high-TDS flows[a]

Constituent	Drainage water concentration (mg/L) Sample date 7-20-76 Low TDS	Drainage water concentration (mg/L) Sample date 3-23-77 High TDS
Calcium	164.0	159.0
Magnesium	52.0	334.0
Sodium	402.0	1,440.0
Potassium	4.0	5.6
Carbonate	-	-
Bicarbonate	331.0	286.0
Sulfate	888.0	3,760.0
Chloride	203.0	542.0
Nitrate	16.0	-
Boron	4.1	12.0
Silica (S_iO_2)	25.0	32.0
TH as $CaCo_3$	625.0	1,820.0
TDS	1,930.0	6,850.0

[a] Data taken from DWR Bryte Laboratory water analyses.

Source: DWR and UC, "Agricultural Wastewater for Powerplant Cooling Development and Testing of Treatment Processes, Volume II," June 1978.

It was reported that the estimated cost of treating drainage water would be $0.34 per thousand gallons or about $111 per acre-foot, on a 1976 cost basis, and $0.50 per thousand gallons or $163 per acre-foot, when escalated at the time of the study to 1984 costs. These are treatment costs only and do not include costs connected with the disposal of any wastestream.

Additional costs escalated to 1984 for brine disposal were reported as being $0.33 per thousand gallons ($108/acre-foot) for evaporation ponds only and $0.89 per thousand gallons ($290/arcre-foot) for brine concentration followed by evaporation ponds. Therefore, according to this study, the sum of treatment and evaporation pond disposal costs totaled $271 per acre-foot; i.e., $163 +$108, in terms of 1984 costs. However, if the selenium or other contaminant levels in the waste brine reach hazardous levels, the disposal costs may be substantially higher because Class I ponds may be required.

Recent cost estimates (those of both the USBR and CH2M Hill) indicate that Class I ponds (double lined with underdrains) cost almost $200,000 per acre to construct. CH2M Hill's estimates show that this equates to about $1,271 to $1,358 per acre-foot for Class I pond disposal, depending on the volume of wastewater to be disposed (CH2M Hill, 1986). The total cost of treating drainage waters for powerplant cooling plus brine disposal probably would substantially exceed $290 per acre-foot. Consequently, it would be overly optimistic to expect, despite the SWRCB's policy to promote the use of agricultural wastewater for inland power cooling, that potential power developers would be willing to pay for drainage water and incur a purchase cost in addition to a substantial treatment cost to use drainage water for powerplant cooling. Realistically, the drainage water will not be marketed to the power companies and be profitmaking.

A study commissioned by the Lower Colorado River Region of the USBR also supports the conclusion that there is a significant cost connected with the use of saline water, as is agricultural drainage water, for powerplant cooling (Loughlin, 1984). The USBR in 1984 contracted for a two-stage study of the use of saline water for powerplant cooling to conserve high-quality water while reducing the salinity of the Colorado River system. An appraisal-level study was conducted on the feasibility of installing and operating a saline water cooling tower verification program at the Utah Power and Light Company's Hunter Station plant in Utah.

The objectives of the first stage were to: (1) compare saline water cooling technology with alternative technologies for using saline water for powerplant makeup water, and (2) to determine whether a saline-water cooling-tower verification program at Hunter Station was technically and economically workable. The objective of the second stage was to determine the incremental cost differences using an existing high quality water as compared to a local saline water supply, using the most promising technologies identified in the first stage.

Table III-3 shows the quality of both the Hunter Station operating water supply and the potential saline water supply from Desert Seep Wash. The quality of water from Desert Seep Wash may be compared to: (1) the quality of drainage water used in the Firebaugh powerplant cooling water study, and (2) the present quality expectation of drainage water to be generated in the Federal service areas by comparing against tables III-2 and III-5, respectively. Water from Desert Seep Wash is generally of better quality than the drainage water in the San Joaquin Valley.

From the first-stage work, Loughlin concluded that "sidestream softening of cooling tower with brine concentration evaporators handling all wastewaters was the most cost effective option. In the second stage of the study, Loughlin identified the elements of increased cost in water supply changeover and the magnitudes of the increases. The costs of chemicals, softening equipment, and evaporation ponds increased substantially--almost a minimum of four times (table III-4). This would indicate, also, that there is a significant cost associated with the use of agricultural drainage water for powerplant cooling as compared to using freshwater supply.

Table III-3. Hunter Station powerplant water chemistry

	Concentration in mg/L	
Constituent	Raw water supply	Desert seep wash supply
Sodium	10-15	692
Calcium	40-60	180
Magnesium	20-30	186
Chloride	3-5	57
Sulfate	60-70	2,291
Bicarbonate	180-220	289
Silica	3-5	
Potassium		11
TDS	300-375	3,844

Source: Loughlin, Jack K., Consulting Engineer, tables IV-2 and V-1 in "Appraisal Study of Saline Water Use Equipment for Power Plant Cooling," August 17, 1984.

Table III-4. Economic impact of water quality on plant costs for sidestream softening options

Cost element	Nonlevelized cost ($1,000)	
	Option VI (361 mg/L TDS)	Option XI (3,731 mg/L TDS)
Chemicals (per year)	394	1,814
Power (per year)	1,245	1,417
Oper. and Maint. (per year)	495	590
Softening Equipment	500	2,500
Brine Concentrators	6,000	6,000
Evaporation Ponds	855	3,105

Source: Loughlin, Jack K., Consulting Engineer, table II-2 in "Appraisal Study of Saline Water Use Equipment for Power Plant Cooling," August 17, 1984.

