

Subsurface drainage evaporation ponds

Kenneth K. Tanji □ Mark E. Grismer □ Blaine R. Hanson

They offer some advantages if well designed and operated

With the scheduled closure of Kesterson Reservoir as a collection basin for saline subsurface drainage waters from farms in the Westlands Water District, attention has turned to on-farm and regional evaporation ponds as alternatives. Some such ponds are already in existence, and their use for disposal of saline drain waters is likely to escalate until a drainage system for the San Joaquin Valley as a whole becomes available.

Both short- and long-term efficacy of evaporation ponds need to be appraised. Problems of concern include possible seepage from ponds to groundwaters, the costs of pond construction and cropland taken out of production, and the potential accumulation in the ponds of toxic constituents to hazardous levels. The State Water Resources Control Board and its Regional Water Quality Control Boards, the University of California, U.S. Department of Agriculture Soil Conservation Service, and others are conducting research to find environmentally acceptable and efficient methods of disposal of unusable saline drain waters.

On-farm vs. regional evaporation ponds

On-farm evaporation ponds offer the discharger an immediate short-term solution and provide more opportunities for reuse of usable drain water than do regional ponds. However, they remove land from production, construction costs must be borne by individual growers, maintenance and monitoring may be limited, and seepage to adjacent lands and a perched water table may occur.

Regional evaporation ponds have the advantages of being built on marginal land, possibly of better design and construction, and with better maintenance and monitoring. Their disadvantages are that they offer limited potential for drain-water reuse, require an extensive collection system, and may cost more to build.

Pond size and salt accumulation

Land taken out of production for evaporation ponds may be as little as 3 percent of the land being drained, if the drainage water is reused, to as much as 33 percent with no reuse. Typical values used by consulting engineering firms are from 15 to

20 percent of the land. Numerous factors influence the size of ponds.

Annual evaporation from surfaces of water bodies along the west side of the San Joaquin Valley is about 55 inches. With an average rainfall of about 6 inches in the area, only about 49 inches of water per year can be evaporated. The evaporation rate would decrease with increasing salinity in the pond water. If one assumes inadvertent seepage from a pond at an average rate of about 11 inches per year, the total depth of water that would be disposed of through evaporation and seepage is about 60 inches per year.

We have estimated the pond surface area required for drainage from a 320-acre farm, of which 240 acres are irrigated and the remainder is in roads, canals, evaporation pond, or nonirrigated land. If 3 feet of water are applied to a crop like tomatoes and the crop uses 2.3 feet, drainage beyond the root zone would be 0.7 acre-foot per acre, assuming no surface runoff. Thus, 240 acres of irrigated land would produce 168 acre-feet per year of drain water.

In addition, assuming a subsurface flux of 0.05 inch per day from upslope irrigated lands, lateral flow across a cross-sectional area of the farm yields about 55 acre-feet. The total quantity of drain water produced is then 223 acre-feet per year for the 240 acres (0.9 acre-foot per acre of irrigated land; 0.7 acre-foot per acre for the entire 320 acres).

Allowing about 5 feet per year for evaporation and seepage, the pond surface area required to evaporate 223 acre-feet per year is about 45 acres. Adding land lost to the pond foundation, perimeter roads, and the like brings the total area required for the pond to 50 acres, or 15.6 percent of the 320-acre tract.

If the drain water collected in the pond has an electrical conductivity of 10 deci-Siemens per meter or 6,400 milligrams per liter total dissolved solids, it would contain about 8.7 tons total dissolved solids per acre-foot. The 223 acre-feet of drain water collected would contain about 1,940 tons of total dissolved solids. As the pond water is concentrated by evaporative salinization, precipitation of various

