Beneficial and Nontraditional Uses of Concentrate

WateReuse
Foundation

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About the WateReuse Foundation

The mission of the WateReuse Foundation is to conduct and promote applied research on the reclamation, recycling, reuse, and desalination of water. The Foundation's research advances the science of water reuse and supports communities across the United States and abroad in their efforts to create new sources of high quality water through reclamation, recycling, reuse, and desalination while protecting public health and the environment.

The Foundation sponsors research on all aspects of water reuse, including emerging chemical contaminants, microbiological agents, treatment technologies, salinity management and desalination, public perception and acceptance, economics, and marketing. The Foundation's research informs the public of the safety of reclaimed water and provides water professionals with the tools and knowledge to meet their commitment of increasing reliability and quality.

The Foundation's funding partners include the U.S. Bureau of Reclamation, the California State Water Resources Control Board, the Southwest Florida Water Management District, and the California Department of Water Resources. Funding is also provided by the Foundation's Subscribers, water and wastewater agencies, and other interested organizations. The Foundation also conducts research in cooperation with two water research coalitions – the Global Water Research Coalition and the Joint Water Reuse & Desalination Task Force.

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FOREWORD

The WateReuse Foundation, a nonprofit corporation, sponsors research that advances the science of water reclamation, recycling, reuse, and desalination. The Foundation funds projects that meet the water reuse and desalination research needs of water and wastewater agencies and the public. The goal of the Foundation's research is to ensure that water reuse and desalination projects provide high-quality water, protect public health, and improve the environment.

A Research Plan guides the Foundation's research program. Under the plan, a research agenda of high-priority topics is maintained. The agenda is developed in cooperation with the water reuse and desalination communities, including water professionals, academics, and Foundation Subscribers. The Foundation's research focuses on a broad range of water reuse research topics including the following:

- Defining and addressing emerging contaminants;
- Public perceptions of the benefits and risks of water reuse;
- Management practices related to indirect potable reuse;
- Groundwater recharge and aquifer storage and recovery;
- Evaluating methods for managing salinity and desalination; and
- Economics and marketing of water reuse.

The Research Plan outlines the role of the Foundation's Research Advisory Committee (RAC), Project Advisory Committees (PACs), and Foundation staff. The RAC sets priorities, recommends projects for funding, and provides advice and recommendations on the Foundation's research agenda and other related efforts. PACs are convened for each project and provide technical review and oversight. The Foundation's RAC and PACs consist of experts in their fields and provide the Foundation with an independent review, which ensures the credibility of the Foundation's research results. The Foundation's Project Managers facilitate the efforts of the RAC and PACs and provide overall management of projects.

The Foundation's primary funding partners are the U.S. Bureau of Reclamation, the California State Water Resources Control Board, the Southwest Florida Water Management District, the California Department of Water Resources, Foundation Subscribers, water and wastewater agencies, and other interested organizations. The Foundation leverages its financial and intellectual capital through these partnerships and funding relationships. The Foundation is also a member of two water research coalitions: the Global Water Research Coalition and the Joint Water Reuse & Desalination Task Force (JWR&DTF).

This publication is the result of a study sponsored by the Foundation and the JWR&DTF, and is intended to communicate the results of this research project. The JWR&DTF is a coalition of national research organizations and federal government partners dedicated to sharing the results of research, engaging in organized planning, and collaborating on research projects focused on water reclamation, reuse, recycling, salinity management, and desalination issues.

The goals of this project were to provide a comprehensive review and evaluation of the full range of potential beneficial and nontraditional uses of concentrate and to assess the feasibility of implementation, economic considerations, and environmental safety.

Ronald E. Young President WateReuse Foundation	G. Wade Miller Executive Director WateReuse Foundation

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EXECUTIVE SUMMARY

Global demand for water is growing rapidly, and the options for additional sources of supply are limited. Conservation and water use efficiency are crucial components of securing adequate water supplies but are not likely to be sufficient to satisfy the ever-increasing demand for water in the United States (Sandia, 2003).

Desalination almost certainly will be a major means of meeting these projected increases in water demand. Inland areas are looking more to brackish groundwater, and coastal areas are looking to seawater desalination (Sandia, 2003). Increasingly stringent requirements for various emerging constituents and water reuse regulations are also raising the demand for the use of membrane technologies.

Production of low-salinity water from desalination of brackish and seawater results in a byproduct termed “concentrate,” having significantly increased total dissolved solids (TDS) relative to the source water. Concentrate must be properly disposed of, and this disposal is becoming increasingly problematic as the size and number of desalination plants increase. Costs associated with concentrate disposal will become a growing fraction of total membrane plant costs, and difficulties with finding a viable concentrate disposal method have led to the delay and even cancellation of some membrane plant projects (AWWA, 2004). New technical and regulatory approaches to concentrate disposal are desperately needed.

CONVENTIONAL CONCENTRATE DISPOSAL

Surface water discharge is the most common and typically the cheapest concentrate disposal option, if available. Characteristics of the receiving water body and the concentrate are critical considerations. Potential impacts to aquatic organisms are a primary consideration. Adverse human health impacts may occur if the surface water is used downstream as a source of potable water or if the water body is used for recreational purposes or for fishing. Surface water disposal is generally not feasible in the rapidly growing, water-short, and landlocked areas of the U.S. desert southwest, which lack perennial riverine supplies. Ecological risk factors are likely to be the major issues for oceanic discharge, and permitting of new ocean discharges is likely to be increasingly difficult.

Sewer discharge is the simplest means of concentrate discharge, if available. Sewer discharge may be limited, especially for larger membrane plants and their associated larger concentrate flows. Regulatory issues are relatively simple, as the membrane plant itself does not need a National Pollutant Discharge Elimination System permit, provided the concentrate does not appreciably change the effluent quality characteristics. The major economic issue is the fee charged by the wastewater treatment plant (WWTP) for the discharge.

Deep well injection is widely used in Florida, where geologic conditions are especially favorable. It is very expensive, but there are significant economies of scale for larger plants. The entire volume injected represents water that is essentially unrecoverable or “lost” for other potential uses, but salts in the concentrate are permanently removed from the basin.

Evaporation ponds are a simple, widely used technology, applicable to all concentrates unless there are unacceptable ecological exposures from certain constituents in the concentrate (e.g., selenium). Use of evaporation ponds is largely limited to areas with a warm, dry climate having high pan evaporation rates. Limited availability of adequate areas of low-cost land further restricts evaporation pond use, especially for desalination facilities with high concentrate volumes that are located in or near urban areas. There is no significant economy of scale for evaporation ponds.

Rapid infiltration is a potential low-cost method of disposal, but regulatory and technical constraints are significant. This disposal method is not likely to be a viable alternative for most membrane facilities.

BENEFICIAL AND NONTRADITIONAL USES

This project focused on the beneficial reuse of concentrate or concentrate byproducts. The nontraditional options that were identified included oil well field injection, solar ponds, land application and irrigation (including halophyte irrigation), zero liquid discharge (ZLD) and near-ZLD, aquaculture, salt marsh discharge, wetlands treatment, and separation and recovery of individual salts. A survey of water utilities (Appendix H) confirmed that various utilities are considering some of these options for concentrate management.

Although a traditional method of disposal, irrigation (land application) was included because it can be a beneficial use, it is infrequently used, and limitations and opportunities have not been adequately described in the existing concentrate disposal or reuse literature. Although infrequently used by water supply utilities, ZLD and near-ZLD were included because they hold considerable potential for increasing the available volume of high-quality water and are closely linked to separated salts recovery.

Oil Well Field Injection

While formation hydraulic capacity is often a limiting factor, injection of concentrate into oil and gas well fields may be technically feasible at some locations. Although the concept has been best developed in Texas, even there it has not yet been done. A clear beneficial use can result when concentrate is used to aid secondary recovery of oil and gas resources. Injection of concentrate is very similar to the well-proven practice of produced water injection. In addition to the formation’s hydraulic capacity, other potentially limiting factors include regulatory constraints, technical constraints such as compatibility with the formation to avoid plugging, and conveyance issues from the source of concentrate to the oil field.

There may be some regulatory flexibility in some states regarding the classification of concentrate injection wells as Class II rather than Class I, at least where they are used for secondary recovery. At least under current Texas regulations, a discharger of concentrate to a Class II well needs to make provisions for alternate disposal when concentrate injection can no longer be justified for secondary oil recovery. In terms of sustainability, it should be recognized that although the capacity of oil and gas well fields to accept concentrate is large in a number of U.S. states, it is finite.

Solar Ponds

Using concentrate as a feedstock for a solar pond is a potential beneficial use, assuming heat energy is utilized for a useful purpose. No desalination facility in the United States currently uses this technology, but solar ponds could become more attractive as energy costs rise, assuming significant technical issues can be resolved. These technical challenges are considerable, including major start-up and control issues. Establishment of the pond requires a solution with approximately 250,000 mg/L of TDS, and dewatering most concentrates to this level will be difficult. Maintaining the gradient of the gradient zone in the pond is critically important and requires a high level of management and monitoring. Maintaining pond clarity would also be a challenge, as algal growth is likely to occur. Moreover, solar ponds constitute a volume reduction method, rather than a means to achieve final disposal of concentrate salts, and landfilling or separated salt recovery will eventually be required.

Land Application and Irrigation

Land application and irrigation can be a viable, beneficial use of concentrate, especially for smaller facilities producing relatively low-salinity concentrates that are close to agricultural areas. Benefits include volume reduction through evapotranspiration, replacing existing uses of high-quality water for irrigation, revenue from sale of irrigated crops, and aesthetic value of created landscapes. Constraints include the high level of TDS in many concentrates and the potential for adverse impacts on groundwater on the soil column. Sufficient flushing of the soil column and efficient capture of drainage water from agricultural systems is likely a requirement for sustained crop production and groundwater protection. Drainage water from many of these sites will need either (1) subsequent treatment and/or volume reduction through further irrigation on yet more salt-tolerant plants or (2) the use of evaporation ponds or brine concentrators to prepare salts for disposal. The long-term viability of multistep irrigation approaches is not yet established. Halophytic plants increase the range of concentrate salinities that can be land applied, but full-scale systems are not well-proven and markets for halophyte commodities are not established.

Zero Liquid Discharge

ZLD is excessively costly with today’s technology, primarily because of the prohibitive energy requirements for operation. The large footprint required is also a significant disadvantage. Near-ZLD approaches such as those that provide 90% volume reduction may have acceptable costs (NRC, 2004). Reducing the volume of concentrate is a critical factor to reduce the current high cost of ZLD technologies (Sandia, 2003). Near-ZLD approaches that reduce the volume of concentrate may either simplify or complicate disposal of the remaining concentrate, depending on local constraints. Solids disposal remains a major issue for ZLD systems, and the cost of solids disposal is likely to increase.

Aquaculture

The primary variables that impact the feasibility of an aquaculture system application for membrane concentrate disposal are existence of a market for the species to be grown, climate, concentrate chemistry and flow rate, land area available, and options for effluent disposal. Marine aquaculture is practiced in the United States but generally with low-salinity water, compared to the high levels present in concentrate derived from brackish groundwater and seawater. No research has been identified on the use of concentrate for aquaculture. In the United States, salt water tilapia for human consumption and brine shrimp as food for other fish are the most likely applications for many concentrates, although a number of other species could potentially be utilized.

Wetland Creation and Restoration

Concentrate from desalting membrane processes could potentially be discharged to naturally occurring or artificially created inland salt marsh areas. When compared to constructed sites, most existing sites are not likely candidates as primary discharge sites due to the low and intermittent flows required to sustain these ecosystems. Additionally, the regulatory permitting processes required to address the impacts of the concentrate discharge on the native conditions would likely be difficult, especially for naturally occurring salt marsh areas.

Constructed salt marsh areas are somewhat more likely to be successfully permitted. Since these sites receive the concentrate as their only source of water, they are subject to a more rapid buildup of constituents than naturally occurring salt marshes. Constructed salt marshes should be designed to address salt buildup through infrastructure design that will allow an operator to maintain a proactive water balance management approach (e.g., between multiple constructed marsh areas).

Constructed Wetland Treatment

Treatment wetlands have been used for several decades for the removal or reduction of pollutants in wastewater effluent but have only been evaluated on a pilot scale for concentrate treatment. Preliminary results from published studies (e.g., Negri et al., 2003) and an unpublished study (Appendix A) indicate that contaminant concentrations and total water volume can be reduced. Treatment wetlands clearly may have a role in reducing the concentrations of a number of constituents, such as selenium and nitrate, and are capable of reducing salt loads, but they are not capable of reducing TDS. The potential exists for treatment wetlands to function as a pretreatment technology before discharge to surface waters for these reasons. The creation of wetlands using treated concentrate could be a significant environmental enhancement where saline wetlands occur naturally.

Other Beneficial and Nontraditional Uses

Other potential beneficial and nontraditional uses are described below.

Stormwater or Wastewater Blending: Blending of concentrate with stormwater, or effluent from wastewater treatment facilities, could in some circumstances help reduce salinity-related effects of discharge of freshwaters to some estuarine or marine environments, particularly for small receiving water bodies where the discharges represent a significant portion of the ambient water flow. This novel approach to concentrate use would require careful analysis of variability in discharge and receiving water quality to determine beneficial blending ratios, receiving water benefits, and ultimate compliance with surface water standards. Blending with continuously discharged WWTP effluent could reduce the necessity of potentially cost-prohibitive storage for blending with stormwater runoff.

Recreational Uses: Potential recreational uses of concentrate are generally a subset of irrigation and wetland reuse alternatives. As described previously, this could include irrigation of highly salt-tolerant turf grass species on golf courses, soccer fields, or other recreational areas. Salt marshes and wetland areas could also provide recreational benefits, such as bird-watching.

Transport of Mineral Resources: Transport of mineral resources could be a beneficial use, but logistics are not likely to be favorable due to the remote nature of most mining operations.

In addition, this would not constitute final disposal, as after separation of the mineral resource, the concentrate would still require disposal.

Feedstock for Sodium Hypochlorite Generation: Using concentrate as a feedstock for sodium hypochlorite generation is not likely to be economically viable for anything other than on-site use by seawater desalination facilities.

Dust Control and Deicing: The mixed salt nature of most concentrates, environmental restrictions, and large volumes make it highly unlikely that concentrate could successfully be used for dust suppression or deicing. If pure salts can be recovered, such as $CaCl_2$ or $MgCl_2$, dust control and deicing could be beneficial uses.

Other Direct Uses of Concentrate: There are no general uses for mixed salt solutions, although there may be rare cases where concentrates consist predominantly of one or two salts. Although sodium carbonate production from reverse osmosis (RO) reject has been suggested, the complexity of the production process would be an economic deterrent to its implementation. Production of sodium hydroxide might also be technically feasible; however, the most current technology, which is based on membranes, requires use of very pure sodium chloride solutions. Although theoretically and technically possible, it is highly unlikely that production of these byproducts would result in viable outlets for RO reject.

A possible exception to the lack of direct uses of mixed salt solution (i.e., concentrate) is use of products by a company called Virotec. Virotec has considered colocating one or more facilities along the Texas Gulf coast that would use concentrate from seawater desalination projects (Bill Asher, Virotec International, personal communication). Their process requires a feed having two to four times the TDS of seawater concentrations.

SALT SEPARATION OF MEMBRANE SYSTEM CONCENTRATE

Technological means to accomplish the salt separations and recovery exist, but the commercial viability in site-specific applications is uncertain. No full-scale system for salt separation and recovery has yet been implemented in the United States. There are many applications for the major salts obtainable from concentrates, providing a sufficient economic driver to make their recovery economically attractive. The feasibility of a site-specific operation for salt recovery and sale, however, depends on several factors, including the following:

- Volume of concentrate
- Water quality (salts obtainable from the concentrate)
- Quality (form and purity) of salts obtained
- Reliability and consistency of salt quality
- Types of applications for the obtainable salts (types of markets)
- Existence of a local market
- Size of the local market
- Reliability of the local market
- Combined income from sale of the different salts

There is a need for developing value-added products that utilize salts removed from concentrate to uncouple feasibility from dependence on existing markets, and this likely remains a significant challenge.

A fundamental conflict that must be addressed for successful implementation of salt separation and recovery is the decoupling of the production of concentrate, which is driven by the need for drinking water supply and the sale of salts derived from the concentrate. Drinking water production demands that the desalination process operate on a consistent basis to meet the public health needs of a community; concentrate will be produced on a consistent basis, and its production cannot be interrupted or curtailed as long as water demand exists. Sale of recovered salts from concentrate treatment is tied to the industrial market and the vicissitudes that underlie a supply and demand economy. The price of and demand for the salts are driven by the market and may or may not match the supply that is generated from drinking water production. Successful decoupling of concentrate production and recovery salt sale can most effectively be achieved by providing an alternative means of concentrate disposal.

CONCLUSIONS

A number of emerging potential beneficial and nontraditional uses of concentrate have been identified, but these generally are either not well-proven or do not provide a final discharge for salts contained in concentrate. Clearly, there is no panacea for concentrate discharge, but it may be possible to develop creative local options for beneficial use. A combination of methods, such as linking more conventional options with beneficial or nontraditional uses, may be the most cost-effective and can provide redundancy, reliability, and potentially some ancillary benefits.

In many cases, beneficial and nontraditional options will not be feasible or will only provide an outlet for a fraction of total concentrate produced. However, the convergence of increasing need for desalination with existing constraints on concentrate disposal by conventional methods suggests that all possible disposal options must be considered to meet water resource needs of the future.