Table III-5. San Luis Drain water quality summary

SITE: SLDC41 Check 41 - Weir at milepost 127.05, east of Bass Avenue

Parameter	Units	Number of observations	Maximum value	Minimum value	Average value[a]	Period of record
Field EC	Micromho	49	13900	9570	10490	6/81 - 11/84
Dissolved solids	mg/L	48	11600	6200	9820	5/81 - 3/84
Field pH	SU	53	8.8	6.4	Not applicable	5/81 - 11/84
Dissolved oxygen	mg/L	20	14.0	6.3	11.3	8/81 - 9/83
Calcium (Ca)	mg/L	41	714	464	554	5/81 - 12/83
Magnesium (Mg)	mg/L	40	326	72	270	5/81 - 12/83
Hardness	mg/L	22	2610	2190	2460	3/82 - 12/83
Potassium (K)	mg/L	40	12.0	5.3	6.4	5/81 - 12/83
Sodium (Na)	mg/L	41	2820	1810	2230	5/81 - 12/83
Chloride (Cl)	mg/L	45	2000	1180	1480	5/81 - 8/84
Sulfate (SO_4)	mg/L	41	6500	3710	4730	5/81 - 12/83
HCO_3 Ion.	mg/L	18	256	182	238	5/81 - 5/83
CO_3 Ion	mg/L	15	14	0	1	5/81 - 11/82
Alkalinity	mg/L	22	213	177	196	3/82 - 12/83
Silica (Si)	mg/L	37	48	18	34	6/81 - 12/83
Total Boron (B)	mg/L	33	18.0	12.0	14.4	3/82 - 12/84
Dissolved boron (B)	mg/L	22	30.4	10.4	15.8	6/81 - 9/83
Total phosphate	mg/L as P	39	4.60	0.02	0.17	5/81 - 12/83
Ortho phosphate	mg/L as P	33	0.07	0.00 2 obs at <0.01	0.02	5/81 - 12/83
Total nitrate + nitrite	mg/L as N	43	60.18	2.50	44.52	5/81 - 12/83
Total inorganic nitrogen	mg/L as N	18	60.19	2.54	45.99	5/81 - 9/83
Chemical oxygen demand	mg/L	20	80	18	32	3/82 - 12/83
Biochemical oxygen demand	mg/L	20	5.8	2.1	3.2	3/82 - 12/83
Total organic carbon	mg/L	19	16.0	5.6	10.2	4/82 - 12/83
Dissolved organic carbon	mg/L	19	12.0	5.6	8.3	4/82 - 12/83
Silver (Ag)	ug/L	11	All values at <1		Not determined	3/84 - 12/84
Arsenic (As)	ug/L	11	1	4 obs at <1	1	3/84 - 12/84
Cadmium (Cd)	ug/L	11	2	10 obs at <1	Not determined	3/84 - 12/84
Chromium (Cr)	ug/L	11	30	6	19	3/84 - 12/84
Copper (Cu)	ug/L	11	5	2 obs at <20 1 obs at <1	4	3/84 - 12/84
Iron (Fe)	ug/L	11	210	50	110	3/84 - 12/84
Mercury (Hg)	ug/L	11	0.2	6 obs at <0.1	0.1	3/84 - 12/84
Manganese (Mn)	ug/L	11	50	10	25	3/84 - 12/84
Molybdenum (Mo)	ug/L	11	120	21	88	3/84 - 12/84
Nickel (Ni)	ug/L	11	26	3	14	3/84 - 12/84
Lead (Pb)	ug/L	11	6	5 obs at <1	3	3/84 - 12/84
Selenium (Se)	ug/L	11	420	170	325	3/84 - 12/84
Zinc (Zn)	ug/L	11	240	6	33	3/84 - 12/84

[a]Values less than detection limit not used in calculating averages.

Salt Recovery

If salts or minerals can be economically recovered from agricultural drainage water, there could be a very significant impact on the economic feasibility of certain alternatives, e.g., treatment and evaporation. In the IDP it was reported that 17 chemical and mineral extraction companies were questioned on the commercial value of salts contained in drainage water. Staff estimates of year 2020 tonnages of specific salts were given to the companies. Of the 17 companies, 4 responded, and none was interested in extracting the salts.

U.S. Borax Research Corporation suggested using algae for selective boron removal, but the IDP concluded that the algae boron content would not be rich enough for commercial boron recovery. Kaiser Chemicals suggested that potash (potassium chloride) might be extracted.

DWR in its Master Drain studies, which preceded the IDP studies, also queried mineral recovery companies on the potentials for commercial recovery of minerals. West End Chemical Company, a company operating at Searles Lake in the Mojave Desert, stated that drainage water, based on chemical analysis provided by DWR of drainage water, had no commercial possibilities based on the mineral markets at the time (DWR, 1962).

DWR staff also met with representatives of Leslie Salt Company in Newark, California, to discuss mineral recovery (DWR, 1963). Leslie Salt people did not give a direct answer to the question as to whether salts crystallized from drainage water would have any sale value, but it was Amstutz's impression that they believed that ". . . under present conditions these would have absolutely no value." Material provided by the Leslie Company indicated that proximity to markets and transportation are major factors in the economics of common salt production.

There have also been more recent investigations into salt recovery. Westlands is studying a solar saltworks, along with its test prototype selenium removal plant and deep-well injection at Mendota (Binnie California, 1987). The primary purpose of the saltworks is to evaporate water treated for selenium removal to identify the salts that are deposited under different ambient conditions and at different stages, and to determine the practicality of producing byproduct salts commercially.

The saltworks will consist of five shallow evaporation ponds and a crystallization section. It will be operated over 18 months such that the passage of treated water will be controlled so as to establish the design brine-concentration profile as early as possible during the life of the project and to maintain that profile thereafter.

Despite the past lack of interest of the salt industry in commercial salt harvesting there are salt recovery advocates. There, the SJVDP plans to take an updated look at the feasibility of harvesting and marketing salts in drainage water. Accordingly, the SJVDP is presently preparing to investigate the market for recovered salts, primarily sodium sulfate, and processes to harvest salts.

IV

Aquaculture

Based on environmental and human health concerns, there is little likelihood that subsurface drainage can be used as a culture medium in traditional aquaculture. There is a better chance, however, that biological treatment systems can produce organic materials with some economic value. Such value might be realized through digestion of product and use of the supernatent or gases resulting from the process itself to reduce overall process costs. The algal or bacterial cells could be used as a source of industrial chemicals or possibly as an animal food supplement. The realization of either of these last two possibilities will require considerably more effort devoted to understanding the fate of trace elements in the tissues.

Although there has been little in the way of a formal assessment of marketability, some preliminary conclusions can be developed. The following is a qualitative compilation of the pluses and minuses associated with using subsurface drainage to produce organic biomass.

Pluses

1. A considerable amount of water is available. This is a particular advantage in an area such as the San Joaquin Valley, where water is generally scarce.
2. The drainage contains significant amounts of nitrogen, an essential plant nutrient.
3. Bacteria and algae grow readily in wastewater when suitable cultural conditions are maintained.
4. Using plant system, both bacterial and algal, removal of problem components can be achieved while producing substantial quantities or organic material or biomass.

