NOTATION

A = yield threshold soil salinity above which yields decline
B = percentage yield loss per increase in salinity in excess of A
EC = electrical conductivity
ET = evapotranspiration
HC = hydraulic conductivity
IR = infiltration rate
LF = leaching fraction
LR = leaching requirement
RY = relative yield
SAR = sodium adsorption ratio

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CHAPTER 23

DRAINAGE WATER TREATMENT AND DISPOSAL OPTIONS

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INTRODUCTION

Treating and disposing of subsurface drainage water from irrigated agricultural lands presents unique technical challenges. Complex chemical characteristics of drainage water further complicate treatment options. Treatment of drainage water has long been considered one of the last-resort drainage management options due to its high costs. However, this perspective is changing due to the increasing demand for fresh water caused, in part, by increases in population, industrialization, and agricultural activities in addition to environmental restrictions imposed on state and federal water supply and distribution systems. Additionally, treatment system costs and energy requirements for the most promising treatment technologies have decreased over the last two decades.

For subsurface drainage water containing extremely high levels of salinity, selenium (Se), molybdenum (Mo), and other trace elements, the treatment objectives are as follows:

1. Meet agricultural water management goals.
2. Reduce salt and toxic constituents below hazardous levels.
3. Meet water quality objectives in surface waters.
4. Reduce trace elements below hazardous concentrations for wildlife.

This chapter will cover the treatment and disposal of subsurface drainage from irrigated lands. The current status of the technology of drainage water treatment and disposal options will be reviewed, and current research on treatment technology will be discussed.

TREATMENT OF AGRICULTURAL DRAINAGE WATER

Treatment Technology Needs

Substantial technological advancements in treatment of agricultural drainage water have been made since the first edition of this manual was published in 1990. Long before the Se problem emerged, drainage water reclamation was being seriously considered at the tubular RO plant in Firebaugh in the early 1970s. The motivation for construction of this experimental facility arose from two fundamental issues relevant to agricultural drainage. Of primary concern was augmentation of irrigation water supplies by drainage water desalinization. This was indeed a challenging application of the emerging technology under development at the time. A second goal was directed toward reduction of drainage water volume. Management of salt accumulation could then be enhanced by such waste minimization technology.

The management of drainage from irrigated lands is an important part of any agricultural development plan. History has recorded many instances of fertile lands subsequently made barren by salt (FAO 1973). More recently, traditional approaches to sustaining and optimizing agricultural productivity by salinity control have been complicated by the need to protect public health and the environment from any potential effects of residual fertilizers, pesticides, herbicides, fungicides, and trace toxic substances in drainage from irrigated lands. The environmental impacts of Se and other trace elements in agricultural drainage water was not fully recognized until about 1985, when high levels of Se were identified in biota in Kesterson Reservoir in the San Joaquin River basin, California. The alarm was raised when dead and deformed birds were found at the reservoir (Ohlendorf 1984). Consequently, the need to develop a technology that will adequately control and manage drainage from irrigated lands was recognized.

The treatment of agricultural drainage water effluent presents a challenge due to the complex chemical characteristics of most drainage waters (Lee 1994). One of the major challenges for treating drainage water in the San Joaquin Valley is that typical drainage water is saturated with calcium sulfate ($CaSO_4$). Earlier attempts to use membrane technology to desalinate agricultural drainage water have failed entirely or have been limited to low recovery (<50%) because of $CaSO_4$ fouling problems. Table 23-1 presents a summary of analyses for drainage water taken from three locations within the western San Joaquin Valley. These waters represent water sources utilized by the various treatment demonstration projects described in this chapter.

A variety of processes can be used to treat seawater, brackish, or waste waters to meet industrial, urban, and drinking water standards. Many of

TABLE 23-1. Drainage Water Quality Analysis/Various Agricultural Drainage Sumps Locations, Western San Joaquin Valley, California

Parameter	Buena Vista mg/l	Westlands mg/l	Northerly Area mg/l
Sodium	1400	2200	600
Potassium	4	7	9
Calcium	630	560	290
Magnesium	100	270	93
Total Hardness	2000	2500	1100
Chloride	2400	1600	550
Carbonate	1	4	4
Bicarbonate	320	200	170
Sulfate	1350	4700	1500
Nitrate (as N)	19	48	14
Boron	**5**	**15**	**9**
Selenium	**0.04**	**0.23**	**0.07**
Silica	36	37	22
TDS	**6000**	**9900**	**3300**

Source: California Department of Water Resources.

these processes could potentially be applied to the treatment of agricultural drainage water. Treatment processes for drainage water can be categorized into those that reduce the total salinity of the drainage water and those that remove specific trace elements. Most desalinization processes also remove trace elements, but their costs are often prohibitive. Less costly methods for the removal of trace elements are being developed. Methods for the removal of trace elements can be biological, physical, or chemical.