Beneficial and nontraditional options, including separated salts recovery, tend to have numerous and critically important site-specific considerations that must be considered prior to implementation, including climate, markets, regulatory issues, and ecological risk concerns. Additional research and site investigation appear to be especially warranted for volume reduction technologies, oil well field injection, halophyte irrigation, treatment wetlands to address reductions in the mass of specific constituents, and recovery of separated salts.

CHAPTER 1

INTRODUCTION

Following a discussion facilitated by Sandia National Laboratories and the U.S. Department of Interior, Bureau of Reclamation, a report was developed summarizing U.S. water supply challenges and areas of needed research and development (Sandia, 2003). The report noted that global demand for water is growing rapidly, and the options for additional sources of supply are limited. Conservation and water use efficiency are crucial components of securing adequate water supplies but are not likely to be sufficient to satisfy the ever-increasing demand for water in the United States (Sandia, 2003). The major feasible methods for increasing water supplies in the United States include desalination, water reuse, and recycling (Sandia, 2003).

Desalination almost certainly will be a major means of meeting these projected increases in water demand, "creating new water" from brackish groundwater, impaired rivers, reclaimed waters, and from the large volumes of brackish water (produced water) generated during the production of oil, natural gas, and coal bed methane (CBM) (Sandia, 2003). To meet the water demands, inland areas are looking more to brackish groundwater, and many coastal areas are looking at seawater desalination (Sandia, 2003). Water suppliers in Florida are increasingly using brackish groundwater and estuarine or brackish surface water. Increasingly stringent requirements for various emerging constituents and water reuse regulations are also raising the demand for the use of membrane technologies (CH2M HILL, 2004).

> *"Assuming continued per capita water use, 16 trillion additional gallons per year will be required in the U.S. by 2020 for municipal and light industrial uses. This is equivalent to ¼ of the combined outflow of ALL of the Great Lakes. 50% of the nation's future population growth is forecast to occur in California, Texas, and Florida – regions already experiencing water shortages"* (Sandia 2003).

Production of low-salinity water results in a sidestream of concentrate, significantly more concentrated than the source water that must be disposed, and this disposal is becoming more problematic. Costs associated with concentrate are expected to become a growing fraction of total membrane plant costs (AWWA, 2004). Difficulties with finding a viable concentrate disposal method have led to the delay and even cancellation of some membrane plant projects (AWWA, 2004). It seems clear that there is no "magic bullet" technology that will resolve concentrate disposal needs (CASS, 2005), and new technical and regulatory approaches are desperately needed.

> *"Finding environmentally sensitive disposal options for concentrate that do not jeopardize the sustainability of water resources is difficult, and thus next generation desalination plants will have to either be designed to minimize the production of these concentrates, or find useful applications for them…without alternative technologies, the burdens of concentrate management will preclude widespread adoption of desalination technologies"* (Sandia 2003).

Inland sites will inherently have more significant limitations, as they do not enjoy the relatively inexpensive dilution and wave- and tidal-driven mixing benefits of the ocean. Overall basin salt management is also increasingly important for inland areas, as salts are continually imported and exports tend to be miniscule in comparison.

Critical needs and objectives as defined in Sandia (2003) concerning concentrate disposal are shown in Table 1-1.

TABLE 1-1

National Needs and Critical Objectives

National Need	Near-Term Critical Objectives (2008)	Mid- and Long-Term Critical Objectives (2010 and 2020)
Provide Safe Water	Develop science-related concentrate-specific regulations related to dispersion modeling of mixing zones and ion imbalance Subsurface injection: large-scale regional characterization of U.S. subsurface injection capability	Demonstrate isolation with hydrologic model of receiving formation and formation scale model of U.S. subsurface injection capability
Ensure Adequate Supplies and Ensure Sustainability	Beneficial use: 5% of concentrate Reduce reject to 15% for non-surface water applications. (Note: This level is already common for many groundwater plants.)	Decrease cost of reclaimed waters by 50% (stretch target, 80%) Beneficial use: 15% of concentrate Reduce reject to 5% for non-surface water applications Create a “super concentrate” technology, with complete solidification of residuals and 100% recapture of water Decentralized (point-of-use) treatment and recycling as a way of managing concentrate Watershed-based salinity management strategy
Keep Water Affordable	Reduce operating costs by 20% Reduce cost of ZLD[a] by 20%	Reduce operating cost by 50% (stretch target, 80%) Reduce cost of ZLD by 50% (stretch target, 80%)

Source: Sandia (2003).

[a] ZLD, zero liquid discharge.

Therefore, the major issues for concentrate disposal described by the Sandia report include the following:

- The need to increase the fraction of concentrate that is beneficially used;
- The need to reduce the volume of concentrate that must be handled;
- Development of low-cost, zero liquid discharge (ZLD) technologies;
- Reductions in costs for disposal of concentrates; and
- Tools to facilitate management of concentrate disposal and overall salt management issues on a watershed basis.

It should be recognized that although desirable benefits may accrue, reuse and beneficial reuse of concentrate do not necessarily and, in most cases, do not address the fundamental problem of concentrate disposal (M. Mickley, personal communication). Exceptions would be where reuse results in ZLD. Other types of reuse are primarily a volume reduction or concentration process. Typically, there is an effluent or drainage associated with beneficial uses that must still be captured, evaporated, injected, or otherwise disposed. Reduction of concentrate volume (e.g., through irrigation and capture of drainage) may accrue, but subsequent disposal to surface water or sewer may be made less feasible, rates of evaporation for the more concentrated solutions will be slower in evaporation ponds, corrosion problems may increase when handling the more concentrated solution, and higher organic content (e.g., resulting from wetlands treatment or aquaculture) may complicate and increase costs for subsequent treatment with ZLD technology (M. Mickley, personal communication).

DESALTING TECHNOLOGIES

Desalting processes include reverse osmosis (RO), nanofiltration (NF), electrodialysis and electrodialysis reversal (ED/EDR), and thermal treatment processes (e.g., distillation) (AWWA, 2004). The fastest-growing segment has been RO for salt removal in brackish water resources and seawater (NRC, 2004). ED/EDR technology provides separation of ionic constituents through the use of electrical potential, and NF provides water softening (removal of divalent cations such as calcium and magnesium) and removal of organics, sulfate, and some viruses (NRC, 2004). Membrane classification is shown in Figure 1-1.

“Membrane” will be used here as a general abbreviation for RO, NF, or ED/EDR treatment technologies, as these are the major technologies used in the United States for desalination and disposal of concentrates from these types of facilities is the major focus of this report. Thermal desalination technologies tend to dominate in the Middle Eastern region because of their capacity to produce high-quality water from seawater and the generally low energy costs in the region (NRC, 2004). Microfiltration (MF) and ultrafiltration plants are designed for removal of particulates (AWWA, 2004).

As of 2002, Mickley (2004b) determined that there were 234 municipal desalting plants in the United States, with 187 RO, 29 NF, and 18 ED plants. The International Desalination Association (IDA) inventory (IDA, 2004) lists 2083 industrial and municipal desalination plants in the United States. Concentrate from these treatment processes has elevated levels of total dissolved solids (TDS).

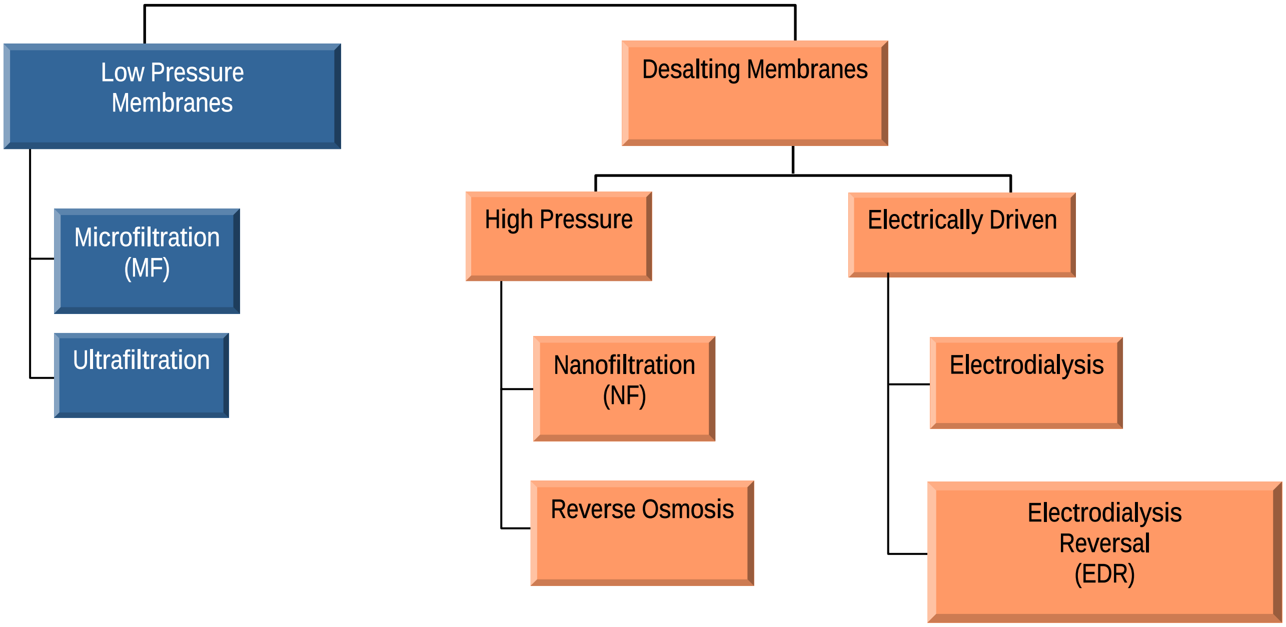

FIGURE 1-1
Membrane classifications.
Source: AWWA (2004).

Characteristics of Concentrate

Concentrate generally has a similar composition in terms of the relative proportions of constituents to those of the feed water (or source water) (AWWA, 2004), only much of the water has been removed. When considering reuse alternatives, the major TDS constituents in concentrate can be diluted, the volume of water they are contained in can be reduced, and some can be precipitated or extracted, but they cannot be destroyed. The constituents that are concentrated are summarized by membrane technology in Table 1-2.

TABLE 1-2
Characteristics of Concentrate

Process	What Is Concentrated
Seawater RO	Primarily sodium chloride, lesser amounts of other salts, trace amounts of particulates and pathogens
Brackish RO	Mixture of salts (dependent upon source ion profile), trace amounts of particulates and pathogens
NF	Primarily divalent ions (calcium, magnesium, and sulfite), lesser amounts of other salts, trace amounts of pathogens and particulates
ED/EDR	Mixture of salts (dependent upon source ion profile), some polar organics, free chlorine

It should be noted that pretreatment processes generally remove viruses, colloids, bacteria, cysts, and particulates from the membrane feed water and, therefore, typical drinking water concentrates largely consist of water, salt, and dissolved organics.

The definition of brackish water is not clear-cut. Some sources consider anything greater than 500 mg/L as brackish, and others use 1000 mg/L. It can be defined as anything with salinity greater than freshwater but less than seawater but generally water with between 1000 and 5000 mg/L of TDS is of the greatest interest, because this is the TDS range of groundwater most widely treated for drinking water (Beuhler and Kinshella, 2005). For the purposes of this report, brackish water is defined as 500 mg/L or more TDS and assumes a brackish groundwater source.

The specific concentration of TDS in the concentrate stream for a given application will depend on feedwater concentration, pretreatment chemicals added, membrane rejection, and membrane recovery. Tables 1-3 and 1-4 provide a summary of the characteristics of membrane and other advanced water treatment process concentrate streams as a function of the feedwater source and treatment technology.

Example water chemistry data for an RO facility in Brighton, CO, are provided in Table 1-5. The RO system at Brighton normally provides 80% recovery.

TABLE 1-3

Typical Desalting Membrane System Design Parameters by Water Source

Parameter (units)	Surface Water	Fresh Groundwater	Brackish Groundwater	Seawater
Feedwater TDS (mg/L)	200–400	400–500	500–10,000	30,000–40,000[b]
Water Recovery (% of feed)	80–90	80–90	65–85	40–60
Concentrate Vol. (% of feed)	10–20	10–20	15–35	40–60
Concentrate TDS (at indicated % recovery) (mg/L)	1330–2660 (85%)	2660–3330 (85%)	2000–40,000 (75%)	60,000–80,000 (50%)
Concentration Factor[a]	5–10	5–10	2.9–6.7	1.7–2.5

Source: adapted from AWWA (2004).

[a] TDS in concentrate versus TDS in feed, assuming 100% rejection.

[b] Estuarine surface water sources may be 25,000 mg/L.

TABLE 1-4

Typical Concentrate TDS by Water Treatment Process

Process	Typical Feedwater TDS, mg/L	Min. Concentrate TDS, mg/L	Max. Concentrate TDS, mg/L
Seawater RO	32,000–45,000	50,000	80,000
Brackish RO	1000–10,000	3000	40,000
ED/EDR	1000–4000	3000	30,000
Softening NF	300–1000	1000	5000

TABLE 1-5

Water Chemistry for Brighton, CO, Reverse Osmosis Facility

		South Platte Wells			Conc. Factor (Concentrate/ Raw)
Component	Units	Raw Water	Permeate	Concentrate	
Ca	mg/L	135.2	3.16	662	4.9
Mg	mg/L	24.5	0.58	118	4.8
Na	mg/L	145	8.6	690	4.8
SO_4	mg/L	250	4.2	1465	5.9
Cl	mg/L	110	3.9	534	4.9
NO_3-N	mg/L	15	1.9	67	4.5
HCO_3	mg/L	326	15	1269	3.9
TDS	mg/L	860	37.1	4536	5.3
EC[a]	dS/m	1.3	0.1	7.1	5.3
SAR[b]		3.0	1.2	6.5	2.2
Temp.	°C	13.4	13.4	13.4	NA[c]
pH		7.2	5.55	7.5	1.04

[a] Electrical conductivity (EC) was estimated based on the TDS/640 as dS/m, where dS/m is mmho/cm.

[b] SAR, sodium adsorption ratio.

[c] NA, not applicable.

Table 1-5 shows that the concentration of individual constituents for RO can generally be approximated by the same ratio as the increase in TDS (e.g., approximately fivefold for this water), although there is some variability in the selectivity of the system for individual ions. For this system, the ions that diverge the most from the average are sulfate and bicarbonate. The overall recovery rate for membrane systems is calculated as follows: (feed rate – brine rate)/feed rate (Conlon, 1990). The sodium adsorption rate (SAR; relevant to land application and irrigation uses of concentrate, described in Chapter 3) increases to a lesser extent than the

TDS for this facility as a result of the nonlinear nature of the SAR function used for the calculation.

Sources of water will impact potential uses of the concentrate, because chemical parameters vary greatly by region of the country. For example, arsenic and selenium are commonly present in concentrates from both desalination of brackish groundwater and agricultural drainage waters in the western United States and may result in deleterious impacts (NRC, 2004).

Suppliers of RO and NF membranes provide proprietary membrane projection programs that can be used to estimate concentrations of major and minor ions in membrane concentrates for a given set of design conditions. These programs are widely available on the Internet for free download or through a supplier. These programs typically do not address levels of trace metals or organics in concentrate.

It is likely that communities will increasingly turn to previously ignored water resources, including reclaimed effluent and brackish groundwater, through technologies that produce concentrate (CASS, 2005). Moreover, both feed source characteristics and chemical additions create the potential for generating hazardous waste, further complicating concentrate disposal (CASS, 2005).

Cleaning Wastes

Concentrate also includes residual chemicals used for feedwater pretreatment (coagulants, antiscalants, disinfectants, dechlorination chemicals, and acids) and sometimes chemicals used for membrane cleaning (acids, alkaline solutions, complexing agents such as ethylenediamine tetraacetic acid, dispersants, or surfactants). Cleaning solutions usually represent less than 0.1% of the total flow (AWWA, 2004; Van Der Bruggen et al., 2003). The bulk of pretreatment chemicals remain associated with the solids produced in pretreatment. Cleaning solutions for ED/EDR may include chlorine for treating biofilms or other organic contaminants. Concentrate may also have intermittent high concentrations of cleaning solutions (AWWA, 2004). Spent cleaning solutions are typically small volumes generated in a batch process approximately every 3 to 12 months (Malmrose, 2005).

Typically, cleaning solutions are either blended with the concentrate (thus, the same discharge method) or discharged separately to the sewer (Mickley, 2004a). Of 110 desalting plants responding to a recent survey on cleaning solution discharge, 61% discharged to a sewer, 22% discharged to surface water, 7% used land application, 6% used deep well disposal, 2% used evaporation ponds, 1% used recycling, and 1% relied on hauling (Mickley, 2004a). Overall, 59% of plants responding indicated that discharge of cleaning wastes was the same as for concentrate.

Other Constituents

Other constituents of concentrate may include metals, pathogens, industrial chemicals, natural pollutants, pharmaceuticals, and other compounds of concern (CH2M HILL, 2004); however, the presence of these constituents is not a general characteristic of municipal concentrate. New constituents of concern in drinking water supplies are regularly identified, increasing the need for advanced water treatment processes, such as membranes, with the end result that these constituents will be found at increased levels in concentrate. Membrane or other bulk removal processes are typically used as a last resort after technical options (e.g., constituent-specific removal) and regulatory efforts have been exhausted.

Flow Rate Fluctuations

The volume of concentrate flow can vary significantly throughout the year and may peak in summer or in winter. For drinking water membrane plants, peak concentrate flows typically occur in summer (for the Northern hemisphere), when potable water demands are greatest. This is in contrast to the Scottsdale Water Campus MF/RO facilities, which treat surplus secondary effluent in winter, when effluent demand for golf course irrigation is low. The resulting RO-treated water is used for groundwater recharge, and the concentrate is discharged to the regional sewer system. Example flows from the Scottsdale, AZ, Water Campus are shown in Figure 1-2.