Minuses

1. Trace elements and perhaps pesticides contained in the wastewater can be concentrated in harvested organic biomass.
2. No market has been developed for plant biomass produced in such aquacultural systems. Concerns about trace element contamination will affect demand for the product. Milorganite, a compost-type product made and solid for years from sewage sludge, is now being reexamined in light of its trace element composition.
3. The limited information on fish growth in these waters makes it difficult to state more than: (1) water from the system tested is not acutely toxic to a wide variety of fish; and (2) there were few obvious signs of chronic toxicity.

Results of a series of studies conducted by State and Federal agencies at test facilities located near Firebaugh, California are summarized in report prepared by Dr. Randall Brown of the California Department of Water Resources. The report is in the SJVDP files. Dr. Brown concludes, "Although more work would increase our understanding of the potential of growing fish in drainage, the reality is that such uses of drainage are very unlikely in the near future. In most cases, there is no apparent advantage to the use of drainage as a culture medium and there is a perceived multitude of disadvantages. A major real disadvantage is that fisheries aquaculture does little, if anything, to improve the quality of the drainage. In fact, intensive fish culture normally degrades the water by adding a significant oxygen demand in the form of uneaten food."

No study of using drainage water as on aquaculture medium is being pursued.

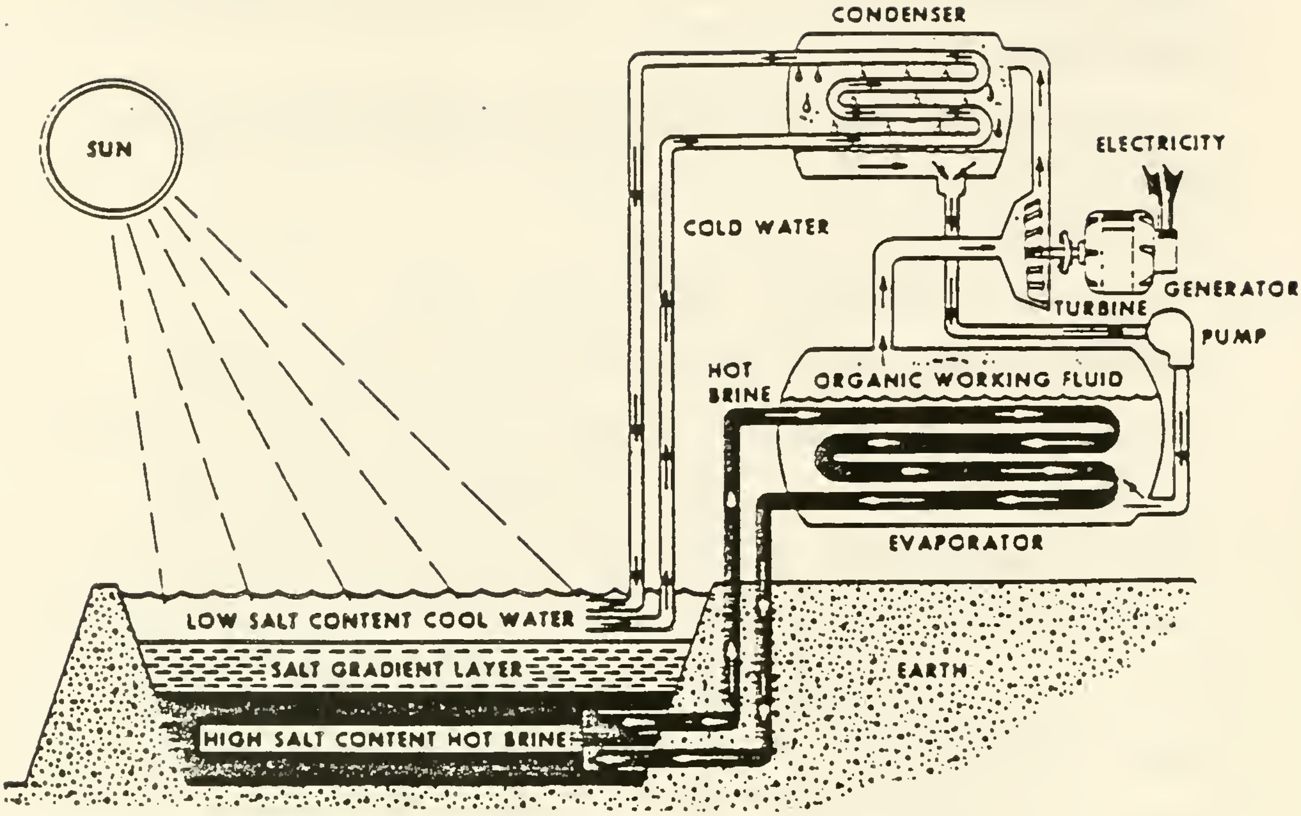
V

Nonconvective Solar Gradient Ponds

Certain drainage water management alternatives such as in-valley evaporation ponds and desalination treatment are not ultimate or complete solutions in themselves because the knotty problem of brine or salt disposal accompanies these alternatives. Solar ponds must be evaluated in the SJVDP because they offer the possibility of using a drainage waste product, salts, for a beneficial purpose--electrical energy production. If agricultural drainage salts can, indeed, be effectively used for electricity generation, solar ponds can be an important component in the conjunctive solution of the energy demand problem as well as the agricultural drainage problem. Accordingly, this section reports on how solar ponds work, what is required to make them work, what we know about them, and what we don't know about them.

Solar Ponds Principle

Several types of solar ponds for converting solar energy to electrical energy are described in the literature, but this discussion is limited to the nonconvective, salt gradient solar ponds. These are about 6.5 to 16.5 feet deep with three distinct zones (see figure III-1). The top layer or the upper convecting zone is typically 0.7 to 1.6 feet deep and consists of uniform, relatively low-salinity water (of up to about



Source: USBR, 1982

Figure III-1. Solar Pond Generation Concept.

60,000 ppm (MIT, 1985). The intermediate zone is the nonconvective gradient zone, in which both the temperature and the salinity increase with depth. This zone is about 2.5 to 5 feet thick and helps to insulate the underlying heat storage zone. The third and lowest zone is usually about 3.3 to 10 feet thick and consists of very saline brine of about 150,000 to 250,000 ppm.

Ordinarily, heated bottom water in water bodies expands to become lighter and rises to the surface to lose its absorbed heat by convection and radiation. However, in salinity gradient ponds the lower zones are prepared and maintained to remain denser than the zones above even when heated. Short wave solar radiation penetrates the upper zones into the heat storage zone and raises its temperature. The stored heat can be used as a low-temperature energy source.