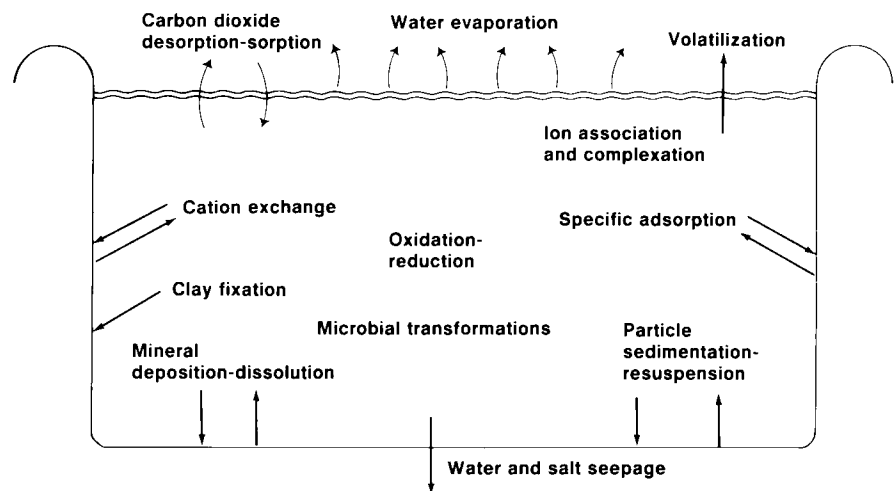


Fig. 1. Numerous physical, chemical, and biological processes influence the complex chemistry of pond water: degassing of carbon dioxide, microbial transformation of sulfate to hydrogen sulfide with subsequent volatilization, ion association and complexation, cation exchange involving replacement of exchangeable calcium from the soil by sodium from the pond water, adsorption of cadmium and fixation of potassium by soil clays, oxidation of organic carbon, reduction of nitrate to nitrogen gases, precipitation of calcite and gypsum with evaporative salinization, and sedimentation and resuspension of colloidal and larger particles.

types of minerals occurs in sequence. As brine in the evaporation pond dries up, mineral salts will be deposited, along with some brine in the void spaces between the crystallizing minerals. If the bulk density of salt crusts in the pond is about 45 pounds per cubic foot, the 1,940 tons of salt would produce a salt crust about 0.5 inch thick per year in the 45-acre pond — 86,000 cubic feet. This rate of salt accumulation would produce, in 20 years, a crust of about 10 inches weighing over 38,800 tons.

Pond water chemistry

Numerous chemical, biological, and physical reactions and processes can take place in a pond (fig. 1). The chemistry is complex and would change with salinization because of evaporation or dissolution of salt crusts with addition of fresh pond waters.

The Hardie-Eugster Model for evaporative salinization of waters (fig. 2) begins with pond water containing the major positively and negatively charged ions (cations and anions). As evaporation takes place, one of the first minerals in large quantities to settle out is calcite. After that, depending on the relative concentrations of calcium and alkalinity ($\text{CO}_3^{2-} + \text{HCO}_3^-$), either gypsum or sepiolite would precipitate, followed by other chemical changes. The resulting waters would be typical of those in, for example, Death Valley and the Carson Sink, or the world's oceans and the Salton Sea, or Owens and Pyramid Lakes.

Since the chemistry of subsurface drain waters in the west side of the San Joaquin Valley is dominated by sodium, calcium, and sulfate, along with some chloride and bicarbonate, it is expected that brine waters produced in evaporation ponds from this region would be similar to ocean water.

Tanji and Doneen in 1966 tested a chemical model on evaporative salinization of bicarbonate waters and soil solutions and predicted the pH and precipitation of calcite quantitatively. More recently, Greg Smith, a graduate student in water science at UC Davis, combined the 1966 Tanji-Doneen model for calcite precipitation with the 1969 Tanji model for solubility of gypsum. Smith's computer-calculated data for a Panoche Drain water sample undergoing two- and ten-fold concentration in volume from evaporation show that substantial quantities of calcite and gypsum are precipitated out (table 1).