In an earlier review, Lee (1994) described available drainage water treatment and disposal technologies. The San Joaquin Valley Drainage Implementation Plan (SJVDIP 1999b) also reviewed treatment technologies for removing Se from agricultural drainage water. The next section summarizes their findings.

Desalinization

The numerous desalinization processes include ion exchange, thermal distillation, electrodialysis, and reverse osmosis (RO). Of these processes, RO is considered to be the most promising for the treatment of agricultural drainage water, mainly due to its comparatively low cost (Tanji and Neeltje 2002). Thermal distillation may be an attractive option if a source of low-cost heat is available, such as waste heat from a power plant facility.

Reverse osmosis is a process capable of removing different contaminants, including dissolved salts and organics. In RO, a semipermeable membrane separates water from dissolved salts and other suspended solids. Pressure is applied to the feed-water, forcing the water through the membrane and leaving behind salts and suspended materials in a brine stream. The energy consumption of the process depends on the salt concentration of the feed-water and the salt concentration of the effluent. Depending on the quality of the water to be treated, pretreatment might be crucial to preventing fouling of the membrane. Pretreatment steps could include multiple filtration, addition of antiscalants, pH corrections, and lime treatment, along with ion exchange. Following is a brief description of the most important desalination efforts performed with subsurface agricultural drainage water.

Firebaugh Water District

The first attempt at drainage water reclamation began in 1971 in Firebaugh, California (McCutchan et al. 1976). A small membrane desalinization pilot plant utilizing hand-cast cellulose acetate tubular membranes was designed and built at the UCLA School of Engineering and Applied Science. The plant remained on-line for approximately 3 years and was operated jointly by UCLA and the California Department of Water Resources (CDWR). Water quality at this site varied in TDS levels between 2,000 and 7,000 mg/L, and calcium and sulfate ion concentrations were near saturation with respect to gypsum. A limiting issue in processing this water was the potential deposition of scale-forming calcium sulfate (gypsum) on membrane surfaces. Scale control was investigated first by treatment with sodium hexametaphosphate, followed by installation of a cation exchange system for calcium removal. Product water recovery based on chemical and ion-exchange treatment was reported at 60% and 90%, respectively.

Los Baños (California) Demonstration Desalting Facility

As a continuation of the reclamation program started in Firebaugh, between 1982 and 1985 the CDWR conducted a pilot-plant-scale demonstration of RO of saline drainage water using cellulose acetate membranes. Throughout the studies, bacterial and chemical fouling of the membrane were major problems. As a pretreatment, the drainage water was treated with potash alum ($KAl(SO_4)_2 \cdot 12H_2O$) and passed through a solids-reactor clarifier; it was then chlorinated, filtered, and processed through an ion-exchange (IX) system using a strong-acid resin for calcium removal before being desalted by RO. The highly concentrated Na RO reject was used to regenerate the IX resin. The spent IX regenerant was concentrated further for use in the solar pond operations at the facility. In spite of this level of pretreatment, the membranes tended to foul due to the precipitation of gypsum and calcite.

The permeate is the product (desalted) water and the concentrate is the brine water. The results show that TDS can be desalted from 9,800 to 640 ppm, boron (B) from 14.5 to 7.6 ppm, and Se from 325 to 3 ppb in a three-stage RO system. The efficiency of removal declines with each stage. The drainage water was saturated with respect to calcite and gypsum.

Other desalting processes tested at the facility included electrodialysis reversal and vapor-compression evaporation. These processes also experienced scaling issues. In addition, a vertical fluted-tube foamy evaporator (VTFE) was tested in solar pond operations that used the pond's hot brine heat as the driving force for evaporation. Heat transfer rates ranged from 500 to 800 Btu/hr-ft^2-YF during the course of testing in the VTFE mode (CDWR 1986).

Buena Vista Water Storage District

From 2000 through 2002, state, local, and private entities collaborated in a project to investigate treatment costs, identify and resolve drainage water treatment issues, and demonstrate the ability of commercially available RO membranes to treat agricultural drainage at the Buena Vista Water Storage District in Kern County, California. In 2000 a 20-gpm RO unit was operated to treat tile-drain water. However, the drainage feedwater was switched to shallow groundwater because of the lack of a sufficient volume of drainage water due to the reduction of irrigation allocations during 2001 and 2002. Raw tile-drainage TDS concentrations averaged 7,010 mg/L, while the shallow groundwater, pumped from two wells, 60 and 80 ft deep, averaged 3,980 mg/L.