Ormat Turbines, Ltd., an Israeli company with solar pond experience in Israel, reports from its experience with solar ponds that about 20 to 25 percent of the incident irradiation can be collected and extracted at about 180 °F to 200 °F (Ormat, 1981). Using specially designed turbines and generators such as those it developed, Ormat has proposed that the low-temperature energy can be effectively converted into electrical energy.

Energy Budget for Solar Ponds

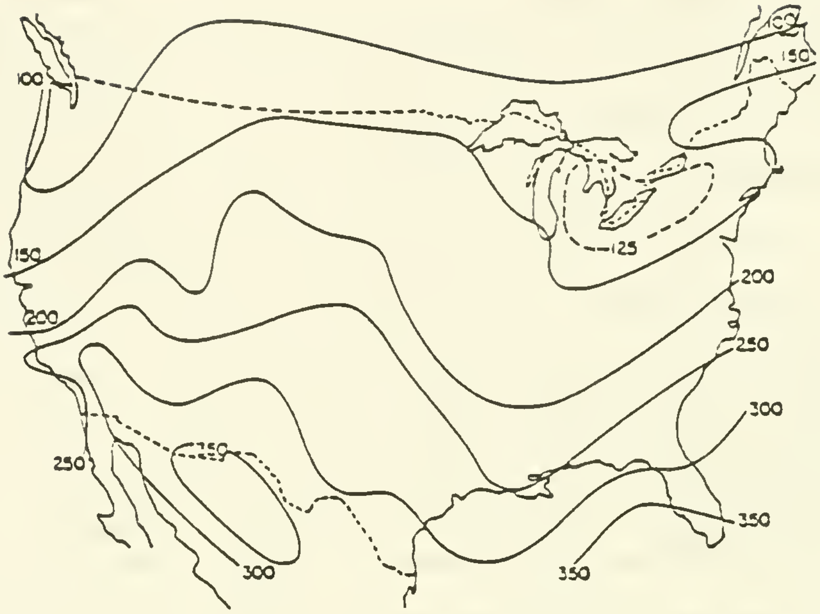
The energy budget for solar ponds depends on five primary factors (MIT, 1985):

- Net incident solar radiation;
- Penetration of solar radiation to the heat storage zone (as affected by solar angle and water clarity);
- Diffusion of heat from the heat storage zone to the intermediate, nonconvecting gradient zone;
- Ground heat loss from the heat storage zone; and
- Thermal energy extraction.

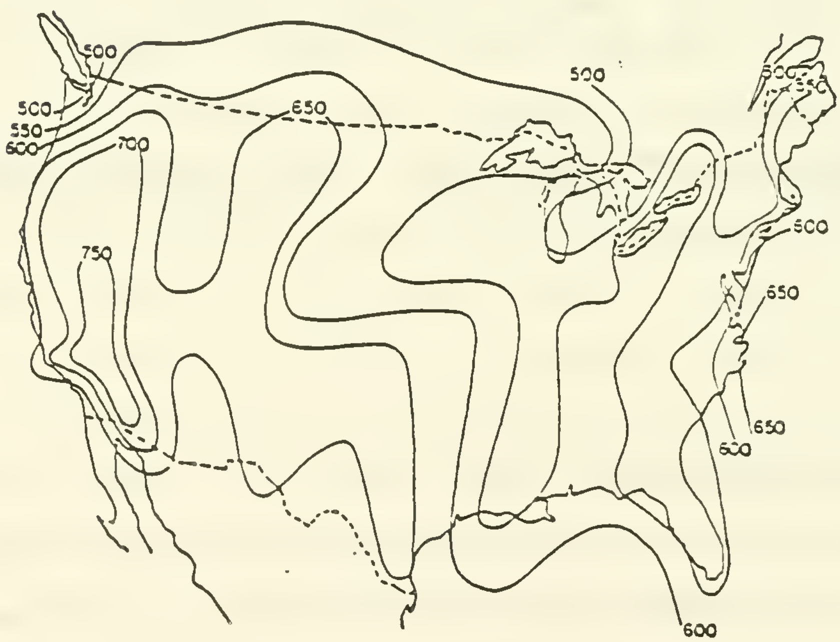
The incident radiation depends mainly on the latitude, cloud cover and haze, season, and time of day. Solar radiation data indicate that the San Joaquin Valley ranks very well among areas in the United States for incident solar radiation (see figure III-2). Because of the effective heat storage capacity of the heat storage zone, the diurnal variation of isolation or the delivery rate of direct solar energy per unit of horizontal surface is not important. About 6 to 10 percent of the incoming solar radiation is reflected from the water surface, so about 90 to 94 percent of the incident radiation penetrates the surface.

Radiation penetration to the heat storage zone can significantly affect the feasibility of using agricultural drainage water for solar ponds. It is a function of the clarity of the water and of the wave length of the incident radiation. The infrared component, which constitutes about half of the solar energy spectrum, is absorbed in the top few centimeters of the water column. The thinner the combined thickness of the upper two zones, the larger is the flux to the heat storage zone.

The clarity or the transparency may be adversely affected by biochemical or physical processes. Ormat reports that the clarity of



a. January (units langleys/day, 1 langley/day = 2,064 W/1.m^2)



b. July

Source: The MIT Report Prepared for EPRI.

Figure III-2. The Average Solar Radiation on a Horizontal Surface at the Ground. (Source: Sellers (2)) the pond solution will depend on the clarity of the brines and the water for dilution and surface washing, their chemical composition, and suspended solids content. It depends also on the method of treatment. Windborne debris and biological growth also contribute to pond turbidity.

While the energy absorbed in the upper two zones adds heat to the pond, it is less significant than the heat absorbed in the lowermost heat storage zone. The MIT report for EPRI reports that transparency is desirable in the upper zones, but absorption is desirable in the heat storage zone, so poor transparency in that zone is supposedly good, especially for thin heat storage zones. However, Ormat asserts that: "Maximal transparency of the pond solution is of prime importance." Ormat illustrated the importance of the significant effect of turbidity on overall solar pond system efficiencies (table III-6). Water in Israeli solar ponds was reported to be between Types 2 and 3.