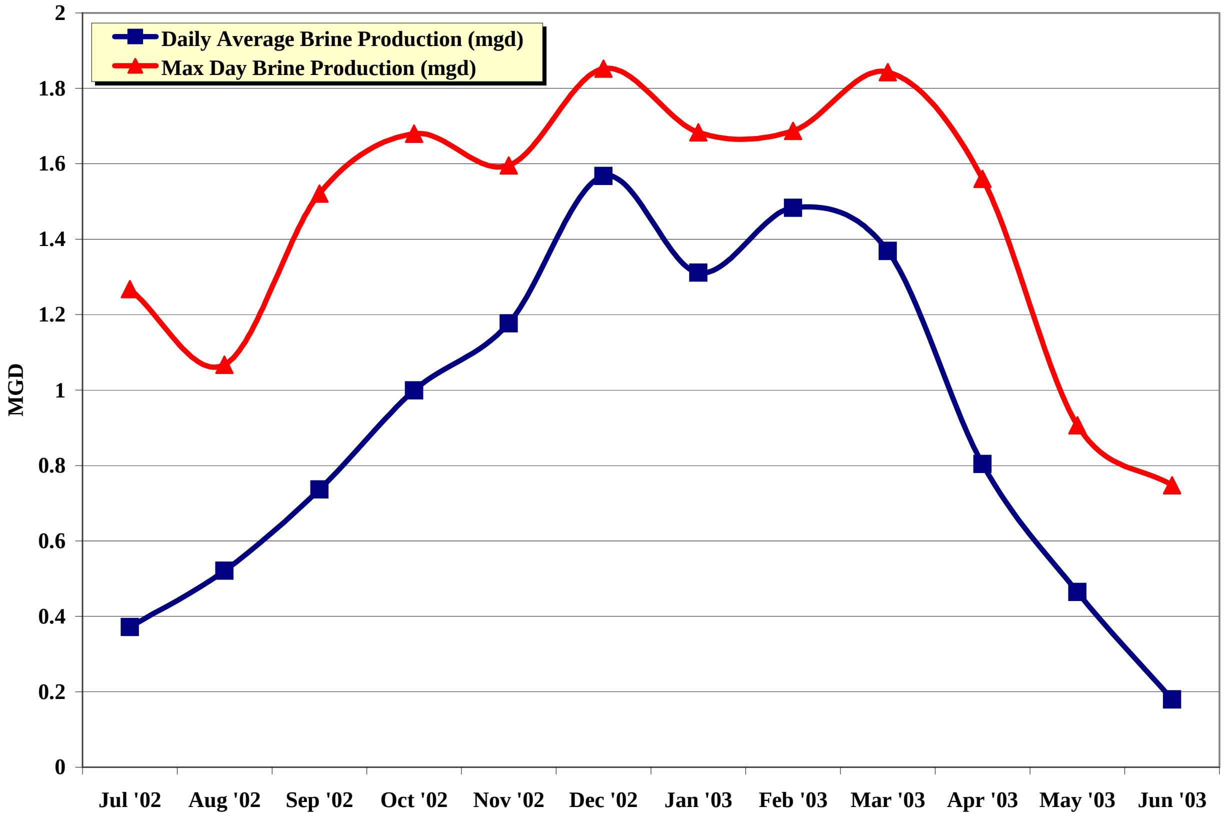

FIGURE 1-2
Scottsdale Water Campus Daily Brine (Concentrate) Production.
Source: CASS (2005).

Regulatory Issues[1]

There are two primary regulatory "blankets" that broadly apply to water treatment facilities implementing membrane technology. The Clean Water Act (CWA), as supplemented by state regulations, addresses facility effluent requirements. The Safe Drinking Water Act (SDWA), as supplemented by state regulations, addresses drinking water quality requirements.

The regulations covering disposal of concentrate or backwash depend on the particular disposal method used. The U.S. Environmental Protection Agency (USEPA) has not established regulations that are specifically directed at disposal of water treatment plant residuals, which includes membrane plant residuals, including concentrate.

USEPA has become aware of increased concentrate disposal issues (USEPA, 2005); however, there has not been any initiation of regulatory change, despite considerable lobbying efforts. Of keen interest is the concentration of particularly harmful substances, such as arsenic and radionuclides. There have been some preliminary discussions to develop effluent guidelines for surface water discharge.

Desalting residuals are classified by the CWA as an industrial waste, but there are no current USEPA regulations specific to concentrate (AWWA, 2004). A standard process has been established to obtain permits for concentrate discharge to surface water, a local wastewater treatment plant (WWTP), and deep well disposal; however, permitting for other options is relatively site specific (Mickley et al., 1993). For most cases, applicable regulations can be summarized as shown in Table 1-6.

TABLE 1-6

Applicable Regulations for Traditional Disposal Methods

Disposal Method	Applicable Regulations
Surface Water Discharge	NPDES (CWA), state and local regulations
Sewer Discharge	State and local regulations, Industrial Pretreatment Program
Land Application	State and local regulations
Deep Well Injection	NPDES (CWA), SDWA (UIC), state and local regulations
Evaporation Ponds	State and local regulations

Source: Mickley (2004a)

NPDES, National Pollutant Discharge Elimination System; IPP, Industrial Pretreatment Program; UIC, underground injection control.

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[1] Material in this section is based on personal communications with A. Hubbard, FDEP; J. Coleman, Maricopa County Department of Health Services, Arizona; C. Varga, ADEQ; K. Holligan, TCEQ; B. Holmgren, NDEP, July 2005; J. Wheeler, E. Burneson, and R. Bastian, USEPA; FDEP Draft Rule 62-620, December 2004; and Mickley (2004a).

These regulations provide risk-based approaches for protection of human health and the environment. Groundwater standards are typically related to aquifer protection and prevention of degradation. Surface water standards are derived for target constituents based on assumptions of common pathways of exposure, like water ingestion, fish ingestion, and toxicity to sensitive aquatic organisms.

Four states were selected for this report as surrogates representing recent regulatory developments. The selection was primarily based on the number of membrane plant installations (Florida and Texas) and growing populations in landlocked areas (Nevada and Arizona), where the need for desalting membrane treatment in the future will be high. California was not included because regulatory issues regarding concentrate disposal were recently reviewed elsewhere (CH2M HILL, 2004). Table 1-7 provides a summary of regulatory information for each of the selected states.

Each state is similar in that it has developed its approach from USEPA guidelines and directives. Each state differs considerably, however, in the details of the specific regulation of concentrate disposal, particularly with respect to the degree to which its regulations are more stringent than USEPA's.

The information presented in the following section was obtained from *Membrane Concentrate Disposal: Practices and Regulation* (2nd ed.) by Mickley and Associates (2004), supplemented by recent (2005) contacts with state and federal regulatory authorities (see footnote 1, above).

Arizona

Desalting plants in Arizona primarily discharge concentrate to the sanitary sewer. Evaporation systems are allowed, provided there is suitable engineering review prior to construction. Land application has been permitted but requires review of the composition of the concentrate. Other fringe disposal options that have been implemented include discharge to an individual septic system (requires an aquifer protection permit) and pump and haul to a nonhazardous landfill. Recent rulemaking activity has been primarily related to the Aquifer Protection Rule, which is under revision.

There are no revisions pending to the Environmental Statues of Arizona Administrative Code relating to concentrate disposal. Drinking water standards need to be met for any recharge or injection application for concentrate disposal. Arizona is seeing an increase in both the number of applications and the volume of concentrate applied. An exception to the groundwater protection rules allows for wastewater from municipal wastewater plants to be used for irrigation. Most of these plants use low-pressure membrane filtration. This is of concern to the Arizona Department of Environmental Quality (ADEQ), and preliminary discussions have been initiated. Arizona is also alert to developments in arsenic treatment and the potential for increased membrane applications.

TABLE 1-7
Summary of Disposal Regulations for Traditional Disposal Options

Disposal Option	Arizona	Florida	Nevada	Texas
Membrane Concentrate Disposal (General Provisions)	(No specific regulations, handled case by case; Aquifer Protection Permit Program could place requirements on surface water, land application, well injection, and NDPES permits	Extensive regulatory requirements for utilities using membrane technology	No special provision required beyond NPDES requirements	Concentrate disposal discharge to state water requires TPDES permit
Surface Water	Not currently used	Is allowed; commonly blended with clean treated effluent to reduce TDS; all water quality standards must be met	Allowed under an NPDES permit	Discharge is allowed but only under a TPDES permit
Evaporation, Percolation Pond	Acceptable with engineering review	Available as a disposal option for low-volume discharger (<50 gpd)	Available option subject to permit requirements for water quality standards	Available option; requires Texas Land Application Permit
Land Application, Irrigation	Allowed, but contingent on the composition; will require a variance to ADEQ rule	Available in combination with deep well injection for backwash and low-chloride reject water	Does not require an additional permit	Available option; requires Texas Land Application Permit
Well Injection	Drinking water standards need to be met prior to injection	Most RO utilities use deep well injection; FDEP issues Class I UIC permit	Not applicable	Available; requires UIC permit
Discharge to POTW[a]	Acceptable with the approval of the receiving agency	Is an available option within the system; most WTPs do not have a POTW nearby; some municipalities use their own; no permit required	Available; does not require permit	Is an available option. Permit not required. Small systems going with this option
NPDES-Related State Regulations				
Type of NPDES Permit	Individual permit; permit requirements contingent on water quality of receiving water body	WTPs using membrane technology; require an individual FDEP/NPDES permit	Individual NPDES permits are issued for any surface discharge in the state	WTPs are considered industrial dischargers and subject to individual TPDES
Monitoring Parameters	Standard water quality parameters	TDS, pH, TRC,[b] flow, chloride, conductivity	TSS, TRC, flow, turbidity	Flow, pH, TSS, TRC
Whole Effluent Toxicity Test Requirement	Required	Required for surface discharger	Not required for WTP discharge, only for POTW permits	Typically not required for WTPs

Source: adapted and updated from Mickley (2004a).
[a] *POTW, publicly owned treatment works.*
[b] *TRC, total residual chlorine.*

Florida

Concentrate disposal has been getting considerable attention in Florida, where there are 127 municipal desalting plants (Mickley, 2004a) and 292 industrial and municipal plants (IDA, 2004). The concentrate disposal options are conventional: surface water discharge, blending with reclaimed water, discharge to a WWTP, deep well injection, and stormwater ponds. There is considerable interest by the Florida Department of Environmental Protection (FDEP) in considering nontraditional options. These would be handled on a case-by-case basis and would be permitted out of the respective district office.

Concentrate disposal in Florida is regulated per Chapter 403 of the Florida Statutes, in particular, Section 403.0882, Discharge of Demineralization[2] Concentrate. As part of Chapter 403, the multiorganization Technical Advisory Committee was developed to assist with further development and revision of concentrate disposal rules. The State is currently finalizing revised rules related to demineralization concentrate disposal (revised Chapter 62 of the Florida Administrative Code). The two primary areas of revision are related to (1) procedural revisions, such as revised permit application forms, and (2) water quality standards, such as revisions to the defined mixing zone requirements. The definition of "demineralization concentrate" has also been added. These revisions are expected to be presented by the Florida Department of Environmental Protection to the Environmental Regulations Commission for adoption on Oct. 27, 2005.

Florida is also focusing on tailored disposal requirements for small membrane systems. Small systems are defined as those producing less than 50,000 gal of concentrate/day. A detailed past review of Florida concentrate regulations is provided in Appendix G.

Nevada

Due to the high evaporation rates and readily available land, the primary concentrate disposal method in Nevada is evaporation. A Zero Discharge Permit is required from the Nevada Division of Environmental Protection (NDEP).

The number of membrane plant installations has been steadily increasing. There is the potential for a considerable increase associated with applying membrane treatment for arsenic removal, which is an issue in Nevada; however, these plants will not generate a concentrate, only a solid waste.

There are currently no revisions to the Nevada Administrative Code that relate to the disposal of concentrate and, to date, NDEP has not received any requests for nontraditional concentrate disposal method applications. NDEP has, however, seen requests for evaporation solids to be applied for weed control.

Texas

Concentrate disposal in Texas is primarily regulated by the Texas Commission on Environmental Quality (TCEQ). Traditional disposal methods are commonly permitted in Texas. TCEQ has seen some proposals for concentrate blending prior to surface discharge, and they expect to see an increase in activity associated with nontraditional methods of disposal.

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[2] Synonymous with desalination.

There is currently no rulemaking in the works that directly relates to concentrate disposal. TCEQ, however, has observed an increase in organizational activity targeted at membrane applications and associated concentrate disposal issues. Two groups in particular have been increasing their efforts in this area: the Texas Water Development Board (www.twdb.state.tx.us) and the South Central Desalting Association (www.desalting.org).

Distribution of Desalting Plants

The majority of desalting plants are in Florida, followed by California and Texas (Mickley, 2004a). Table 1-8 provides the distribution of facilities in the United States.

TABLE 1-8
Location of Desalting Plants Built prior to 2002

State	No. of Plants	State	No. of Plants
Florida	114	Nevada	2
California	33	Alaska	2
Texas	20	Alabama	1
Illinois	9	Kansas	1
Iowa	7	Missouri	1
Arizona	7	Mississippi	1
North Carolina	7	New Jersey	1
South Carolina	6	New York	1
North Dakota	4	Ohio	1
Virginia	4	Oklahoma	1
Colorado	4	Washington	1
Montana	3	Wyoming	1
Nebraska	2		

Source: Mickley (2004a)

Disposal Methods by Location

Concentrate disposal in Florida is predominantly by injection and surface water discharge (Mickley, 2004a). In California, sewer discharge is the most commonly used method, followed by surface water discharge (Mickley, 2004a). For the rest of the United States, surface water discharge is the most commonly used method, followed by sewer discharge (Mickley, 2004a). Other methods of disposal, such as evaporation ponds, land application, and recycling or reuse, are infrequently used (Mickley, 2004a). Results of a survey regarding discharge type are summarized in Table 1-9.

TABLE 1-9
Discharge Type By Location: Plants Built between 1993 and 2001

Discharge Type	Florida, %	California, %	Rest of U.S., %	Total, %
Surface	24	33	54	41
Sewer	10	57	30	31
Injection	55	5	0	17
Evaporation Pond	0	0	4	2
Land Application	3	0	2	2
Recycle	0	5	2	2
Reuse	7	0	0	2
Unknown	0	0	7	3
Total	**99**	**100**	**99**	**100**
No. of Plants	29	21	46	96
% of Plants	30	22	48	100

Source: Mickley (2004a).

Disposal Methods by Size of Facility

Smaller plants are more likely to use evaporation ponds, land application, and reuse. Larger plants are more likely to use deep well injection (especially in Florida) and are less likely to use surface discharge. Survey results reported by Mickley (2004a) regarding disposal by size are provided in Table 1-10.

TABLE 1-10
Disposal by Size in MGD: Plants Built between 1993 and 2001

Discharge Type	<0.3 MGD, %	0.3–1 MGD, %	1–3 MGD, %	3–6 MGD, %	6–10 MGD, %	10+ MGD, %	Total %
Surface	30	33	41	61	50	14	41
Sewer	50	50	31	11	10	29	31
Injection	0	17	14	22	30	43	17
Evaporation Pond	5	0	4	0	0	0	2
Land Application	5	0	4	0	0	0	2
Recycle	0	0	3	0	0	14	2
Reuse	5	0	3	0	0	0	2
Unknown	5	0	0	6	10	0	3
Total (%)	**100**	**100**	**100**	**100**	**100**	**100**	**100**
No. of Plants	20	12	29	18	10	7	96
% of Plants	21	13	30	19	10	8	100

Source: Mickley (2004a)

Selection of Disposal Alternatives

Determination of the most feasible, most cost-effective disposal method is highly site specific and often requires considerable time and expense. Potential site-specific limiting factors include the following (AWWA, 2004):

- Suitable geology for deep well injection and presence of a nonpotable (greater than 10,000 mg/L of TDS) receiving aquifer
- Concentration of specific constituents
- Seasonal low flows in receiving (surface) water
- Climatic limits (i.e., evaporation ponds, solar ponds, land application)
- Local WWTP capacity or ordinance limitations
- Demand for irrigation water and quality of water required for local crops
- Suitability, availability, and cost of land

Trends in concentrate disposal between 1992 and 2002 included fewer plants discharging to surface water, increasing discharge to sewer and deep wells, and less use of evaporation ponds and irrigation (Mickley, 2004a). This decreased usage was due to the increased size of membrane plants and the non-cost-effectiveness of evaporation ponds and land application for larger volumes of concentrate produced (M. Mickley, personal communication). Many conventional options are often eliminated based on issues other than cost (M. Mickley, personal communication).

Important issues that complicate selection of disposal alternatives include the following (CASS, 2005; M. Mickley, personal communication):

- Lack of availability of conventional options, regardless of concentrate volume
- More stringent regulation and increased public concern
- Concern over the loss of water contained in concentrate
- Increasing system flows over time, resulting in the need for alternate disposal
- Sewer disposal can reduce WWTP capacity and reduce options for reclaimed water reuse
- Power costs may increase
- Many newer technologies do not have a sufficient track record

In addition, decentralization of water treatment processes may be a necessary future direction (Sandia, 2003), and this will impact appropriate concentrate disposal strategies, including beneficial and nontraditional uses.