After calcite and gypsum have settled out of the pond water, the sequence of mineral precipitation in brines becomes complex. Other carbonate minerals of sodium may precipitate, such as nahcolite, soda, and trona, followed by hydrated sul-

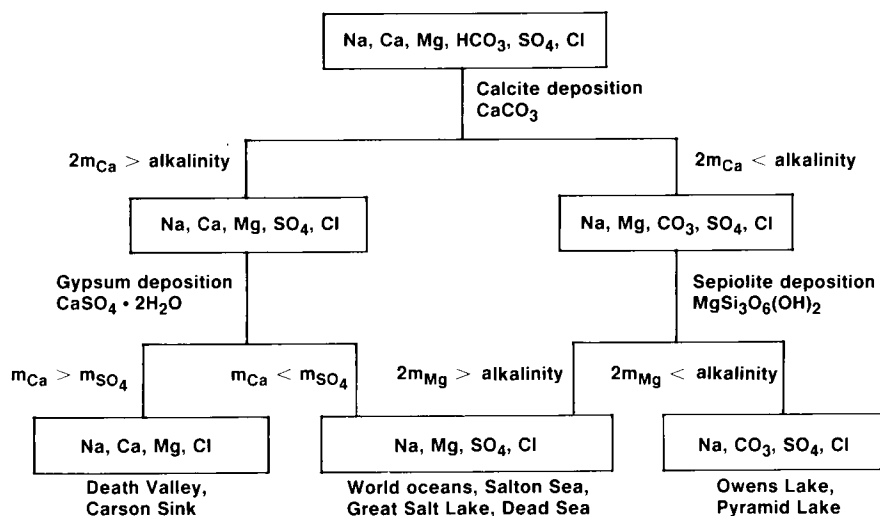


Fig. 2. The Hardie-Eugster Model shows the probable pathways of evaporative salinization, precipitation of mineral salts, and typical brines. Calcite is one of the first minerals to settle out in large quantity, followed by either gypsum or sepiolite, depending on the concentration of calcium and alkalinity.

fate minerals of magnesium such as epsomite, hexahydrate, and starkeyite, sulfate minerals of sodium such as mirabilite and thenardite, double sulfate minerals of sodium and magnesium such as loewite, bloedite, and konyaite as well as halite (NaCl). All of these evaporite minerals have been identified in salt crusts in dry creek beds in the Upper Colorado River Basin during intensive studies by Tanji and others. The Mancos Shale, a primary source of dissolved mineral salts in this basin, is geochemically similar to the Moreno Formation in the California Coast Range, a source of salts and trace elements that may find their way into evaporation ponds.

Following evaporative salinization of drain waters in ponds, the deposited salt crusts would be subject to dilution-dissolution, that is, mineral dissolution from the introduction of fresh subsurface drain waters into the ponds. The sequence of mineral dissolution is just the opposite of evaporative salinization. The first minerals to dissolve were the last to precipitate out (chloride and sulfate minerals), and

the last minerals to dissolve were the first to precipitate out (silicates, carbonates, etc.).

This cycle of evaporative salinization and dilution-dissolution regulates the chemistry and salinity of pond waters. It also affects hydraulic conductivities of pond bed materials, and influences any considerations of drain water reuse by blending with fresh water or direct reuse.

Pond design

Current design criteria for saline-water evaporation ponds rely heavily on U.S. Soil Conservation Service specifications. The pond must be large enough to satisfy needs of the land area being drained, the volume of subsurface drain water collected, and the rate of evaporation for that region. Ponds must have: a minimum embankment top-width of 14 feet; freeboard of 1.6 feet or equal to the maximum wave runup; an inside slope of 6:1 and outside slope of 2:1; and a foundation stripped of all vegetation. Seepage through the embankment and bed material must be controlled, and there must be a subsurface

TABLE 1. Precipitation of calcite (CaCO_3) and gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) in Panoche Drain Water undergoing evaporative concentration

Panoche Drain Water	Evaporative concentration factor		
	1X	2X	10X
	----- millimoles/liter -----		
Calcium (Ca^{2+})	20.0	5.7	1.6
Sodium (Na^+)	24.5	49.0	245.0
Magnesium (Mg^{2+})	13.0	26.0	130.0
Chloride (Cl^-)	15.6	31.3	156.0
Sulfate (SO_4^{2-})	43.0	54.0	245.0
Bicarbonate (HCO_3^-)	3.0	1.4	2.8
Carbonate (CO_3^{2-})	0	0.04	0.2
pH	8.3	8.4	8.6
Calcite precipitation	—	2.3	13.6
Gypsum precipitation	—	27.1	180.0

Source: Greg Smith, Department of Land, Air, and Water Resources, University of California, Davis, 1985.