Table III-6. Comparison of solar pond system efficiency with varying solar radiation penetration

OCEAN WATER Sample No.	RADIATION REACHING 1.0 m (3.3 ft.)(%)	MEAN EFFECIENCY OF THE SPPP* (with ideal Carnot Engine)
2	39	3.1
3	32	2.2
4	22.5	1.5

*Solar Pond Power Plant

Because water and brine transparencies are so critical to the efficacy of solar ponds, the effect of using agricultural drainage water on water and brine transparency is a critical uncertainty. Chemical composition of drainage water from the valley will be widely variable and contain salts of low solubility. The Engineering and Research (E&R) Center of the USBR reports that the most important technical considerations regarding solar pond brines relate to the solubility-temperature relationship of the salts in the brine and solution transparency (USBR, 1982). Material listed that can degrade clarity included precipitated salts, turbidity from disturbed bottom sediments and windblown material, microbial growth, organic matter, and certain transition metal ions.

Drainage waters in the valley have been observed to be relatively high in calcium and sulfate as well as other constituents. Calcium sulfate ($CaSO_4$) is a salt of relatively low solubility that reaches saturation when the drainage water is concentrated and precipitates from solution; its solubility is both low and inversely proportional to temperature, causing additional $CaSO_4$ to precipitate as the solar pond heats to its operating temperature. If this precipitation were to occur in either of the two zones overlying the heat storage zone it could affect transparency and reduce pond thermal efficiency. However, the $CaSO_4$ precipitate is dense and may settle. According to DWR solar pond researchers at Los Banos, the low solubility salts make up a minor part of the drainage solution. Precipitates in DWR ponds have been reported to sink to the bottom relatively quickly.

It is reported that $CaSO_4$ can also potentially form a scale on the heat exchange surfaces. Accordingly, the efficacy of solar ponds should be tested using drainage water brines to determine the nature and extent of problems, solar radiation penetration in the brine, and the heat exchange efficiency and maintenance. There are researchers, however, who do not expect this $CaSO_4$ scaling problem. They believe the brine solution would be cooling as it goes through the heat exchange loop and the $CaSO_4$ would therefore become more soluble.

Diffusion of heat from the heat storage zone to the nonconvecting gradient zone thence to the upper convecting zone and the atmosphere accounts for much of the system heat loss. The flux depends on the temperature gradient in the gradient zone and the thermal conductivity of water. The temperature gradient, in turn, depends on the thickness of the gradient zone, the temperature of the overlying convecting and the underlying heat storage zones, and the distribution of radiation absorbed in the gradient zone.

To sustain an effective solar pond the salinity gradient must be maintained against loss by diffusion of salts from the deeper, denser zones to the upper zones. This is done by low velocity injection of highly saline water into the pond from below and by flushing the surface zone with low salinity water. Figures III-3 and III-4 illustrate how agricultural drainage water and solar ponds might be conjunctively managed. Figure III-3 shows a system wherein brine makeup is supplied by evaporated drainage water, while figure III-4 shows desalination coupled system wherein brine makeup is supplied from desalination brine reject.

Heat loss to the ground occur through conduction to the soil and by convection or seepage from unlined ponds. Conductive loss can be

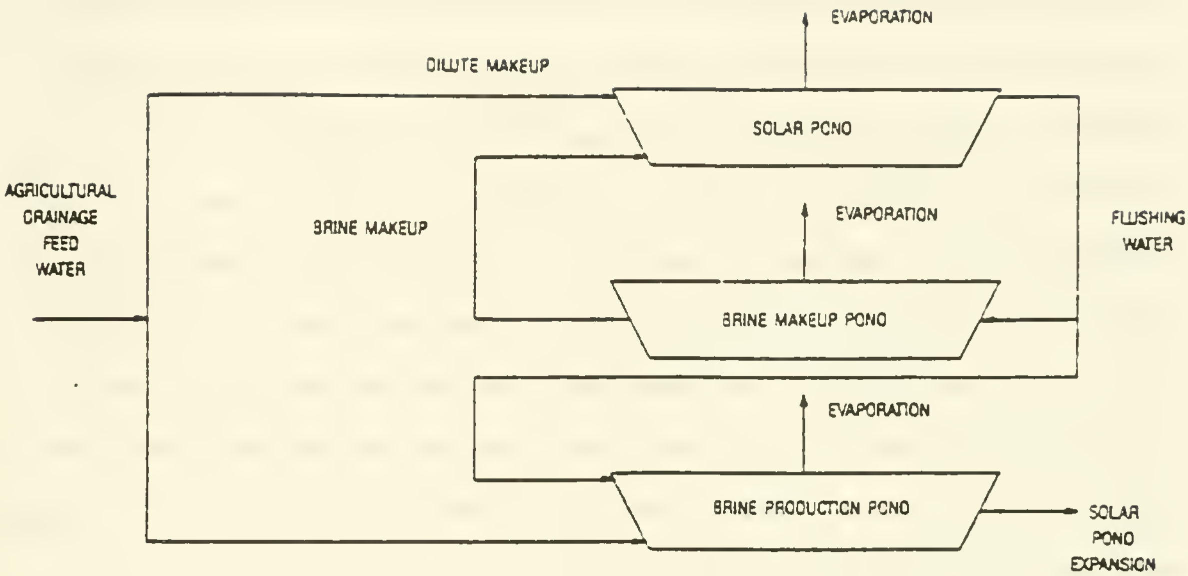


Figure III-3. Brine concentration by evaporation.