Geographic Regions

To facilitate the evaluation of the geographical applicability of disposal options, the same geographic regions that were defined by Sandia (2003) are used in this report and are defined as follows:

Rural Inland Communities: This area includes Montana, North Dakota, South Dakota, Wyoming, Colorado, Oklahoma, New Mexico, and Texas (excluding the Gulf Coast). The vast but overused Ogallala aquifer underlies a significant portion of this region, and other brackish aquifers are commonly found in addition to the Ogallala (Sandia, 2003).

Mid-Atlantic: This area includes Delaware, New York, New Jersey, Maryland, Pennsylvania, Virginia, and the District of Columbia. This region has the following characteristics (Sandia, 2003):

- Wet and humid
- Intense water demand from the growing population as well as industry and agriculture
- Large rivers and surface impoundments are the current major sources of water supply
- The groundwater resources that are being used are increasingly stressed
- Salt water intrusion from the Atlantic Ocean is an increasing potential hazard
- Power generation, habitat, and recreational uses stress surface water supplies

Inland Urban Areas: Urban areas of the intermountain west and southwest, such as Las Vegas, Phoenix, and El Paso, are included in this category. This region has the following characteristics (Sandia, 2003):

- Rapid growth, a diversity of water demands, typical precipitation of less than 9 in., and traditional water sources that are increasingly impaired
- Surface water is an important source of supply; water reuse and recycling are expected to become increasingly important
- Salinity levels of the surface water and traditional groundwater sources have been increasing over time
- Desalination will become increasingly important, but concentrate disposal is highly problematic
- Deep well injection is not allowed in many locations, land area requirements for evaporation ponds are prohibitive, and surface water discharge is typically not an option

Oil, Coal, and Gas Basins: These areas are scattered across the central two-thirds of the United States and include portions of Montana, Wyoming, Colorado, Utah, New Mexico, Oklahoma, Texas, Louisiana, Kansas, Iowa, Illinois, Kentucky, Ohio, West Virginia, Pennsylvania, and New York. California also has a number of oil fields and produced water issues, but from a water resources standpoint it is grouped with urban coastal communities, below. This region has the following characteristics (Sandia, 2003):

- Large volumes of produced water are brought to the surface as part of the recovery of energy resources
- Brackish water, often containing petroleum hydrocarbons and other contaminants, may increasingly be seen as a source of water

Urban Coastal Communities: This region includes much of coastal California, the Gulf Coast, and the eastern seaboard of the United States. These areas have the following characteristics in common (Sandia, 2003):

- Rapid population growth and unsustainable growth in water demand
- Population growth and urban sprawl have resulted in expansion of urban areas into traditionally rural areas that formerly were a source of water supply for coastal communities
- Freshwater aquifers are typically depleted
- Subsidence from large groundwater withdrawals has been a problem-
- Important trends will include seawater desalination, increasing recycling, decreasing the cost of purifying reclaimed water, and upgrading impaired waters

Cost of Water

The value of water is an important factor in comparing disposal options, as the cost of obtaining high-quality water is likely to continue to increase throughout the country. Some disposal options allow recovery of usable water, and water planners are likely to prefer concentrate management options that result in the least possible loss of water (CASS, 2005).

Economic theory suggests that one way to evaluate the net benefit foregone from the loss of water would be to evaluate the opportunity cost associated with the next best alternative, that is, the cost of bringing in new water supplies. Extracting additional water from concentrate is currently not feasible due to the associated prohibitive costs. Given the present technology, communities are best served by turning to traditional available sources of water, even as these sources become more scarce and expensive.

A method that is widely employed in water resources is using the cost of the most likely alternative to evaluate the opportunity cost (USWRC, 1983). Depending on the relative availability of alternative water resources, the opportunity cost would be composed of the cost of developing, transporting, and treating the alternative water supplies. Thus, this cost can then be compared to the cost of recovering additional water from concentrate before final disposal.

The cost of water from desalination facilities varies depending on location, ownership of the facility, financing used, operating contracts, distribution infrastructure costs, conveyance to consumer, and other issues (Sandia, 2003). The desalination industry currently uses total water cost as a means of comparison, which includes amortized capital costs, energy costs, consumable costs, and operational costs.

Sandia (2003) reported that capital costs for an advanced desalination and water purification facility were approximately seven to eight times that of a conventional plant (i.e., flocculation, sedimentation, dual-media filtration); however, conventional technology for newer plants typically includes membrane technology such as MF. Improvements in technology have been lowering desalination costs, while the move toward membrane treatment such as MF in conventional plants is raising conventional costs. Current brackish water desalination technologies produce water at a rate of $1 to $3/ 1000 gal, which is roughly five to six times that for conventional treatment of freshwater (Sandia, 2003). Typical values for treated water costs are shown in Table 1-11.

TABLE 1-11
Water Costs to the Consumer (Including Treatment and Delivery)

Supply Type	Cost, $/1000 gal
Existing Traditional Supply	$0.90–2.50
New Desalted Water	
Brackish	$1.50–3.00
Seawater	$3.00–8.00
Combined Supply	
50% Traditional + 50% Brackish	$1.20–2.75
90% Traditional + 10% Seawater	$1.10–3.05

Source: AMTA (2001), as cited in NRC (2004).
Note: Costs include fees for distribution and administrative expenses. Costs for inland desalination may be higher than shown where concentrate disposal is a major cost item. Costs are representative of urban coastal communities.

Regional Salt Balance

Understanding the relative inflows and exports of salts is becoming increasingly important for inland communities. The Central Arizona Salinity Study (CASS) was developed in response to these concerns (Rossi et al., 2005). Salt balance calculations have shown that approximately 1.5 million tons of salt/year are imported into the Phoenix area (Rossi et al., 2005). The fate of these salts from preliminary estimates is as follows (Rossi et al., 2005):

- 39% discharged to groundwater through recharge and agricultural irrigation
- 22% trapped in the vadose zone following urban irrigation
- 8% deposited in lakes, evaporation ponds, and other water bodies
- 31% deposited in consumer and industrial appliances, water supply infrastructure, evaporative coolers, cooling towers, and other places of evaporation

Similarly, aquifers in agricultural areas near Tucson are experiencing increasing salinity from the application of high-TDS irrigation water combined with fertilizer applications (Rossi et al., 2005).

Major Ion Toxicity

Membrane concentrates may cause toxicity in aquatic environments under disposal alternatives such as wetlands treatment, freshwater marsh and salt marsh restoration, and aquaculture beneficial uses. Relevant results from the American Water Works Association Research Foundation (AwwaRF) study on major ion toxicity are summarized here (Mickley, 2000; all information in this section is derived from this source). The concentrates studied in detail were from Florida, but the report also describes expected results for concentrates from other regions.

National Pollutant Discharge Elimination System (NPDES) permits now require whole effluent toxicity (WET) tests. Concentrates have been shown to fail these tests with certain test organisms, and the mechanism has been shown to be an ion imbalance relative to the background water quality the test organisms normally inhabit. The WET test in Florida utilizes the mysid shrimp (*Mysidopsis bahia*) as a test organism, and this species appears to be especially sensitive to ionic imbalances. The requirements for which organism to use and the test procedure (whole effluent or whole effluent with a concentration factor) are state specific. Most states do not require the sensitive mysid shrimp, because the mysid shrimp are not native to their respective areas (M. Mickley, personal communication).

The origin of this toxicity in the AwwaRF study was traced to the concentrations of calcium and fluoride. “Major” ions in the AwwaRF study were defined as Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, Br^-, SO_4^{2-}, Sr^{2+}, and $B_4O_7^{2-}$. The following were major conclusions of the study:

- Excess calcium was the cause of toxicity for seven of the nine concentrates.
- Excess fluoride was the major and possibly only contributor to toxicity in two of nine concentrates and likely was a contributing factor in two others.
- Deficit potassium was a contributing factor to toxicity in one concentrate.
- The proportions of major ions present in seawater are critical. The more that concentrations of certain ions in concentrates diverge from these relative proportions, regardless of salinity level, the greater likelihood of toxicity.
- The degree of imbalance or extent of dissimilarity from seawater relative proportions can be quantified by the percent difference from balance (PDFB) value. Since PDFB values are similar for raw waters and concentrates, raw water chemistry drives the ion imbalance. This is important because the PDFB value can be used to predict major ion toxicity problems based on raw water analysis.
- Results of the study can be used to evaluate NF/RO plants operating with similar membranes and operating characteristics as plants evaluated in the study.
- To date, major ion toxicity from membrane concentrate as per the WET test has not been identified anywhere other than in Florida (Mickley, 2004a). Raw water data from Arizona, California, Illinois, Nebraska, New Jersey, Pennsylvania, and Texas were analyzed in the report. Results showed that brackish groundwater from several states was more likely to result in calcium toxicity than Florida groundwater; however, since these states do not require the mysid shrimp WET test, major ion toxicity has not been previously recognized. Only New Jersey and Texas were less likely to have calcium toxicity. If membrane plants in other states are required to conduct mysid shrimp WET tests, evidence of major ion toxicity is likely to be the result. The study also concluded that fluoride toxicity would likely result from concentrates at many other locations.
- Major ion and fluoride toxicity is for all practical purposes restricted to groundwater sources, as those raw water proportions are most likely to diverge from seawater norms.
- Treatment is not currently economically feasible for specifically removing excess calcium or fluoride, and dilution or better diffusion of discharges may be options.
- The occurrence of major ion toxicity is characterized by sharp concentration thresholds that lead to it being mitigated at low dilution ratios of 4 or higher. Partially because of this characteristic and the “different” nature of this toxicity compared to heavy metal or pesticide toxicity, the State of Florida has modified regulatory requirements for small systems (M. Mickley, personal communication).

Another issue for Florida is discharge of nutrients. Concentrates from brackish groundwater sources may have elevated nitrogen levels that could pose a problem when discharged to surface water bodies.

Human and Ecological Risk Analysis

The National Research Council (NRC, 2004) has stated that the most appropriate and feasible option for concentrate disposal tends to be highly site specific to the project. The characteristics of the concentrate as well as the receiving environment can be highly variable depending on the site and, therefore, risks need to be assessed using the specifics of the source materials and receiving environment.

Many of the potential risks are addressed when meeting the regulatory requirements that are based on common exposure pathways. This includes protection of potable water supplies and surface water standards developed for designated uses. These surface water standards are generally based on the lower of the criteria for protection of sensitive aquatic organisms or criteria for protection of human health from ingestion of fish (and, possibly, potable use). Regulatory requirements may include using toxicity (WET) testing that may demonstrate issues with major ions as well as trace constituents.

Risk analysis can supplement regulatory requirements, and alternate exposure pathways may be more relevant for certain options. Risks associated with the disposal of concentrates depend largely on whether humans or ecological receptors (plants and animals) are potentially exposed to them and which ionic or other constituents are found in the concentrates. Regulations do not necessarily address all potential exposure pathways. For example, use of concentrate for irrigation in a park or in ponds attracting avian receptors results in higher exposures and adverse impacts. For human health evaluations, the general focus is on public health rather than workers, specifically those involved in the water treatment industry. These industry workers are trained to understand health and safety issues and take precautions as appropriate. However, for off-site uses of concentrate (agricultural fields or aquaculture facilities), worker exposure may be evaluated to determine if information on safe use of this water is warranted.

Since standards are not necessarily promulgated for all constituents that may be detected, constituents without promulgated regulatory standards might be evaluated. Site-specific water quality criteria may be derived that are more relevant than default values. Risk-based calculations can be used to derive protective concentrations consistent with the assumptions used to derive standards. This strengthens the demonstration that the existing concentrate composition is safe for the intended use. A range of emerging contaminants may be detected for which no standards are currently available, and this risk evaluation provides an avenue to address and reduce public concerns for many trace constituents.

Ecological risks from those constituents are most likely to occur if the discharge is to surface water, an evaporation pond, salt marsh, or freshwater wetland, if the concentrate contains constituents that are either directly toxic to plants or animals, or if constituents may bioaccumulate in aquatic food webs. Risk assessment provides an approach for characterizing concentrates with respect to specific exposures and potential adverse effects. Guidance for conducting such assessments is available from USEPA (1989; 1998; 2004) and other agencies, but approaches must be adapted to particular projects. Because there is no universal pattern for ecological risk assessment, agencies rely heavily on professional judgment.

The best approach is to conduct the assessment in a phased manner, so that the results from one phase are used to determine whether further studies are needed and, if so, specifically what additional information is needed (see Lemly and Ohlendorf [2002] for further discussion). In this way, only the necessary amount of study is conducted but all the needed information is obtained. For example, only one of several trace constituents may exceed default water quality criteria. However, further analysis may determine that alternate receptors of interest at that site are less sensitive to this constituent and that the discharge to this water body does not pose a risk.

Human health and ecological risk factors are discussed for the various alternatives in Chapters 2 and 3.

DOCUMENT ORGANIZATION

Chapter 1 provides an introduction to the issues associated with concentrate disposal. Chapter 2 provides a summary of the more conventional methods of concentrate disposal, to provide a reference point for the evaluation of possible beneficial or nontraditional uses of concentrate. Chapter 3 provides information on beneficial and nontraditional uses of concentrate as a liquid, and Chapter 4 provides information on technologies and markets for salts separated from concentrates. Chapter 5 provides a summary, comparisons, and tools to aid in the evaluation of disposal options.

Caveat on Costs of Disposal Options

Costs of disposal options presented in this report should not be applied directly without careful examination of site-specific considerations. Relatively little information is available for many of the beneficial and nontraditional disposal options described in Chapter 3 or for recovery of separated salts as described in Chapter 4.

CHAPTER 2

TRADITIONAL DISPOSAL

As described previously, the current means of membrane concentrate disposal for water utilities are (in order of decreasing frequency of use) surface water discharge, sewer discharge, deep well injection, evaporation ponds, land application and irrigation, recycling, and reuse. Most existing U.S. plants use surface water discharge, sewer discharge, or deep well injection for concentrate disposal.

This chapter provides a summary of each of these established disposal options to provide a basis for comparison with other potential beneficial and nontraditional alternatives (see Chapter 3).

The description of each disposal option includes a general description, implementation considerations, geographical limitations, regulatory issues, cost, human health and ecological risk issues, and the applicability and impact of the disposal method on overall basin salt management.

SURFACE WATER DISCHARGE

Discharge to surface water is the simplest disposal option in terms of required equipment for most membrane process plants and also typically has the lowest cost. Not surprisingly, it is the most commonly used method (Mickley et al., 1993). Surface water discharge includes release to water bodies such as rivers, lagoons, and the ocean (AWWA, 2004). Although simple and low cost, at some sites environmental issues associated with permitting feasibility and regulatory concerns can severely limit this option.

For the purposes of this report, ocean beach injection is considered a variant on oceanic discharge rather than as deep well injection, because these wells are typically rather shallow and there is a relatively direct connection to the surface water.

Implementation Issues

Major implementation issues for surface water discharge include water body, physical and chemical characteristics of the concentrate, posttreatment issues, conveyance, and the outfall.

Water Body

The most important factor in determining the feasibility of membrane concentrate disposal by discharging to surface water is the availability of a suitable body of water for membrane concentrate of a given quality. Characteristics determining the suitability of a specific body of water for acceptance of membrane concentrate include the following:

- Water quality of both the membrane concentrate and the water body
- Volume and flushing characteristics of the water body
- Environmental sensitivity of the water body
- Proximity of the water body to the membrane treatment facility
- Flow rate of the membrane concentrate

Several types of surface water discharges may be used (WDTF, 2003a), including the following:

- Direct ocean outfall: commonly used by desalination facilities in the Middle East
- Shore discharge: used by smaller plants; takes advantage of the turbulent mixing zone created by wave action. Desalination plants on the islands of Malta and Santa Catalina, CA, are examples.
- Power plant outfall: Concentrate is blended with the large volume of cooling water discharge from a power plant. The Tampa Bay Water desalination facility in Florida uses this method.
- Beach well disposal: Injection wells in beach sands are used to allow mixing with ocean water within the sand and to take advantage of the turbulence from wave action for additional mixing. This method is used by the Marina Coast District seawater RO plant near Monterey, CA.
- Discharge to rivers or canals: typical of inland facilities with surface water discharge, but also includes (1) coastal communities in Florida that discharge to the Indian River estuarine area or brackish canals that feed it and (2) facilities near Chesapeake Bay, Elizabeth River (Virginia), and others.

In southern California, most planned and proposed desalination facilities will use existing ocean outfalls for disposal, either by direct discharge for coastal plants or by discharge to a brine interceptor for inland plants (CH2M HILL, 2004). Inland discharges of concentrate to inland water bodies in California are rare because of water quality regulations (CH2M HILL, 2004).

Physical and Chemical Characteristics of the Concentrate

The physical and chemical issues include concentrate density, pH, and aquatic toxicity issues from specific constituents, such as high hydrogen sulfide (H_2S) or ammonia (NH_3) or low dissolved oxygen (DO) from groundwater sources (Mickley, 2004a). Surface waters for which there are high water quality standards may have discharge issues for other inorganic ions and metals in the concentrate that exceed background levels (e.g., radionuclides).

Raw waters are typically low in contaminants and, thus, low in concentrates (Mickley, 2004a). However, some locations can have specific problems. Concentrate from plants desalting brackish groundwater may have excessive levels of radionuclides or H_2S or inadequate levels of DO that require treatment prior to discharge (AWWA, 2004). For example, 16 plants in Florida, Iowa, Illinois, and Missouri identified radium as the reason for using membrane technology (Mickley, 1993), resulting in concentrates high in radium. Chlorine used for maintenance of ED/EDR plants may require treatment before discharge (AWWA, 2004).

Concentrate from a seawater desalination facility can easily double the salinity at the point of discharge, as well as contain cleaning solution chemicals, both of which can be toxic to marine organisms (CH2M HILL, 2004). A draft report by the California Coastal Commission (2004) notes that few species are likely to be unaffected by significant increases in salinity and that various chemicals in concentrate can be a concern (CH2M HILL, 2004).