Subsurface drainage evaporation ponds, which may take more than a quarter of the land being drained out of production, have to meet rigid state standards to minimize possible adverse environmental effects. Below, drainage water is pumped from a subsurface collection system to pond surface. About 50 inches of saline water per year can be disposed of through pond evaporation. (Photos courtesy George True).

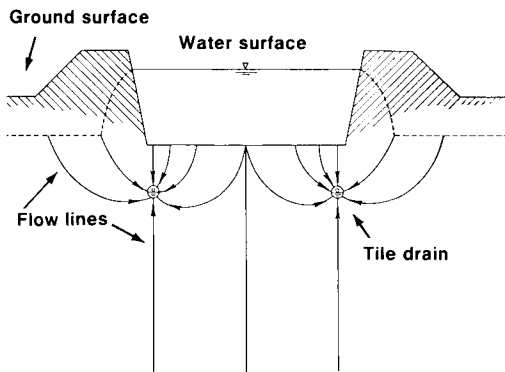


Fig. 3. Proposed evaporation pond design in which drain tiles are placed beneath the pond instead of at the perimeter. Schematic shows calculated flow lines, which would intercept seepage through bed material and recirculate it to pond surface.

drain around the perimeter of the pond. Internal dikes may be designed to construct cells within the pond and to allow transfer of water from cell to cell and deposition of salts in a progressive evaporation system.

Innovative and cost-effective improvements in pond design need to be evaluated. For instance, Mark Grismer has proposed a drainage system directly beneath the pond instead of only the perimeter (fig. 3), which would intercept nearly all seepage through the bed material and recirculate it to the pond. One advantage of this design is that the interim waiver policy requirement specifying the maximum soil-barrier hydraulic conductivity under a pond could be relaxed (it is difficult to monitor the rate of seepage under ponds). (The maximum permissible hydraulic

conductivity is about 0.01 foot per year when the pond overlies usable groundwaters or about 1 foot per year when the pond overlies unusable groundwaters.) Another advantage is that the design may be a cost-effective alternative to double-lining, if that is required. The effectiveness of double-lining ponds and pits containing hazardous substances is currently being debated.

Regulatory policy

The interim waiver policy established by the California Regional Water Quality Control Board — Central Valley Region — allows certain agricultural subsurface drain-water disposal activities without formal adoption of state waste discharge requirements. This policy specifies evaporation pond design and maintenance to minimize adverse environmental effects.

For other Central Valley areas, the Regional Water Quality Control Board issues permits for evaporation ponds on a case-by-case basis. Agricultural drain waters generally are not considered to be a hazardous waste. But, if the constituents in the subsurface drainage waters exceed the limits specified in the California Administrative Code, drain water would be subject to the more stringent regulations governing surface impoundments. These regulations require that surface impoundments be double-lined, the cost of which may be too high for irrigated agriculture.

A section of the Code does provide for exemptions from waste discharge requirements. The regional board may grant exemptions if it is found that hazardous waste constituents will not migrate from the surface holding area and pose a significant potential of polluting groundwater basins or surface waters.

Summary

In the absence of a master drainage system for the San Joaquin Valley and the increasing constraints placed on discharge of saline irrigation return flows, the construction of on-farm and regional evaporation ponds is one of the options for disposal of saline subsurface drain waters. It is essential that evaporation ponds be designed and operated in an environmentally acceptable and efficient manner. Pond design must provide effective containment of salt and toxic constituents, and information is needed on pond water chemistry and mineralogy so that potential reuse of drain waters and the extent of chemical and biological immobilization of toxic constituents can be assessed.

Kenneth K. Tanji is Professor of Water Science, Mark E. Grismer is Assistant Professor of Agricultural Engineering and Water Science, and Blaine R. Hanson is Extension Irrigation and Drainage Specialist, Department of Land, Air and Water Resources, University of California, Davis.