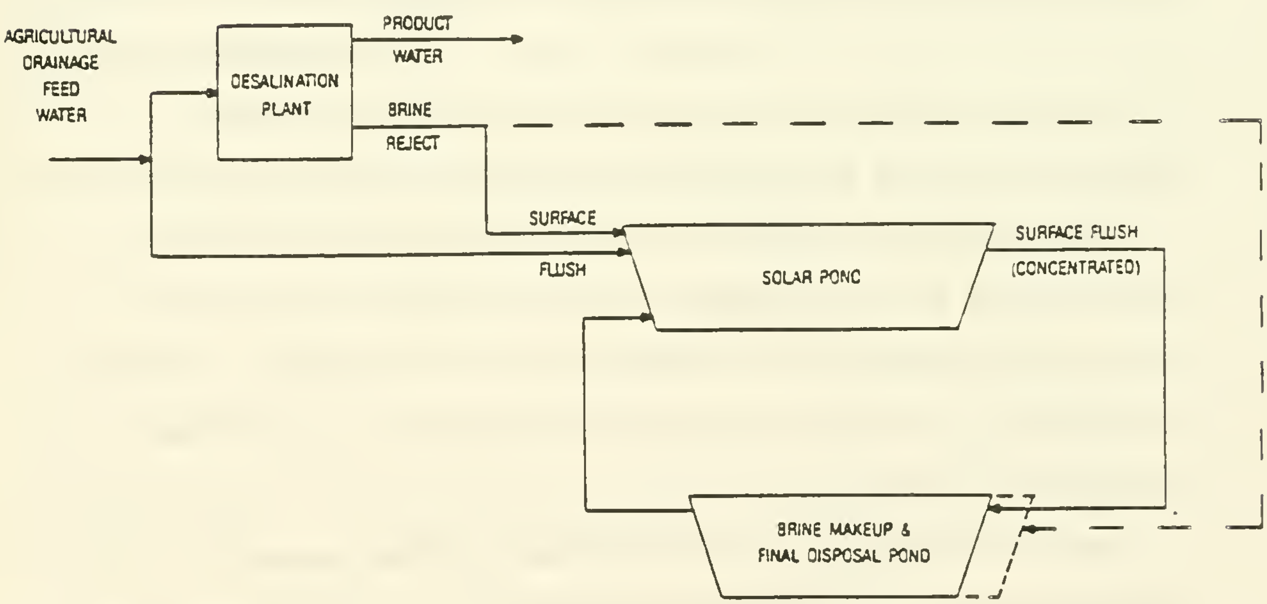


Figure III-4. Solar-pond-coupled desalination system.

significant. It depends on specific site conditions--the thermal conductivity of the soil (moist soil, for instance, has a higher thermal conductivity than dry soil), the depth to water table, and ground-water movement. Seepage loss can therefore affect both convective and conductive heat losses. At DWR's Los Banos site, shallow, low permeability soil overlies an essentially impermeable clay layer. In this setting, DWR is finding very little conductive heat loss to "moving water," although there is the unavoidable conductive loss, which is decreasing with pond age. In fact, there appears to be thermal storage down to a meter or so. Similar subsurface conditions will not be uncommon in the west side of the valley.

However, seepage loss limits will probably be more rigidly dictated by water quality control regulations than by thermal efficiency needs. With the heat storage brine concentrated to TDS levels of 150,000 to 250,000 p/m, selenium and possibly other trace element contaminants in untreated drainage water concentrated about 20 to 40 times would exceed hazardous waste limits and could necessitate costly Class I pond construction for both solar ponds and evaporative makeup water ponds.

Energy extraction is reported to be accomplished by two methods. One is to place the heat exchangers in the heat storage zone, while the other, the more frequently mentioned method, is to extract hot brine from the pond, pass it through an external heat exchange, and return the cooled brine to the pond.

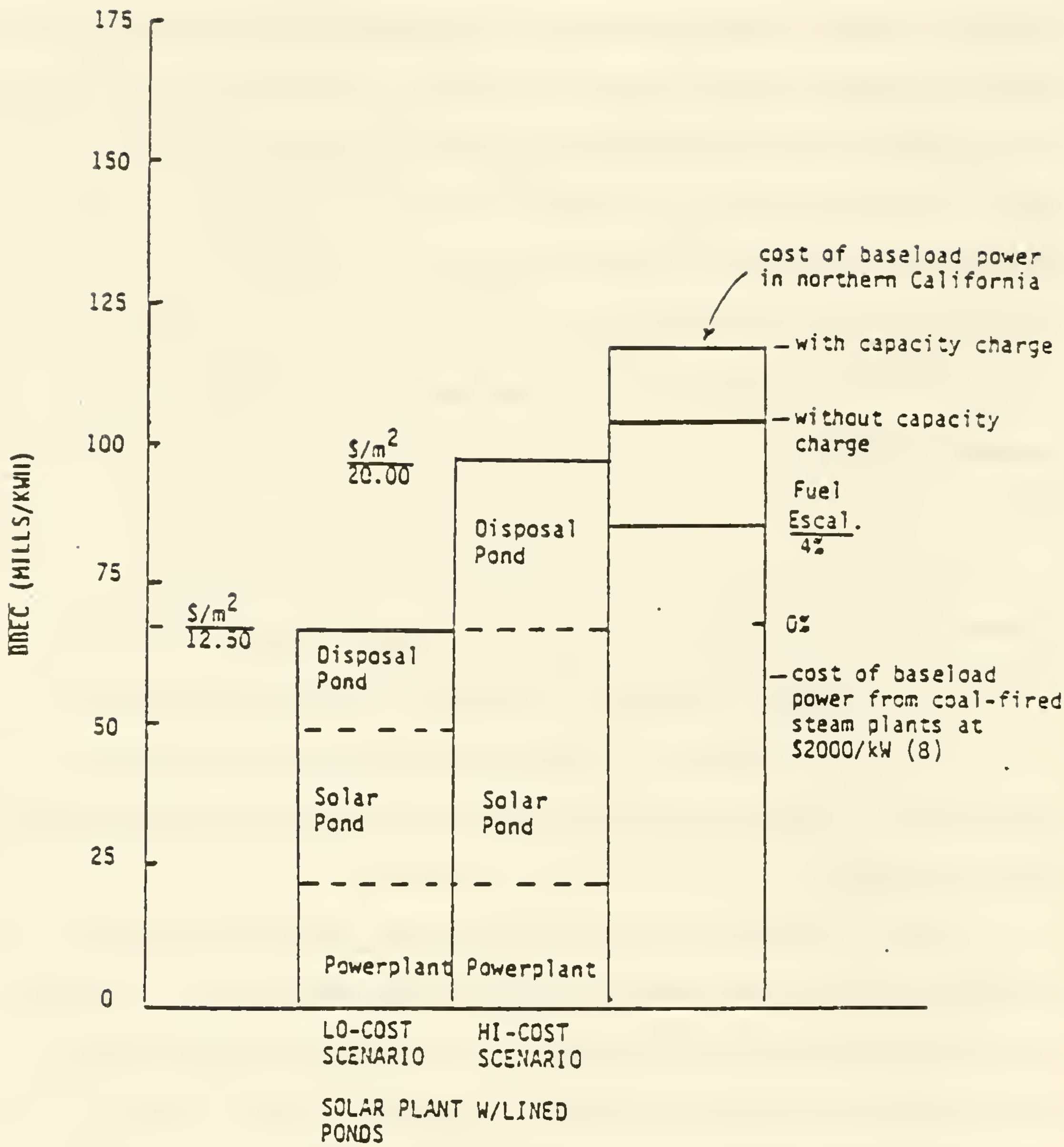
There is uncertainty as to the large-scale performance and concomitant cost of heat exchange and power generating facilities. The thermal energy conversion will operate with a temperature difference of only about 40-70 °C (72-126 °F) between the heated brine in the heat storage zone and the cooling water. Suitable conversion devices capable of operating with these relatively small temperature differences must be used. According to the EPRI report, the cost of the powerplant mainly depends on the size and the cost of the heat exchangers, which, in turn, depend on the overall heat transfer coefficients (including fouling) for evaporation and condensation and on the density of the vapor at the condenser conditions.