Buoyancy is a discharge issue that is much less common for other types of wastes. If the concentrate is higher in salinity than the receiving water, the concentrate sinks after discharge, where it may impact the benthic ecosystem (Mickley, 2004a). Temperature is closely related to buoyancy, which is especially relevant for desalination plants sharing an outfall with once-through cooling power plants.

Blending

Codisposal of concentrate in an existing outfall along with wastewater may make surface water disposal feasible (Morales and Smith, 2004). Blending is a common practice in Florida, such as mixing with treated effluent before discharge to reduce salinity (Mickley, 2004a), and the majority of the 62 ocean outfalls in southern California discharge a blend of wastewater effluent and brine and concentrate (CH2M HILL, 2004).

Posttreatment Issues

Depending on membrane concentrate quality and discharge permit guidelines, discharging membrane concentrate to a surface water may require posttreatment. Membrane concentrate may be posttreated to remove toxic constituents and/or aerated to increase the DO concentration.

Posttreatment of membrane concentrate most commonly includes aeration and static mixing to increase the DO concentration of the concentrate stream prior to discharging into surface water. Air is introduced by the air compressor into the concentrate stream. Mixing energy is then imparted on the discharge stream by a static mixer that serves to increase the transfer efficiency of oxygen into the discharge stream. Additional posttreatment may include appropriate processes to remove constituents in the concentrate stream that may be harmful to the receiving surface water and pH adjustment (Mickley, 2004a). In Florida, H_2S in the concentrate must be removed by aeration or oxidation.

Conveyance Issues

Subsequent to posttreatment, concentrate is conveyed to the discharge point where it is released into the receiving water body. Conveyance infrastructure required to transport the membrane concentrate to the discharge point may include a pipeline, open channel, or lined ditches. The materials used to construct the conveyance system are an important consideration due to the corrosivity of the membrane concentrate resulting from high TDS concentrations. The time required for conveyance of the membrane concentrate to the discharge point is also a key consideration in applications where sparingly soluble salts (such as carbonates, sulfates, and silicates) are supersaturated. Given a sufficient amount of time, precipitation of these salts may occur in the conveyance system, resulting in scaling of infrastructure surfaces.

Pumping Issues

During the design of a membrane concentrate conveyance system, the pumping system is a critical consideration. Depending on the energy of the membrane concentrate exiting membrane treatment and the energy requirements for conveyance of the membrane concentrate to the discharge point, a pumping system may or may not be required. Typically, concentrate has sufficient residual pressure to not require repumping unless posttreatment requires breaking head (e.g., aeration).

Outfall Issues

Adequate mixing with the receiving body ensures that the membrane concentrate does not create localized water quality differences. The goal is rapid initial dilution and effective dispersion (CH2M HILL, 2004). Outfall design, however, can be complex for some locations (Mickley, 2004a). Outfall design can range from a pipe dropping water into a surface water body to a complex, submerged diffuser (Mickley, 2004a). Diffusers can be designed to reduce the adverse impact of differences in buoyancy (Mickley, 2004a). Diffusers are also used to achieve mixing and dilution in a “mixing zone” so that background water quality is not impacted once the concentrate and receiving stream leave the mixing zone.

Other Issues

Other significant implementation issues are summarized in Table 2-1.

TABLE 2-1

Summary of Other Implementation Issues for Surface Water Discharge

Parameter	Discussion
Geographical and Climatic Relevance	Applicable to most regions of the United States; oceanic discharge is most flexible; unlikely to be an option for most inland desalination facilities (Ahuja and Howe, 2005)
Level of Water Utility Control	Very high level of control
Membrane Cleaning Solutions	Site specific, but generally can be addressed through posttreatment or separation of concentrated streams for sewer discharge
Proven Technology	Well-proven, widely used

Regulatory Issues

The feasibility of implementing discharge to surface water for membrane concentrate disposal is contingent upon the ability to obtain adequate permitting and associated economics. Regulatory issues involved with discharging membrane concentrate to surface water primarily involve obtaining an NPDES permit and any permits associated with conveyance to the discharge site. In some cases, individual states have implemented their own NPDES guidelines that must be followed. Requirements for obtaining an NPDES permit include determinations of membrane concentrate quality and quantity. In addition, prior to issuance of an NPDES permit, reporting guidelines to the regulating agency are to be determined.

An NPDES permit will only be issued if stringent guidelines imposed by national and state authorities are met. These guidelines are dependent on the body of water being discharged into as well as secondary treatment standards. Additional information regarding the application process for an NPDES permit is provided in the *U.S. EPA NPDES Permit Writers’ Manual* (USEPA 1996). NPDES permits for ocean discharges typically focus on habitat impacts and specify limits for total suspended solids (TSS), biological oxygen demand (BOD), toxicity, and residual chlorine (CH2M HILL, 2004).

Typically, due to the high TDS of ocean water, there is no TDS limit on ocean discharging. In Florida, there would likely still need to be demonstrated compliance through the use of a mixing zone in order to meet the state’s antidegradation policy. However, discharge to other surface waters will likely have some restrictions on the TDS level of the membrane concentrate. The San Antonio Water System (SAWS) determined that their projected concentrate of 36,000 mg/L of TDS would preclude surface water or groundwater discharge unless it could be diluted to 1000 mg/L (Morales and Smith, 2004).

Specific constituents that may be problematic to permit include TSS, TDS, nitrogen, phosphorus, arsenic, and barium (AWWA, 2004). If salinity at the point of discharge increases by more than 10%, the discharge can be difficult to permit (AWWA, 2004). Blending concentrate with lower-salinity water such as wastewater, surface water, groundwater, or cooling tower water may be required in some instances (AWWA, 2004). For example, permitting may be more favorable in instances where concentrate is blended with cooling water discharge from power plants using seawater in a once-through system (AWWA, 2004).

As described in Chapter 1, WET tests can limit surface water discharge, as has been observed in Florida due to the concentrations of calcium and fluoride and the use of mysid shrimp as the test organism (AWWA, 2004; Mickley, 2000). Virtually all new NPDES permits require bioassays (WET tests) (Mickley, 2004a), but the test organism to be used is determined by the regional and local regulatory groups (M. Mickley, personal communication).

In many cases, a detailed environmental impact study will be needed to obtain a permit to discharge membrane concentrate to an ocean outfall (CH2M HILL, 2004). If an initial environmental impact report is favorable, a temporary permit may be issued during design and construction of the treatment facility. A permanent discharge permit will not be issued until extensive tests are done to determine constituent concentrations with the actual discharge. A bioassay test must also be conducted and passed before an ocean discharge permit can be issued.

The Coastal Zone Management Act requires all federal permittees who affect a state’s coastal zone to comply with state guidelines regarding coastal zone management. These guidelines could affect any ocean discharge requiring one or more federal permits. The coastal zone includes states adjacent to the Great Lakes and all East, West, and Gulf Coast states (Pontius et al., 1996). A mixing zone may be granted, and concentration criteria and bioassay criteria (WET) are defined at the boundary of this zone (Mickley, 2004a).

The 2004 Effluent Guidelines Plan, proposed by USEPA [sections 304(b) and 304(m) of the CWA], includes a new category for existing water treatment plant discharges. New federal limits could be imposed on either sewer discharges (indirect discharges) or discharges to waters of the United States (direct discharges). Final action on the proposal is slated for August 2007. Increased use of seawater desalination, combined with increased public awareness of ocean water quality, suggests that increased restrictions on ocean discharges could be imposed (CH2M HILL, 2004).

Computer programs are used to determine the near-field and far-field mixing and dilution associated with discharges through outfalls to surface water environments. Dilution occurs as ambient water is entrained into the effluent discharge through the process of transfer of momentum. USEPA has supported a number of initial dilution models, including Visual PLUMES, CORMIX, and UDKHDEN. These models focus on the near-field plume behavior as it enters an ambient water body. The near-field dilution of the plume is primarily a function of the exit velocity of the plume, ambient current velocities, buoyancy differences between the effluent and the ambient fluids, and possible interactions between plumes if the effluent is discharged through a multiport diffuser structure.

Outfalls are generally designed in order to meet environmental requirements (such as maximum concentrations) at a certain distance from the outfall terminus. Inside this distance, generally termed the mixing zone, constituent concentrations are allowed to be above compliance standards. Diffusers are designed to maximize mixing, generally by increasing the initial effluent velocity through a number of ports in a diffuser structure and by limiting plume overlap, so that constituent concentrations are below water quality standards at the boundary of the mixing zone.

Assumptions are often required during the developmental phase of numerical models, and the standard near-field models have their share of assumptions. One usually relevant example is that the models generally assume an infinite water body. That is, the models assume no interaction with the shoreline or other structures that would limit mixing and dilution in the plume. Experience in the application of these models allows for proper treatment of discharges that do not adhere to the assumptions used in the model development. For example, the use of image sources is frequently necessary to take into account the influence of boundaries on the spreading and evolution of the discharge plume.

Near-field dilution models can be applied to both inland and coastal discharges. In the case of coastal discharges, far-field models are generally used to account for tidal action that can carry diluted effluent back into the mixing zone, thus limiting future dilution. Multidimensional hydrodynamic models are often used to determine the long-term and far-field impacts of coastal or estuarine outfalls.

Gaining the needed approvals for new ocean outfalls in California would be a costly, lengthy, and difficult process and would include permits from the State Water Resources Control Board, Regional Water Quality Control Board, U.S. Army Corps of Engineers, California Coastal Commission, California Department of Fish and Game, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration (NOAA) fisheries (or National Marine Fisheries Service), local agencies, completion of the California Environmental Quality Act process, an Endangered Species Act evaluation, and consultation with the State Lands Commission (CH2M HILL, 2004).

Future regulatory issues may include concentrating contaminants of human origin, such as nitrate and pesticides from agricultural areas, arsenic from mining waters, and even endocrine-disrupting compounds (Mickley, 2004a). Increasingly stringent regulations on discharges will complicate surface water discharge in the future (Sandia, 2003). For example, although not yet an issue in the United States, pesticide and arsenic removal treatments of concentrate have been conducted in Europe (Mickley, 2004a).

Cost Considerations

Costs associated with the discharge of membrane concentrate to surface water include the following:

- Engineering costs associated with obtaining required discharge permits
- Design and construction costs for required posttreatment, conveyance system, and outfall structure, including diffuser requirements (AWWA, 2004)
- Land acquisition costs for easements or colocated plants

- Operation and maintenance (O&M) costs associated with posttreatment, conveyance system, and outfall structure, including labor, chemicals, and power costs
- Ongoing water quality testing and permit renewals

Development of a simple cost model for surface water discharge is not feasible because of the number of cost inputs and large range of design considerations (Mickley, 2004a). All disposal options require some type of conveyance; however, surface water disposal often includes the sometimes costly and complex element of underwater conveyance, which may be up to four times as expensive as on land (Mickley, 2004a).

Capital Cost

Major capital cost elements include the following (Mickley, 2004a):

- Conveyance of concentrate to the shoreline
  - Pump
  - Pipeline
  - Fabrication
  - Trenching of pipeline
- Pipe from shore to outfall
  - Pipeline
  - Possible underwater fabrication
  - Dredging or trenching
  - Outfall structure
- Pipe (diffuser)
  - Risers
  - Ports
  - Fabrication
  - Possible trenching

Sharing of outfall structures with WWTPs, power plants, or other discharge facilities has several advantages, including sharing outfall costs, advantages of dilution, and the relative ease of obtaining a modified versus a new permit (Mickley, 2004a).

Costs associated with obtaining required discharge permits include data collection and interpretation, permit preparation, and data reporting once the facility begins discharging membrane concentrate.

Design and construction costs include equipment for posttreatment of membrane concentrate, if required, and infrastructure for the conveyance system and outfall structure. Equipment for posttreatment of membrane concentrate to increase the DO of the discharge stream typically includes an air compressor and static mixer. Additional posttreatment equipment may be required to remove toxic constituents and comply with discharge permits.

Capital costs for the conveyance of membrane concentrate to the discharge point include design and construction of conveyance infrastructure, such as a pipeline, open channel, or lined ditch. These costs may also include right-of-way acquisition, permitting, and surface restoration.

The outfall structure from which the membrane concentrate is discharged is typically a length of pipe with numerous ports on either the side or bottom to distribute the membrane concentrate in the receiving surface water. Ocean outfalls are more complex structures and are more expensive to construct. They usually consist of a pipeline that transports the membrane concentrate stream some distance from the shoreline into the ocean before discharging in a single stream or from multiple ports in the pipeline.

O&M Cost

O&M costs related to disposal of membrane concentrate include chemicals and labor required for posttreatment, power consumed during posttreatment and conveyance to the discharge point, and maintenance of conveyance and outfall infrastructure. Monitoring costs can be considerable, especially if the discharge is near an environmentally sensitive area (AWWA, 2004).

Economic Risk Factors

Economic risk factors include changing permit requirements and the discovery of previously unknown or underestimated environmental impacts.

Cost of Lost Water

Surface water discharges may be recoverable by a downstream user for inland discharges. Ocean discharges return to the global water cycle, but if discharged at less than seawater salinity (e.g., brackish groundwater RO concentrate less than 35,000 mg/L of TDS), this could be considered a “loss” of higher-valued water.

Human Health and Ecological Risk Factors

Many of the regulatory constraints discussed previously are based on potential adverse impacts to human health or ecological receptors. When discharging to surface water bodies, potential impacts on aquatic organisms are primary considerations. Human health impacts may occur if the discharge degrades water quality for potable water use downstream, limits recreational use of the surface water body, or restricts fish ingestion because of accumulation of toxic constituents.

For inland facilities, ecological receptors would be sensitive to significant salinity changes. The NRC (2004) has stated that surface water discharges should be avoided for inland facilities to avoid degradation of surface water and groundwater. In addition to cumulative increases in salinity downstream potentially resulting from multiple dischargers, surface water standards for toxic constituents and pathogens are developed to be protective of public health based on designated uses for the streams. As emerging constituents of interest are identified, human health risk-based concentrations may be derived based on standard assumptions for potential potable use and/or fish ingestion for bioaccumulative constituents. For many constituents, water quality criteria are more conservative for protection of aquatic receptors because of higher exposures for these receptors.

Ecological risk factors are likely to be one of the major constraints for facilities with an oceanic discharge. Concentrates may contain elements that are toxic to aquatic organisms or may cause food chain impacts. Some constituents (such as the major ions identified in Chapter 1) cause direct toxicity to aquatic organisms, while others that may be present in concentrates (such as arsenic, mercury, and selenium) may bioaccumulate in the aquatic food chain and cause unacceptable levels of exposure for fish or wildlife. To determine whether they are likely to cause toxicity in surface waters, the significance of the various constituents can be evaluated on a site-specific basis by comparing waterborne concentrations to ambient water quality criteria or other ecological benchmark values.

An ecological risk assessment or environmental impact analysis is the recommended approach for evaluating the potential ecological significance of constituents to the receiving water body. In an ecological risk assessment, the receiving environment (whether inland or oceanic surface waters) is characterized to identify potentially affected plants and animals, the concentrate is characterized to identify constituents and the concentrations that may occur in the receiving environment, ecological benchmark concentrations for direct and indirect effects (such as ambient water quality criteria and food chain concentrations causing effects in higher trophic levels) are determined (through literature searches or site-specific testing), and the expected concentrations are compared to the ecological benchmarks. Guidance for conducting such an assessment is available from USEPA (1998).

Applicability to Other Salt Streams and Overall Basin Salt Management

Inland surface water discharge results in an increased salt load for downstream users, who must then implement technologies to again remove excess salt (Sandia, 2003) for water supply purposes.

Conclusions

Surface water discharge is the simplest, most common, and typically the cheapest disposal option, if available. Characteristics of the receiving water body and the concentrate are critical considerations. Blending with WWTP discharge or cooling water discharge provides a number of advantages, including shared infrastructure and reduced impacts on the receiving water. Potential impacts to aquatic organisms are a primary consideration, and human health impacts may occur if potable water quality is degraded downstream, recreational uses are limited, or there are restrictions for eating of fish. Ecological risk factors are likely to be the major issues for oceanic discharge, and increasing difficulty with permitting new ocean discharges is likely unless regulations are updated and/or technologies improve.

SEWER DISCHARGE

Sewer discharge is typically a low-cost, easy-to-permit solution for small membrane plants (AWWA, 2004), depending on the size of the WWTP. Smaller membrane plants typically do not result in a large impact on WWTP operations (AWWA, 2004). This method of disposal is particularly attractive for low-TDS and/or low-flow membrane concentrates, such as those from NF softening. Industries in the Phoenix area also commonly use sewers to discharge concentrates (CASS, 2005).

Wastewater effluent mixing involves combining the membrane concentrate with the treated wastewater effluent at a WWTP to take advantage of the blending capacity of a lower-TDS stream. The combined stream can be discharged in accordance with existing permits or land applied.

Implementation Issues

Due to the simplicity of this method of membrane concentrate disposal, implementation issues are minimal.

Concentrate Discharged to Sewer (Mixing with WWTP Influent)

Implementation issues for concentrate discharged to sewer are limited to negotiation of fees and potentially an assessment by the WWTP of any impacts on WWTP operations and treatment processes. New concentrate discharges that increase WWTP effluent TDS may pose difficulties for smaller plants, especially those that rely on golf courses and other reuses for disposal (CASS, 2005). Studies have shown that wastewater treatment processes are inhibited with TDS concentrations exceeding 3000 mg/L (CASS, 2005).