The overall TDS removal was 97% throughout the operation of the project. Treatment costs were estimated to range from $651/acre-ft for a 1 million gallon per day (MGD) plant to $459/acre-ft for a 10 MGD plant, irrespective of costs to collect and transport saline water to the plant or the cost to dispose of the concentrated reject brine. A final report prepared by Boyle Engineering Corp. of Bakersfield, California was published in December 2003 (Boyle Engineering et al. 2003). Figure 23-1 outlines the process flow diagram used for this desalination project.

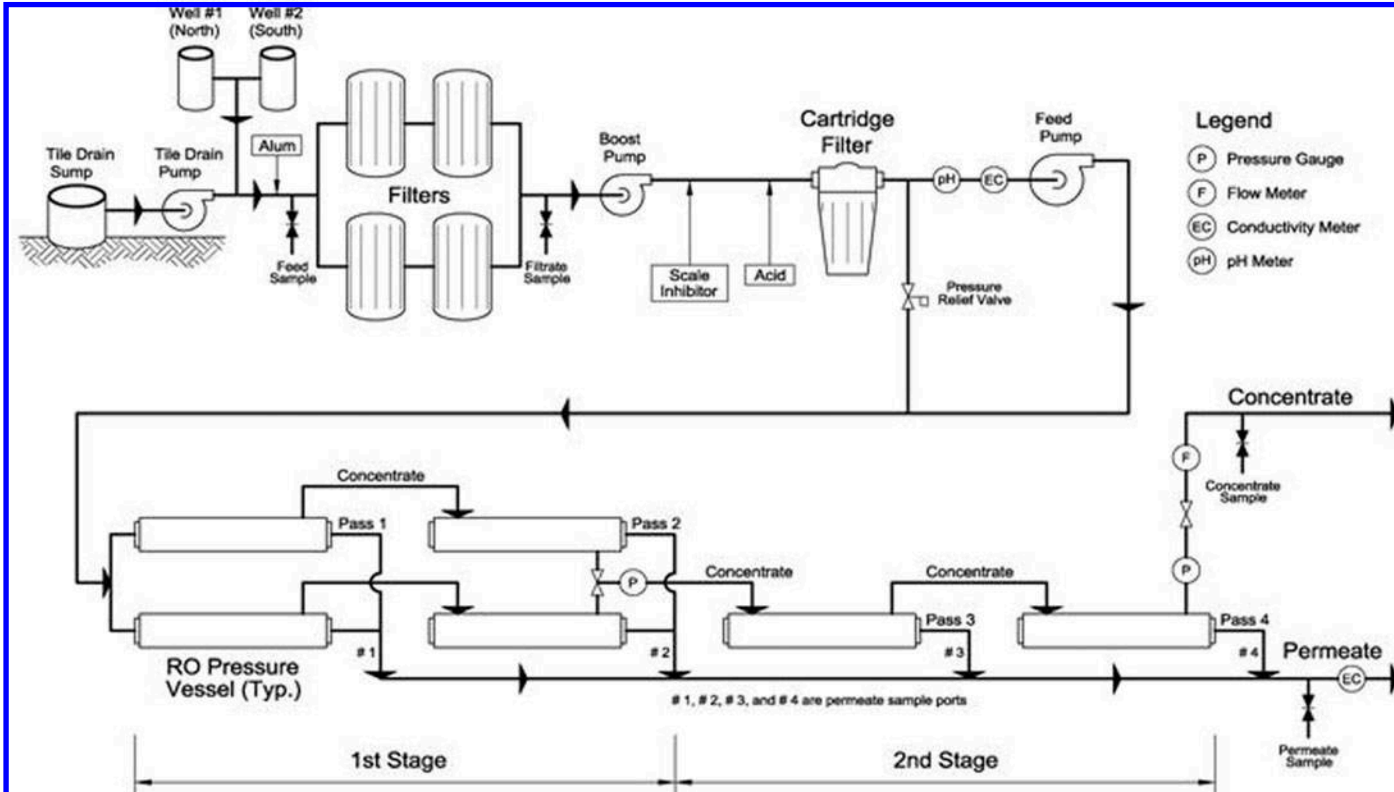

FIGURE 23-1. Process flow diagram for Buena Vista Water Storage District demonstration desalting. From Boyle Engineering Corp. (2003).