Costs

Solar energy ponds have considerable merit in that they offer possibilities of conserving conventional energy resources while mitigating agricultural drainage problems, but cost remains a key consideration and therein lies a major unknown in the large-scale implementation of solar pond technology; wide ranging solar pond energy costs are reported.

In a USBR E&R Center study of solar ponds at Los Banos, it was estimated that the levelized bus bar energy cost for baseload operation of the N^{th} 50-MW powerplant would amount to about 100 mills/kWh (1982 costs)--lower than the projected cost of baseload power in northern California (see figure III-5) (USBR, 1986). This estimate was based on the "hi-cost" scenario of using lined ponds, brine from an RO coupled treatment plant, 7-7/8 percent Federal discount rate, a baseload plant factor of 70 percent, and plat service life of 30 years.

By contrast, MIT in its report to EPRI estimated that the levelized bus bar cost of energy for a gross 50-MW (40-MW net) solar pond



Source: USBR preliminary estimates for performance and cost of solar ponds at Los Banos - San Luis Drain - Central Valley Project, August 1983.

Figure III-5. Levelized bus bar energy costs for baseload operation (Mth 50-MW plant).

installation at Salton Sea would amount to about 353 mills/kWH (1983 costs). This estimate was based on dense brine being available with no need for evaporation ponds, lined solar ponds, and a plant capacity factor of 56 percent.

There are many differences that would account for the difference in these cost estimates. However, the wide difference in the estimates (about three and a half fold) point out that there are major uncertainties in predicting solar pond energy recovery costs. In these cases, one of the items leading to the large cost differences is the powerplant cost. The USBR E&R Center estimate was based on powerplant costs of $600/kW, while the MIT estimate was based on $2,590/kW, exclusive of contingency.

By contrast, Ormat reported for its Salton Sea proposal that the power generating cost of the first 5-MW phase and the second 5-MW phase would be $8,100,000 and $6,680,000, respectively. These include the cost of plant equipment: construction materials: construction and installation; engineering and design; and management, supervision and administration. The plant cost evidently decreases with increasing capacity. For the first 10 MW, it was estimated to cost about $1,478/kW in this case.

Another major cost affecting unknown is the earlier mentioned possibility that the solar ponds and the evaporative brine makeup and brine production ponds may need to comply with stringent Class I construction standards because of the concentration of trace element contaminants to hazardous levels. CH2M Hill, in a report for the USBR, estimated that Class II ponds would cost $20,000 per acre, whereas

Class I ponds would cost $200,000 per acre (CH2M Hill, 1986). If Class I containment is required, the resultant cost increase is very substantial; the solar and evaporation ponds would cost about $\$50/m^2$ or more. By comparison, the USBR's E&R Center based its estimate on unit costs of $\$12.50/m^2$ for solar ponds and $\$7.50/m^2$ for final disposal and brine makeup ponds. MIT estimated on the basis of solar ponds costing about $\$16.7/m^2$ (i.e., $\$5.27/m^2$ for pond construction and $\$11.4/m^2$ for lining).

However, the argument can be made that except for salt removal from the valley, the end-product residue from any in-valley drainage water collection and storage scheme will have the same constituents and should be subject to the same regulation and, therefore, costs. The cost difference between solar ponds and evaporation-storage ponds should therefore not be significant, but the solar ponds may produce significant economic benefits.

Solar ponds would not be the attractive hazard that evaporation ponds could be. They would be constructed deep with steep side walls, and, therefore, aquatic plants would not grow to attract wildlife and waterfowl. Moreover, solar ponds, as evidenced by DWR's Los Banos ponds, would practically be sterile and would be free of contaminated food chain biota.

DWR's Solar Pond Project

DWR is conducting pilot tests on a half-acre nonconvective solar pond at its Los Banos RO testsite. The experience and knowledge gained from this operation provide some insight in assessing solar ponds.

The pond system is comprised of two 0.5-acre surface area ponds abutting each other. Each pond is 12.5 feet deep and has an associated

3.5-foot-deep evaporation-holding pond of the same area. The bottoms of the solar ponds are about 4 feet below the original grade in very low permeability soils. The ponds are lined with two-ply chlorosulphonated polyethylene liners of 0.036 inch thickness. The liners are underlain with a drainage/gas vent system of perforated 4-inch pipe bedded in permeable material. Ground resistance and temperature sensors also underlie the liners.

Because of the operational delays of the RO units which were to have supplied the concentrated brine, 990 tons of salts were purchased in 1985 to make a brine similar to the concentrated natural brine--high in sodium, magnesium, chloride, and sulfate--for use in one of the ponds. DWR strove for a 32:1 concentration brine with the following major constituents and concentrations:

Sodium	78,600 mg/L
Magnesium	9,000 mg/L
Chloride	49,000 mg/L
Sulfate	126,000 mg/L
Nitrate	2,300 mg/L

The brine produced turned out to be higher in sodium and nitrate than the natural brine, but DWR does not believe that this difference was sufficient to significantly affect the simulation of natural brine performance. However, while drainage water will have a high calcium content, the above chemical composition does not indicate the addition of calcium. Accordingly, the simulation of agricultural drainage water composition may be questioned.

Brine clarification was an important part of the operation. When the brine was finally mixed in the pond, it had a strong, muddy yellow color and very poor clarity. DWR believes the magnesium chloride, which was purchased as a brine, was the primary source of problems. Powdered charcoal (eventually 880 pounds) was mixed with brine into a slurry and then added and mixed with the brine in the pond. The pond began to clarify quickly after stratification began, and by 10 days after stratification, the pond bottom was clearly visible.

Pond stratification was started on August 26, 1985, using a method of progressive injection with brine mixed in two 33,300-gallon tanks of water drawn from the city of Los Banos domestic supply. Muriatic acid was added to each batch to adjust the pH to about 4, and copper sulfate was mixed in to provide a concentration of about 5 mg/L for algae control. Figure III-6 depicts the stratification profile in terms of relative density.