Concentrate Discharged with WWTP Effluent (Mixing with WWTP Effluent)

For concentrate discharged with WWTP effluent, requirements include a pipeline to convey the membrane concentrate to the WWTP discharge where the concentrate is blended with wastewater effluent. Depending on the pressure of the membrane concentrate, a pumping system may be required as well. The West Basin Municipal Water District in El Segundo, CA, uses this approach (WDTF, 2003a).

Other Issues

Other significant implementation issues are summarized in Table 2-2.

TABLE 2-2

Summary of Other Implementation Issues for Sewer Discharge

Parameter	Discussion
Geographical and Climatic Relevance	Generally universally applicable
Level of Water Utility Control	High level of control, within the bounds of the agreement with the WWTP
Membrane Cleaning Solutions	Generally easily addressed through WWTP treatment process or dilution with wastewater
Proven Technology	Well-proven, widely used
Biosolids Impacts	Some concentrates may result in adverse impacts on biosolids, especially land application programs

Regulatory Issues

Regulatory issues are the primary obstacle for disposing of membrane concentrate by mixing with wastewater effluent. Constraints associated with discharge to wastewater systems include NPDES permit constraints on the wastewater agency’s downstream discharge.

If the combination wastewater effluent and membrane concentrate stream complied with USEPA National Pretreatment Standards or state-specific standards, this method of disposal would be feasible. If, however, the NPDES guidelines would be exceeded, this would require either an additional NPDES permit for the membrane concentrate or a revised NPDES permit for the WWTP. Obtaining an additional NPDES permit for the membrane concentrate alone is the same as discharge to surface water. A revised NPDES permit for a WWTP allowing the combination of membrane concentrate with wastewater effluent would be difficult, but not impossible, to obtain. The membrane plant itself does not need an NPDES permit to discharge to the sewer (Mickley, 2004a).

Local sewer ordinance and CWA Industrial Pretreatment Program requirements will also apply to the concentrate (AWWA, 2004).

High-TDS and/or high-flow membrane concentrate streams could increase the TDS of the WWTP discharge over permitted regulations. If the TDS limitations of the WWTP discharge would be exceeded, this alternative for membrane concentrate disposal would be infeasible unless a revised permit allowing the higher TDS effluent could be obtained.

The primary regulatory risk is the potential for regulatory changes that affect the WWTP which will affect concentrate discharge.

Cost Considerations

Cost considerations include the infrastructure required to convey the membrane concentrate to the collection system. Depending on system hydraulics, a pumping facility may be required as part of the conveyance infrastructure. Typical conveyance cost considerations discussed previously are applicable.

Capital Cost

Requirements for infrastructure are site specific but may include pretreatment facilities, pumping, and conveyance.

O&M Cost

The major O&M cost is typically a negotiated fee paid to the local WWTP. This requirement has a large influence on the economic feasibility of membrane concentrate projects. Other impacts can include disruption to the biological process, as it is shocked by higher-TDS water, and scaling of equipment. Pumps can be especially prone to scaling where certain surfaces which are irregularly shaped or prone to heating can cause scale nucleation sites to form. Other O&M costs include operating and maintaining the conveyance.

Economic Risk Factors

Economic risk factors include the potential for increases in sewer fees, changing permit requirements, and underestimating environmental impacts of the ultimate combined discharge.

Cost of Lost Water

Where the WWTP outfall is inland, the water contained in concentrate discharged to a sewer may be recoverable by a downstream user. Similar to direct surface water discharge, ocean discharges are returned to the global water cycle, but if discharged at less than seawater salinity (e.g., brackish groundwater RO concentrate less than 35,000 mg/L of TDS), this could be considered a “loss” of higher-valued water.

Human Health and Ecological Risk Factors

Risks associated with sewer discharge are relatively low, assuming that constituents (1) would not be present in the concentrate at concentrations that represent a health risk for workers in the wastewater treatment plant, (2) would not adversely affect operation of the treatment system, and (3) would be treated to meet acceptable discharge permit conditions.

Applicability to Other Salt Streams and Overall Basin Salt Management

Any salt stream could potentially be discharged to a local WWTP; however, the total salinity of the influent must not exceed that required to maintain the treatment process at the WWTP.

Conclusions

Sewer discharge is the simplest means of concentrate discharge, if available. The availability of sewer discharge may be limited, especially for larger membrane plants. Regulatory issues are relatively simple, as the membrane plant itself does not need an NPDES permit. The major economic issue is the fee charged by the WWTP for the discharge.

DEEP WELL INJECTION

Concentrate can be injected through wells that penetrate far below the surface into porous subsurface geologic formations in a process known as deep well injection (CH2M HILL, 2004). Well depth is typically 1000 to 8000 ft (Mickley, 2004a). Nearly all plants using this disposal method are located in Florida (AWWA, 2004). Deep aquifers tend to be relatively low quality compared to nearer-surface drinking water aquifers and, thus, are acceptable for deep well injection (Mickley, 2004a).

Implementation Issues

Implementation issues for membrane concentrate disposal by deep well injection include site selection, well classification, membrane concentrate compatibility, and public perception.

Site Selection

Before deep well injection can be considered a viable alternative for membrane concentrate disposal, an appropriate site must be located. The site must have favorable underground geology conducive to deep well injection. Favorable factors include the following:

- A porous injection zone capable of sustaining adequate injection rates over the life of the membrane facility.
- An impermeable layer is required to prevent migration of the injected concentrate into an underground source of drinking water (USDW). A USDW is defined as any underground aquifer containing water with TDS at less than 10,000 mg/L. Suitable formations often have greater than 10,000 mg/L of TDS and are found at considerable depths (NRC, 2004).
- Injection may not be feasible in areas where seismic activity (earthquakes or faults) could potentially occur. Few if any sites in California exist that can be shown to be devoid of faults, fissures, or risk of earthquakes (CH2M HILL, 2004). Moreover, injection of concentrate could result in the activation of faults or increased seismicity (CH2M HILL, 2004).

- The injection zone must contain and isolate the discharge and not be in regions with recoverable resources, such as ores, coal, oil, or gas (Mickley, 2004a).
- The site should also be a sufficient distance from any wells penetrating the impermeable layer that may serve as a pathway through the impermeable layer and into a USDW.

Alternate Disposal Requirements

A second permitted disposal method is required for use when the well is shut down for periodic maintenance and testing.

Well Classification

Another implementation issue for deep well injection is the determination of the applicable class of well for a given site and waste quality. Five different classes of wells exist, which are categorized by the liquid waste origin and characteristics. A description of each well class is included in Table 2-3. The two classes of wells applicable to disposing of membrane concentrate are Class I and Class V wells.

TABLE 2-3

Description of Deep Well Classes

Deep Well Class	Description
I	Injectate equal to or greater than 10,000 mg/L of TDS
	Geologic confining layer present to prevent contamination of upper-level USDW
	Injectate may have a poorer quality than the USDW into which it is being injected
II	Wells used in the recovery of natural gas or oil (e.g., produced water injection)
III	Wells used to mine sulfur by the Frasch process (and other minerals, exclusive of oil and natural gas)
IV	Wells used to dispose of radioactive waste
V	Injectate is of greater quality than the water into which it is being injected
	Injectate is less than 10,000 mg/L of TDS

Source: adapted from CH2M HILL (2004).

In practically all cases, a Class I injection well is required, because the injectate (membrane concentrate) is typically of lower quality than the water below which it is being injected. For a Class V well to be applicable, the injectate must have less than 10,000 mg/L of TDS and be of better quality than the water into which it is being injected. This means that every constituent in the injectate must be at a lower concentration than in the receiving water. As a result of this stringent qualification, a Class V injection well is extremely difficult, but not impossible, to permit.

A schematic of a Class I injection well is shown in Figure 2-1. A typical Class I injection well consists of concentric pipes that extend several thousand feet below the ground surface into a highly saline, permeable injection zone, which is confined vertically by impermeable strata.

The outermost pipe or surface casing extends below the base of any USDW and is cemented back to the surface to prevent contamination of the USDW. Directly inside the surface casing is a long string casing that extends to and sometimes into the injection zone. This casing is also cemented back to the surface to seal off the injected waste from the formations above the injection zone. The casing provides a seal between the wastes in the injection zone and the upper formations. The waste is injected through the injection tubing inside the long string casing, either through perforations in the long string or in the open hole below the bottom of the long string.

The space between the string casing and the injection tube, called the annulus, is filled with an inert, pressurized fluid and is sealed at the bottom by a removable packer, preventing injected wastewater from backing up into the annulus. The annular fluid is typically maintained at a higher pressure than the fluid being injected to prevent injectate from leaking out of the injection casing. Additionally, monitoring of the annular fluid pressure provides a reliable method to detect the development of a leak.

Compatibility

Injected wastes must be compatible with the mechanical components of the injection well system and the aquifer. Pretreatment of injectate may be required to ensure compatibility with the geologic formation and water into which it is being injected. High concentrations of suspended solids (typically greater than 2 ppm) can lead to plugging. Organic carbon may serve as an energy source for indigenous or injected bacteria, resulting in rapid population growth and subsequent fouling. Concentrate streams containing constituents above their solubility limits (e.g., silica) may require pretreatment before injection into a well.

Public Perception

Implementation of deep well injection for disposal of membrane concentrate can be a public perception problem. In some instances, environmental groups opposing disposal of wastes by deep well injection have been successful in convincing the general public that deep well injection poses a significant risk of groundwater contamination, regardless of the precautions taken. Depending on the persuasion of the general public, deep well injection may not be acceptable, regardless of engineering precautions taken to ensure public health.

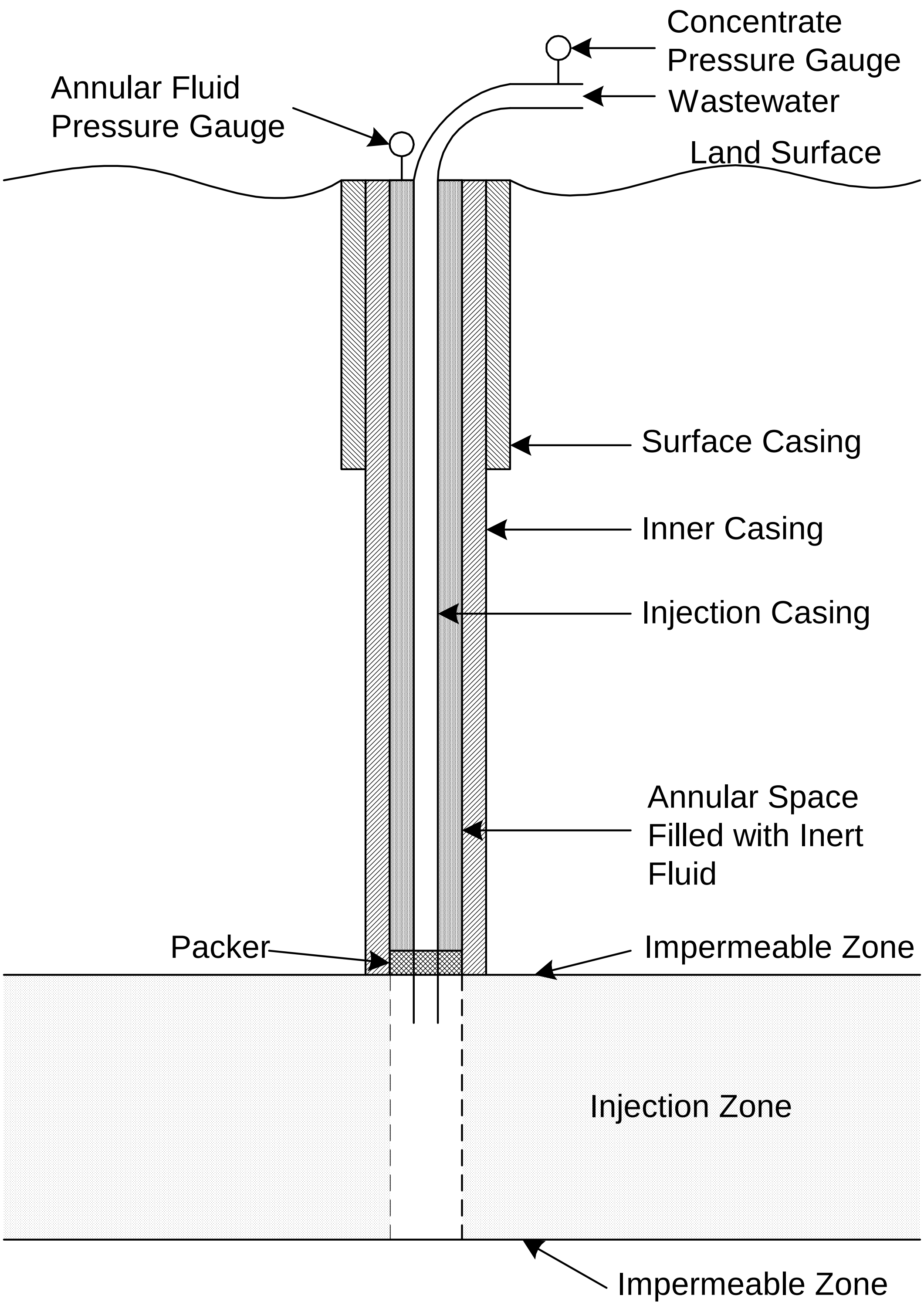


FIGURE 2-1
Typical Class I Deep Well Injection Schematic.
Source: CH2M HILL (2004).

Other Issues

Other significant implementation issues for deep well injection discharge are summarized in Table 2-4.

TABLE 2-4
Summary of Other Implementation Issues for Deep Well Injection Discharge

Parameter	Discussion
Geographical and Climatic Relevance	Favorable geology (strata capable of receiving the concentrate and separated from drinking water supplies by impermeable strata) are found in the mid-continental region, the Great lakes, and Gulf Coast (Mickley, 2004a); this option is currently widely used only in Florida, a state with favorable geology (AWWA, 2004); it is not a viable option in the basin and range region of central Arizona (CASS, 2005)
Level of Water Utility Control	Very high level of control
Membrane Cleaning Solutions	Site specific, but generally can be addressed through pretreatment or separation of concentrated streams for sewer discharge
Proven Technology	Well-proven, widely used

Regulatory Issues

Regulations governing the permitting of injection wells reside at the state level. However, most states have adopted the UIC guidelines set forth in the SDWA of 1979. Some states may have more stringent guidelines, but at a minimum, the UIC guidelines must be met. Deep well injection is not permitted in many states (Mickley, 2004a), due to potential contamination of drinking water aquifers (Sandia, 2003). In Texas, for example, injected water needs to meet drinking water standards (Morales and Smith, 2004), though there is some uncertainty as to exceptions for saline aquifers. The only classes of wells applicable to concentrate are Class I and Class V (CH2M HILL, 2004).

Permitting a Class V injection well is very difficult. To obtain a Class V injection well permit, the membrane concentrate being disposed of *may not increase the concentration of any constituent of the water into which it is being injected*. This requirement prevents a Class V injection well permit from being issued in practically all scenarios associated with membrane concentrate disposal. In some states, membrane concentrates from municipal or industrial facilities must be disposed of in Class I wells regardless of constituent concentrations. However, reclassification of the waste to allow disposal in a Class V well has been successful in a few cases. The injectate must also be less than 10,000 mg/L of TDS (CH2M HILL, 2004).

Permit requirements for Class I injection wells are also extensive. Subpart B, section 146.12 of the UIC regulations states, “All Class I wells shall be sited in such a fashion that they inject into a formation which is beneath the lowermost formation containing, within one-quarter mile of the well bore, an underground source of drinking water.” Other requirements include the need for an impermeable strata located above the injection zone to isolate what is injected from an overlying USDW (CH2M HILL, 2004). Extensive testing and modeling are required to demonstrate that a Class I well will not adversely impact a USDW, where a USDW is defined as any underground water source with less than 10,000 mg/L of TDS (CH2M HILL, 2004).

To confirm injection capacity, a test well is drilled and used. The test well is typically initially permitted as a Class II well to expedite the permit process but is constructed as a Class I well. If the test well is ultimately used for deep well injection, it will then be reclassified as a Class I well.

The time required to permit can be considerable, and USEPA is unlikely to make changes to deep well injection rules. El Paso Water Utilities began the permit process for a 2200-ft-deep well in December 2003, and the process is ongoing (CASS, 2005).

Cost Considerations

The cost associated with deep well injection of membrane concentrate depends on several factors, including permitting costs, site location, flow rate of membrane concentrate, permeability of geology, depth of injection zone, concentrate pretreatment, and well type.

Capital Costs

Major capital cost considerations include well depth and diameter, pretreatment, pump size and pressure, and the extent of monitoring, such as the number of monitoring wells needed (AWWA, 2004). In general, deep well injection is expensive, but there are economies of scale for larger plants (AWWA, 2004). The largest proportion of capital costs relates to labor and testing (drilling, reaming, cementing, and testing) rather than well materials (Mickley, 2004a). Concentrate is by federal definition an industrial waste, and injection wells for industrial wastes require expensive tubing and packer construction (Mickley, 2004a).

Major components of a deep well injection system, including function and well depth, are provided in Table 2-5 and are based on cost models developed by Mickley (2004a). A single 10-in. well is used as an illustration. The change in cost is relatively small with increased volumetric capacity (well diameter) (Mickley, 2004a). Most Florida monitoring wells used to monitor water quality in the upper, drinking water aquifer in the “boulder zone” of south Florida are placed at approximately 2000 ft below ground (Mickley, 2004a).

Pump requirements in terms of flow and pressure are also site specific, with pressure requirements ranging from as little as 3 pounds per square inch (psi) to as much as 5000 psi (Mickley, 2004a).