Panoche Drainage District

Through the Energy Innovation Small Grant (EISG) program, the California Energy Commission sponsored a pilot demonstration project to demonstrate technical feasibility of a conceptual RO process. The patented double-pass preferential-precipitation reverse osmosis (DP^{3}RO™) process is a two-pass membrane process that induces preferential precipitation of calcium sulfate in the first pass. The first pass employs tubular membranes. Treated water costs, as stated in the 2003 final report (Enzweiler and Strasser 2003), are estimated to range between $564/acre-ft and $801/acre-ft for drainage that ranged from 3,625 mg/L to 10,500 mg/L TDS concentration.

The DP^{3}RO™ process was periodically operated at Panoche Drainage District's (PDD) DP25 test site from April 2005 through April 2006 (USBR 2008a). Continuous testing did not extend more than a week at a time due to equipment and programming constraints. In addition, due to the location of Panoche's test site, remotely monitoring and operating the system was difficult. Despite many problems, the system was operable for a total of 30 days, of which 23 were trouble-free. During this trouble-free period, the system operated with a greater than 80% recovery rate.

Westlands Water District

From 2003 through 2005, state, federal, and local entities investigated RO drainage water treatment at Red Rock Ranch (RRR) near Five Points, California, and the Panoche Drainage District (PDD) near Firebaugh, California. The 2003 study at RRR consisted of the operation of a pilot-scale membrane unit that tested RO and nanofiltration membranes to evaluate cost and performance in the treatment of agricultural drainage water. In 2004 the pilot membrane test unit was moved to the DP25 test site in PDD. To further develop technical feasibility and costs, testing at PDD took place during two phases; Phase I occurred from August 2004 to December 2004, and Phase II occurred from August 2005 to December 2005.

After the initial treatment process, the concentrate reject brine stream was further treated to remove Se and nitrates by a new biotreatment technology using bioreactors. Testing indicated that operating the RO unit at a recovery greater than 50% was not practical when treating the concentrate reject brine for Se and other constituents due to the propensity of the reject to precipitate calcium sulfate. This condition was shown by operating the RO unit at a recovery of 64% using a single antiscalant at the beginning of Phase II from August 17 to October 13, 2005. Reducing the recovery to 55% along with the changing to antiscalant to a mixture of two antiscalants from October 26 to December 12, 2005, did not alleviate the condition. These projects provided data to develop full-scale reverse osmosis treatment plant design parameters and cost estimates (Table 23-2) in the evaluation of drainage solution alternatives for the San Luis Unit of the Central Valley Project in California (USBR 2008b).

Desalination Studies at the University of California–Los Angeles

Investigations at the Polymer and Separations Research Laboratory at the University of California–Los Angeles continued to develop the understanding of the principles that lead to scale formation resulting in membrane fouling. A series of rigorous laboratory tests were performed in problematic areas associated with membrane desalting, using simulated or actual drainage water. The work provided a fundamental understanding of the process of surface mineral scale formation and developed diagnostic tools and protocols for assessing the effectiveness of antiscalants and the propensity for membrane scaling (Rahardianto et al. 2006). Tests were performed to compare and rank antiscalant effectiveness and showed that the method was useful for assessing the impact of particle matter in the induction of mineral salt crystallization. The work prompted a detailed study on drainage water collected from five sumps of varying water quality located throughout the San Joaquin Valley. The drainage water was first analyzed for constituents; then potential biofouling assays were performed on field samples using two reference membranes. Prefiltration needs based on turbidity and silt-density index analyses were evaluated, mineral salt-scaling thresholds were determined, and mineral

TABLE 23-2 Full-scale Reverse Osmosis Treatment Plant Design Parameters and Cost Estimates for the San Luis Drainage Feature Preferred Alternative

Parameter	North Westlands	Central Westlands	South Westlands	Panache (Northerly Area)
Nominal feed flow, gpm	570	1,690	1,070	11,000
Influent TDS (mg/L)	15,000	11,000	14,000	6,100
Product recovery	50%	50%	50%	generally 50%
Number of vessels	19	38	24	308
Membrane elements	114	228	144	1,848
Power (Kw-hr/year)	959,000	3,230,000	2,110,000	11,000,000
Building area (sq. ft.)	5,865	8,383	7,575	18,560
Construction cost (2006)	$8,000,000	$12,500,000	$10,000,000	$40,000,000

Source: USBR (2008a).