Pond performance was considered acceptable in terms of attained temperature. Figure III-7 illustrates the temperature attained in the heat storage or lower zone. A temperature of 186 °F was attained after about 300 days on July 1, 1986, when heat energy extraction commenced. The heat exchange loop consisted of about 600 feet of 3-inch ID galvanized steel pipe plus 80 feet of insulated 3-inch ID CPVC pipe. The temperature drop across the loop (from the lower zone intake temperature to return temperature) was 22 °F to as high as 31 °F, depending on ambient temperature. At an approximate flow rate of 148 gal/min, the rate of heat extraction was estimated to be about 466 to 660 kilowatts thermal.

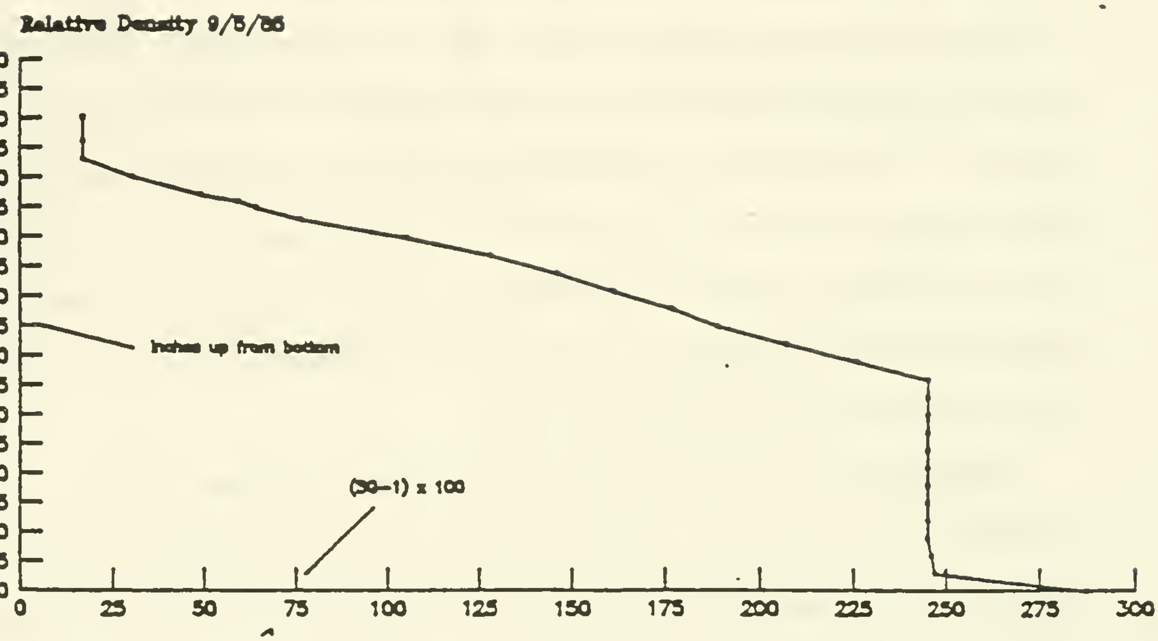


Figure III-6. Stratification Profile.

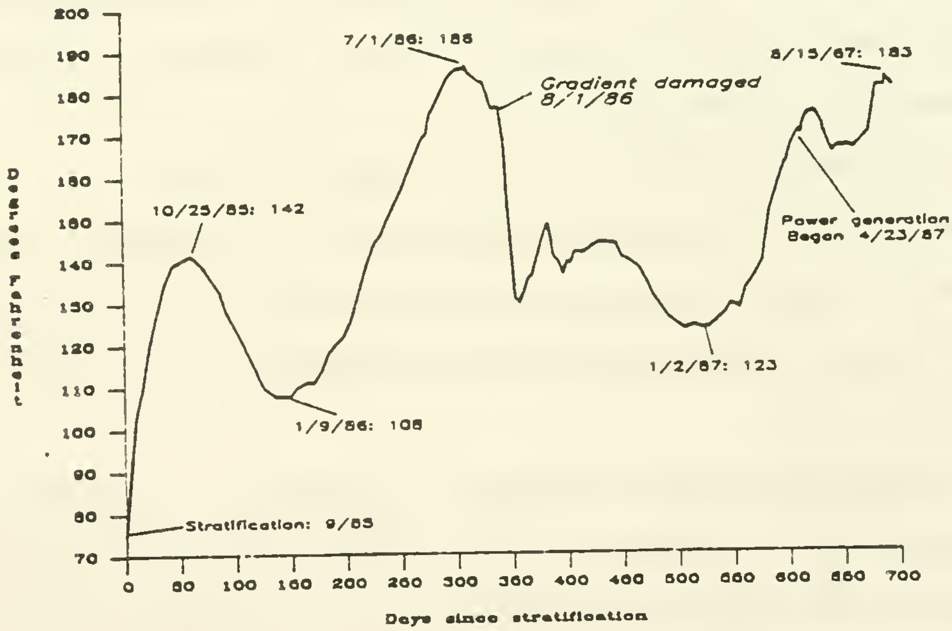


Figure III-7. Lower Zone Temperature.

DWR also operated a Rankine-cycle power generation unit for about 60 hours in the first half of 1987. The unit was reported to operate relatively trouble free after a failed lubricant flow sensor was replaced. Despite the cooling water not being available at the coolant design temperature of 65 °F (about 72 °F), power production of nearly 10 W, the design output, was achieved. A small (100 gal/min) evaporation cooling tower was installed in June 1987 and operates on a once-through cooling pass to cool the cooling water.

The state of the heat storage zone undergoes changes, and maintenance is required. In early August 1986, the gradient zone was damaged (see figure III-7) reducing its thickness from about 30 inches to 8 inches. This was due to an operational error.

Since stratification, the density of the heat storage zone brine had steadily decreased because of normal salt transport up through the less dense gradient. While the specific gravity of the lower zone averaged 1.246 shortly after stratification, the specific gravity was 1.213 about 500 days later, at the end of 1986.

The thickness of the lower zone was about 37 inches at stratification. The thickness increased with salt transport upward, but in 1986, freshwater injection into the gradient zone and brine extraction from the lower zone reduced the lower zone thickness to about 25 inches at the end of 1986.

Other DWR work includes a variety of experiments in support of the solar pond work was performed at DWR's Bryte laboratory. These included evaporating raw agricultural drainage water to concentration ratios greater than 30:1. The purpose was to determine the fate of brine constituents during evaporation and to measure evaporation rates, changes in electrical conductivity, and other factor relevant to understanding the behavior of drainage water at high concentrations. A report on this project is expected to be completed soon.

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