Obtaining a permit for deep well injection is costly, as it involves extensive geologic investigations, construction of a test well to exacting Class I standards, and complex permit applications (CH2M HILL, 2004). Spending in excess of $1 million during the permitting process is not uncommon.

TABLE 2-5
Summary of Injection Well Costs by Depth for a 10-In.-Diameter Well (2001 $, in thousands)

Cost Category	2500 ft	5000 ft	7500 ft	10,000 ft
Logging, Testing, Survey	295	360	425	490
Drilling and Reaming	500	925	1350	1775
Installed Tubing	280	500	725	950
Installed Packer	95	95	95	95
Installed Casing	600	1075	1475	1880
Installed Grouting	290	520	710	910
Monitoring Well (at 2000 ft)	600	600	600	600
Mobilization and Demobilization	640	800	850	900
Total	**3300**	**4875**	**6230**	**7600**

Source: Values are approximated from the figures in Mickley (2004a).

The location of the disposal site impacts the capital and operational costs of conveyance of the membrane concentrate from the membrane treatment facility to the disposal site. An increase in distance between the treatment facility and the disposal site results in increased capital costs associated with additional conveyance infrastructure and an increase in operating costs resulting from greater energy usage as previously discussed.

The flow rate of membrane concentrate determines the number of wells required to dispose of the concentrate into the site-specific geology. Data obtained by operating the test well provide the permeability of the injection strata, which is then used with the concentrate flow rate to determine the number of wells required.

The depth of the injection zone significantly increases the construction cost of the disposal wells. An increase in well depth increases the materials of construction as well as the complexity of construction operations.

O&M Cost

Operating costs are primarily driven by pumping power costs, with comparatively minor costs for chemicals and operating labor (Mickley, 2004a). For example, operation of a 150-gal/min (gpm) pump at 3150 psi gauge costs approximately $50,000/year, and maintenance consists of checking and repairing the casing as needed (Mickley, 2004a). Chemicals (e.g., corrosion inhibitors) cost as much as $7000 for a 150-gpm flow (Mickley, 2004a), and monitoring costs can be significant (AWWA, 2004). Other costs may include periodic video inspection and rehabilitation or cleaning of the well.

Pretreatment costs may include TSS removal and pH adjustment to minimize scale formation in the aquifer, but the cost of pretreatment is site specific (Mickley, 2004a). Pretreatment costs may also be incurred depending on the compatibility between membrane concentrate and the geologic strata of the injection zone. The membrane concentrate may require pH adjustment or other treatment to prevent precipitation of constituents in the injection layer.

Possible chemical reactions between the membrane concentrate and the geologic strata must be thoroughly analyzed to prevent a total loss of capital investment.

Cost of Lost Water

Once injected into a deep well, the water contained in the concentrate is unlikely to be economically recoverable for another use (Sandia, 2003) and, therefore, the entire volume is “lost.”

Economic Risk Factors

In addition to the potential for regulatory changes, economic risks include plugging of the injection zone and impacts to a USDW, despite precautions.

Human Health and Ecological Risk Factors

The primary human health exposure pathway for deep well injection relates to potential migration to public or private potable water supplies. One study indicated that there have been “relatively few injection well malfunctions that have resulted in contamination of water supplies” (Stryker and Collins, 1987, as cited by Mickley, 2004a), although Gordon (1984) documented instances where this has occurred and drinking water resources have been adversely affected.

At least five mechanisms of failure that may result in drinking water contamination have been identified (Stryker and Collins, 1987, as cited by Mickley, 2004a):

- Escape through the well bore into a USDW because of insufficient casing or failure of the injection well casing due to corrosion or excessive injection pressure
- Escape vertically outside the well casing from the injection zone into a USDW
- Escape vertically from the injection zone through confining beds that are inadequate because of high primary permeability, solution channels, joints, faults, or induced fractures
- Escape vertically from the injection zone through nearby wells that are improperly cemented or plugged or that have inadequate or leaky casing
- Contamination of groundwater directly by lateral travel of the injected wastewater from a region of saline water to a region of freshwater in the same aquifer

Ecological risks from deep well injection are low, unless failures (as described above) result in discharge of the concentrate to surface waters (or ponding at the surface) or in shallow subsurface discharge within the rooting depth of plants that affects surrounding vegetation.

Applicability to Other Salt Streams and Overall Basin Salt Management

Deep well injection is technically applicable to many other salt streams but may require pretreatment to be compatible with the geologic formation. Regulatory constraints are likely more significant than technical constraints.

In terms of overall basin salt management, a key advantage of deep well injection is that salts are removed from the system and will not impact downstream water users as long as the injection zone remains isolated.

Conclusions

Deep well injection is widely used, especially in Florida, where geologic conditions are favorable. It is, however, very expensive, but there are economies of scale for larger plants. The entire volume injected represents lost water, but salts are permanently removed from the basin.

EVAPORATION PONDS

Evaporation ponds rely on solar energy to evaporate water from concentrate, leaving behind precipitated salts, which are typically landfilled (CH2M HILL, 2004). Evaporation ponds tend to be more feasible in arid climates where net evaporation rates are high, minimizing land area requirements (CH2M HILL, 2004). This technology may be appropriate for lower-volume flows in areas of the arid southwest United States, where evaporation rates are high, precipitation is low, and land is relatively flat and low cost (Mickley, 2004a). The practicality of evaporation ponds is not limited by membrane concentrate quality, and evaporation ponds can accept concentrate from seawater, brackish groundwater, and softening applications (CH2M HILL, 2004). The largest facility known to be using this technology handles 1.5 million gal/day (MGD) (AWWA, 2004).

In the most common case, membrane concentrate is conveyed to evaporation ponds, where it is spread out over a large area and allowed to evaporate. Multiple ponds are typically constructed to allow continual receipt of membrane concentrate while some ponds are taken offline for periodic maintenance. Periodic maintenance sometimes includes allowing the evaporation pond to sit idle to firm the consistency of the precipitated salts. Once the precipitated salts have reached a satisfactory consistency, the ponds are cleaned by removing and transporting the precipitated salts to a landfill for ultimate disposal. Alternatively, ponds may be designed to have sufficient capacity for the life of the facility.

Solar evaporation is an ancient technology that has been used to concentrate seawater to recover salt (sodium chloride [NaCl]). Major advantages and disadvantages for evaporation pond disposal are as follows (Mickley, 2004a):

Advantages

- Easy to build
- Low maintenance compared to mechanical systems
- Mechanical components limited to pumps for conveyance
- Typically, least costly approach with the combination of small flows, low-cost land, and high evaporation rates

Disadvantages

- Large land area requirements if evaporation rates are low
- Expensive liners are often required
- Seepage can pose a risk for groundwater
- Minimal economy of scale
- High costs for larger plants

Implementation Issues

Factors affecting the feasibility of implementing evaporation ponds for membrane concentrate disposal include flow rate, potential use of evaporation enhancements, the availability and cost of suitable land, and climate.

Flow Rate and Area Requirements

Membrane concentrate flow rate is the primary factor affecting the area required for evaporation ponds. The greater the flow rate of membrane concentrate, the larger the area required for an evaporation pond. An estimate of the evaporation pond area can be obtained from the membrane concentrate flow rate and net evaporation rate. Figure 2-2 shows the net evaporation rates for areas in the United States. Areas with large negative net evaporation rates are attractive for siting evaporation ponds. An estimate of the pond area required should take into account the reduced evaporation rate of a brine solution compared to a typical surface water. A general guideline is to apply a factor of 0.7 to the evaporation rates shown in Figure 2-2. This reduces the evaporation rate by 30% to account for the lower evaporation rate of the brine solution.

Generally, ponds are designed to have sufficient storage capacity to allow accumulation of salts throughout the life of the facility without cleanout (Ahuja and Howe, 2005). The Palo Verde nuclear generating station in Arizona has been using its ponds since 1985, and solids disposal has not yet been required (CASS, 2005). If this is not the case, the actual pond area constructed should be greater than the minimum pond area required, to allow for a standby area that is put into service when other ponds are being cleaned. The standby area required will depend on the number of ponds constructed and the amount of time a pond will be offline for maintenance and/or cleaning. Furthermore, additional area is required for construction of dikes to contain the membrane concentrate. As a general guideline, 20% of the actual pond area should be added to accommodate dikes and a small buffer zone.

The depth of an evaporation pond can be calculated as follows:

$$\text{Depth of Evaporation Pond} = \text{Water Depth} + \text{Salt Storage} + \text{Freeboard}$$

The water depth of an evaporation pond should be sufficient to accommodate additional concentrate volume buildup during the portion of the year when the net evaporation rate is below the annual average net evaporation rate. This will depend on monthly hydrologic data for the particular geographic location.

Pond design factors include an allocation for salt storage and a freeboard depth sufficient to contain precipitation and allow for wave action when the pond is at the maximum water level. Wave allowances need to include run-up of waves on the face of the dike. Freeboard values typically range between 2 and 4 ft to take into account both precipitation and wave action.

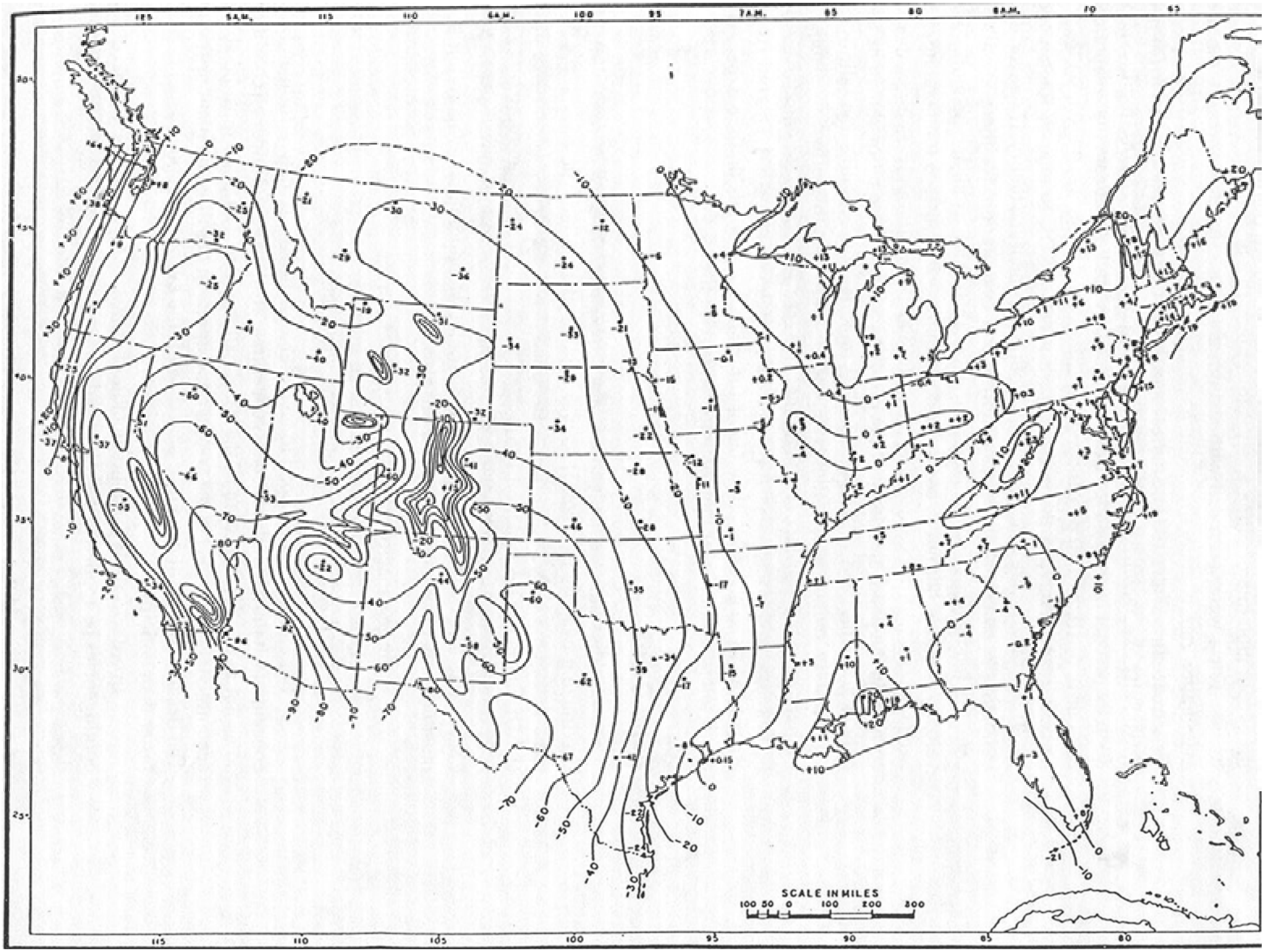


FIGURE 2-2
Map of Net Evaporation Rates in the United States.

Evaporation Enhancements

In many cases, the required area for evaporation ponds can prove to be a disadvantage. A hybrid method, incorporating misting equipment and solar evaporation ponds, may prove to be more attractive in instances where large evaporation pond areas are of concern. Brine solution in the evaporation ponds is pumped through misting equipment that sprays the brine into small droplets in the area over the evaporation ponds. By spraying the brine into small droplets, the surface area for evaporation is greatly increased, thereby increasing the evaporation rate for a given pond area. The droplets evaporate, leaving behind salt, which falls into the evaporation pond and is removed during periodic cleanings. A typical layout of an evaporation pond utilizing misting equipment is shown in Figure 2-3.

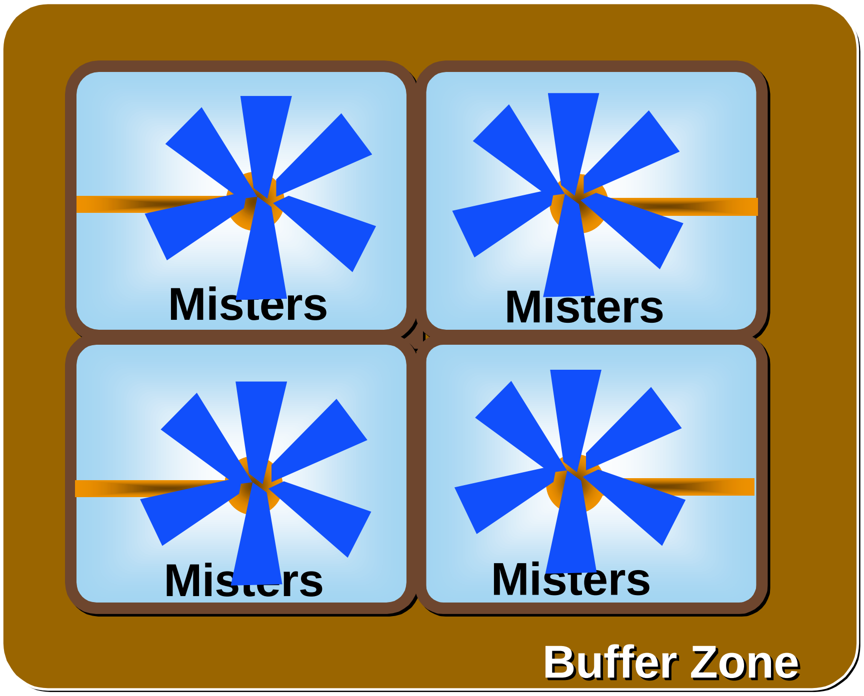


FIGURE 2-3
Conceptual Layout of Solar Evaporation Ponds with Misting Equipment.
Source: CH2M HILL (2004).

Misters are located at the center of each evaporation pond to minimize the potential for “salt drift” out of the pond area. In addition, a buffer zone should be provided to contain the salt drift on-site. Salt drift can also be minimized by installing a wind speed indicator to automatically take the misting equipment offline when the wind reaches a speed determined to cause salt drift in excess of the buffer zone allocated. Lack of adequate allowances for drift results in deposition of salts on the land, buildings, and equipment in the surrounding area (CASS, 2005).

An alternate technology to enhance evaporation and reduce the area required is currently being evaluated at the pilot scale in Israel (CASS, 2005; Gilron et al., 2003). Concentrate from the pond is pumped to the top of a series of vertical cloth surfaces that are suspended above a trough. The solution flows down the cloths, water evaporates, and salts accumulate. Precipitated salts are removed from the cloths by wind action and can be collected and landfilled (Fig. 2-4) (CASS, 2005).

Odor

Although fairly simple to construct and operate, evaporation ponds may pose a public nuisance problem. Depending on the constituents of the brine solution, the highly concentrated brine solution created during operation of the ponds tends to emit noxious odors. Therefore, the ponds should be sited away from residential areas, if possible.

Other Issues

Other significant implementation issues for evaporation ponds are summarized in Table 2-6.

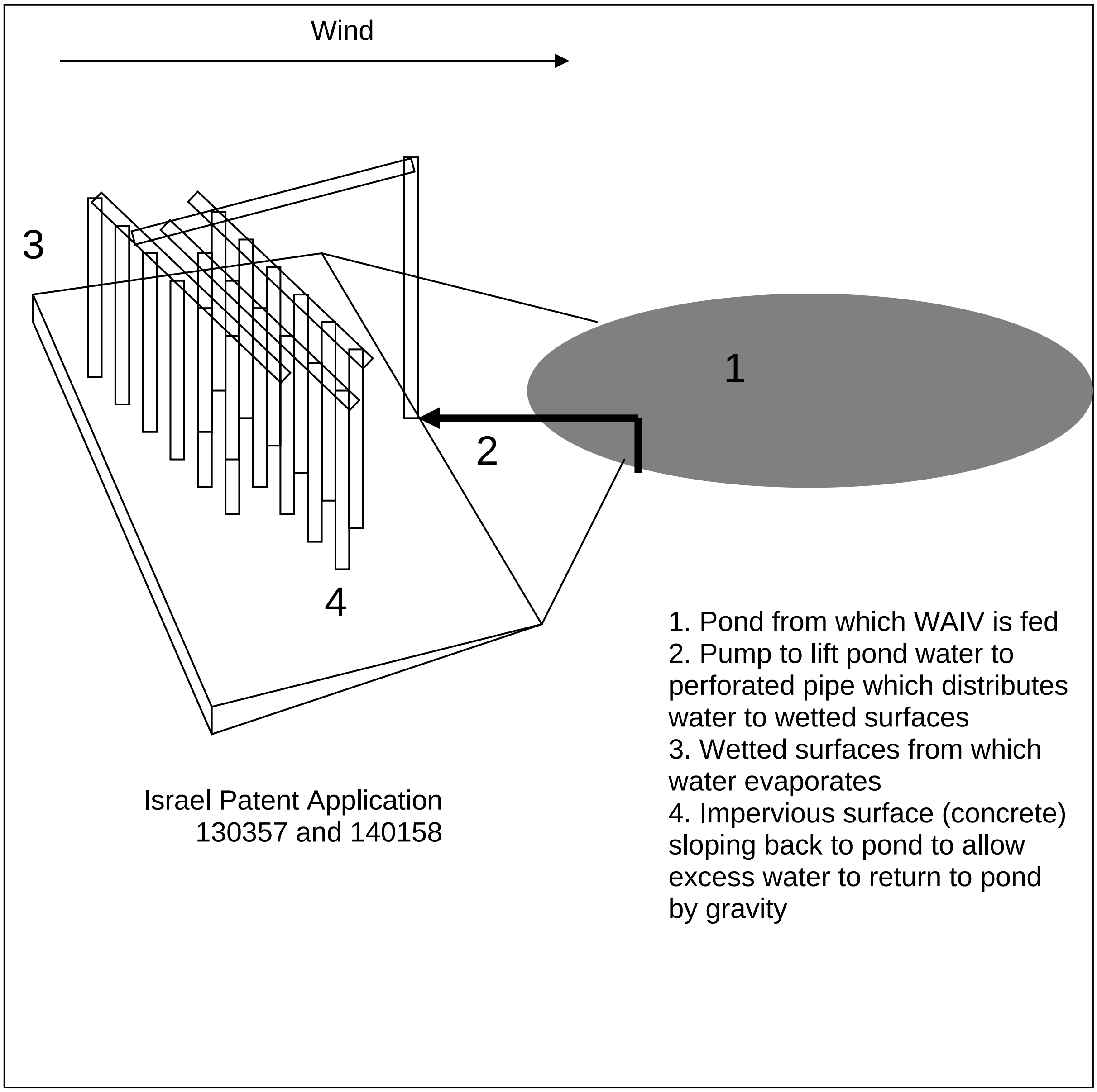
Regulatory Issues

Evaporation ponds must be lined to prevent seepage into the groundwater, or the ponds would be considered Class V injection wells. Permitting of an evaporation pond as a Class V injection well is extremely difficult. Given the proper lining, however, permitting of an evaporation pond is a relatively simple process involving specific state and local regulations. If misting equipment is included to reduce the required area of the evaporation pond, regulatory approval may be slightly more difficult due to the issue of “salt drift.”

Disposal of the precipitated salt and sludge will be regulated under the Resource Conservation and Recovery Act (RCRA). If the material fails a toxicity characteristic leaching procedure test, it will be classified as a type D hazardous waste and require burial in hazardous waste landfill, and tipping fees will be significantly greater (AWWA, 2004).

Most states require a liner (Ahuja and Howe, 2005; Mickley, 2004a), and shallow ponds are more likely to lead to drying, cracking, and failure of the liner (Ahuja and Howe, 2005).

Ecological impacts on wildlife are likely to be an increasing concern, especially where selenium, arsenic, or other constituents of concern are found at high concentrations.



Israel Patent Application 130357 and 140158

1. Pond from which WAIV is fed
2. Pump to lift pond water to perforated pipe which distributes water to wetted surfaces
3. Wetted surfaces from which water evaporates
4. Impervious surface (concrete) sloping back to pond to allow excess water to return to pond by gravity

FIGURE 2-4
Wind-Aided Intensified Evaporation.
Source: adapted from CASS (2005).

TABLE 2-6

Summary of Other Implementation Issues for Evaporation Pond Discharge

Parameter	Discussion
Geographical and Climatic Relevance	Most applicable for a warm dry climate (high net evaporation rate), such as much of the southwestern United States; evaporation ponds are also used in arid and semiarid regions of the Middle East and Australia, where net evaporation rates are high and adequate land is available (Van Der Bruggen et al., 2003)
Level of Water Utility Control	High
Membrane Cleaning Solutions	Generally not an issue
Proven Technology	Well-proven, widely used

Cost Considerations

Costs for evaporation pond construction are site specific, but detailed cost considerations and a cost model have been provided by Mickley (2004a). Major factors affecting costs include climate, concentrate volume and salinity, land costs, liner costs, and pond life or frequency of cleanout (AWWA, 2004). Capital cost and O&M cost are described in the following sections.

Capital Costs

The most important factor affecting the cost of solar evaporation ponds is the type of liner and leak detection required. Liners are typically polyvinyl chloride or Hypalon. In many cases, a double liner is required. Double liners are more likely to be required where high-quality aquifers are present and/or where the concentrate is considered contaminated (hazardous) (Mickley, 2004a). Moreover, depending on applicable regulations, leak detection may be required, which typically consists of installing drains below the evaporation ponds and monitoring for leakage through the pond liner. The liner and leak detection system can account for 60–70% of the total construction cost for evaporation ponds.

Other costs to consider include the earthwork required to construct the dikes that contain the ponds and the cost of the land. Evaporation ponds can require large tracts of land and are sensitive to land costs. Capital costs are summarized in Table 2-7. Conveyance costs to the pond are not addressed in this estimate.

TABLE 2-7

Evaporation Pond Disposal Capital Costs (in 2001 $)

Variable	Variable Range	Example
A Evaporative Surface (acres)	0–100	10
B Dike Height (ft)	4–12	8
C Total Liner Thickness (mils)	20–120	60
D Land Cost ($/acre)	0–10,000	5000
E Land Type (see note)	1, 2, 3, 4	3

Calculation of Total Acreage	Action	Result
F Ratio of total acres to evaporative acres	(Data from Fig. 10.2 and 10.3 in Mickley, 2004a)	1.36
G Total Acreage	= A * F	13.6

Unit Area Cost	Action	Cost
H Land ($/acre)	(Same as D)	$5000
I Land Clearing (see note) ($/acre)		$4000
J Dike ($/acre)	(Fig. 10.4 and 10.5 in Mickley, 2004a)	$8600
K Nominal Liner ($/acre)	(Fig. 10.7 and 10.8 in Mickley, 2004a)	$22,680
L Liner ($/acre)	= (K * D)/60	$22,680
M Fence ($/acre)	(Fig. 10.9 and 10.10 in Mickley, 2004a)	$4500
N Road ($/acre)	(Fig. 10.11 and 10.12 in Mickley, 2004a)	$770
Total Unit Cost	(H + I + J + L + M + N)	$45,550
TOTAL	(H + I + J + L + M + N) * G	$619,480
	Engineering (10%)	$61,948
	Contingency (10%)	$61,948
Grand Total		**$743,376**

Source: Mickley (2004a).

Note: Land clearing costs are assumed as follows: (1) brush, $1000; (2) sparsely wooded, $2000; (3) medium wooded $4000; (4) heavily wooded, $7000.

If misting equipment is used, both capital and operational costs should be considered. Capital cost information can be obtained by contacting a supplier of misting equipment.

O&M Cost

Landfill costs are incurred during periodic maintenance of evaporation ponds. Salt sludge must be disposed of in either a municipal landfill or an approved RCRA landfill, depending on the makeup of the salt sludge. Disposal of salt sludge in a RCRA-approved landfill will increase costs due to the liner and leak detection system required. Operation of waterfowl deterrent devices may require some ongoing labor and expenses, as well. The city of Chandler, AZ, installed bird screens above its ponds to eliminate the bird aircraft strike hazard to the nearby Chandler Airport (CASS, 2005).

If misters are included, operational costs will include power for brine pumping to the misters as well as periodic maintenance (approximately 2% of the capital cost per year). Power costs for the misting equipment depend on the concentrate flow as well as the operating pressure. An increase in operating pressure results in a higher operating cost due to increased energy usage but a lower capital cost due to a decrease in the number of misters required.

Some income opportunities may exist to offset operational costs. Brine shrimp production is used in the ponds in some locations (Van Der Bruggen et al., 2003) to provide a beneficial use (see Chapter 3). Also, recovery of separated salts may be a potential option to reduce operating costs (NRC, 2004).

Cost of Lost Water

The purpose of the pond is to evaporate water to the atmosphere, and this represents a local loss of the water resource (Sandia, 2003). Moreover, the evaporated water is essentially high-value, pure water. On a national scale, most of the evaporated water is likely to fall back as precipitation within the continental United States, but it may fall on areas with much less acute water supply issues.

Economic Risk Factors

Potential economic risk factors for evaporation ponds include regulatory changes, liner failure, and increases in tipping fees for landfilled residual salts.

Human Health and Ecological Risk Factors

Public health impacts from use of evaporation ponds are minimized by limited potential exposures at the ponds. Measures implemented to prevent seepage into groundwater reduce potential impacts to potable water supplies. There is also a potential exposure pathway via the air. This may only be a nuisance problem; however, if misters are used, nearby residents may be exposed to a number of potential constituents (chemicals or pathogens) that may be present in the aerosol. The design and implementation should consider minimizing this pathway.

Generally, human health evaluations focus on public health rather than worker exposures. It should be noted, however, that a health and safety plan to address potential worker exposures is warranted to reduce unacceptable exposures to residual salts or inhalation of aerosols.

Waterfowl, shorebirds, and other aquatic birds are attracted to surface water, including evaporation ponds, and the presence of these birds can lead to ecological risks with some concentrates. Despite the high waterborne concentrations of salts found in evaporation ponds, certain kinds of aquatic organisms (such as brine shrimp or brine flies) may thrive there and create viable feeding habitats for birds. In a well-known example, excessive selenium caused mortality of and severe birth defects (teratogenesis) in birds at Kesterson Reservoir in California (Ohlendorf, 2002). Kesterson Reservoir and numerous evaporation ponds in the San Joaquin Valley were used to dispose of subsurface drainage water from irrigated agriculture that contained elevated concentrations of selenium and other water-soluble salts (some of which are identified as major ions in concentrates; see Chapter 1).

Bird exposure can be successfully controlled by several different methods if the evaporation pond system is small, but effectiveness is reduced and costs are high if the system is large (Bradford et al., 1991; Marsh et al., 1991; Salmon et al., 1991). One technique is to periodically fire gas-powered cannons, creating a loud “boom” to scare birds away from the evaporation ponds. However, the sound from the cannons generally carries a long distance and can be a nuisance to neighboring residential areas. Birds also become habituated to the noise, and effectiveness decreases. In addition, the method is less effective if the birds are not able to find alternative habitat nearby. Another technique is to broadcast the sound of the birds’ natural predators over a loudspeaker system. The sound emitted from these systems does not carry as far as the cannons and, therefore, minimizes the potential for public complaints.

Applicability to Other Salt Streams and Overall Basin Salt Management

Evaporation ponds have been applied to many types of waste. More concentrated solutions tend to be more cost-effective, as less land area is required. Evaporation ponds are a benefit for overall basin management because salts are confined and controlled and do not pose a salt burden on downstream users.

Conclusions

Evaporation ponds are a simple, widely used technology, applicable to all concentrates. Use of evaporation ponds is largely limited to areas with a warm, dry climate, and the availability of sufficient low-cost land limits the potential use of evaporation ponds, especially for larger facilities in or near urban areas.

RAPID INFILTRATION

Rapid infiltration systems allow membrane concentrate to percolate through the soil at relatively high loading rates (4–80 in./week, depending on soil permeability), eventually ending up recharging groundwater, recharging surface water, or being collected by wells and used for other purposes. Most soil types have capacity for removing heavy metals and phosphorus but no capacity for removing dissolved salts, such as sodium and chloride, which pass through the soil and on to the final destination of the water. Therefore, rapid infiltration systems are typically used to treat low-TDS membrane concentrate that may have high concentrations of heavy metals or phosphorus. Rapid infiltration may be appropriate for low-volume plants in some locations (AWWA, 2004).

Figure 2-5 illustrates two types of rapid infiltration systems that can be used for disposing of membrane concentrate. Figure 2-5(a) shows a rapid infiltration pond that is used to recharge groundwater. Figure 2-5(b) shows a rapid infiltration pond that is used to remediate the membrane concentrate and recover it to be used for other purposes such as irrigation. This may be a viable alternative for a membrane concentrate with a toxic constituent, such as boron, which may be removed in the soil so that the remediated water can be applied to vegetation. Infiltrated water may intermix with the water in the existing aquifer or pool in a layer above it (CASS, 2005). An alternative approach is the use of shallow or vadose wells that inject concentrate above the water table (CASS, 2005).

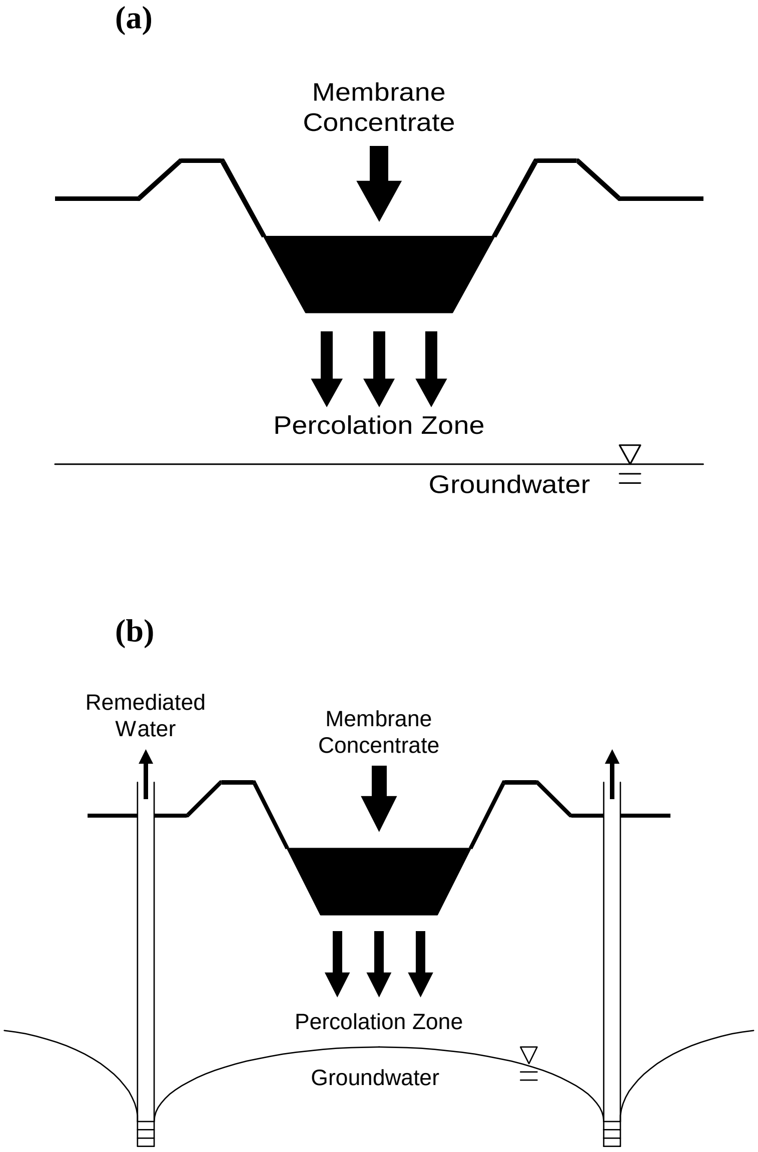


FIGURE 2-5
(a) Rapid Infiltration; (b) rapid infiltration with recovery.

Implementation Issues

The most constraining criterion associated with rapid infiltration for disposal of membrane concentrate is the quality of the membrane concentrate. As mentioned previously, rapid infiltration does not have the capability to reduce TDS, only to remove or attenuate certain constituents. Therefore, the concentrate stream must be low in TDS, or the underlying aquifer must be of very low quality. This limits the use of rapid infiltration ponds to mainly NF softening facilities and some brackish groundwater RO facilities.

Finding a suitable site is another issue associated with use of rapid infiltration for membrane concentrate disposal. A site with highly permeable soil (sand or loamy sand) must be available. In addition, groundwater below the site must have a higher concentration of every constituent compared to the remediated concentrate water (i.e., a Class V injection well). If the groundwater is of better quality than the remediated concentrate water, rapid infiltration would not be a feasible alternative due to degradation of groundwater quality.

Operation of a rapid infiltration system should include a rest period, typically between 5 and 20 days, to allow the applied water to completely drain from the soil and restore aerobic conditions. This is especially important when vegetation is planted in the rapid infiltration basins to maintain soil permeability.

Other Issues

Other significant implementation issues for rapid infiltration are summarized in Table 2-8.

TABLE 2-8

Summary of Other Implementation Issues for Rapid Infiltration Discharge

Parameter	Discussion
Geographical and Climatic Relevance	Rapid infiltration is most commonly found in Florida, where permeable soils are available and low-TDS concentrate streams are produced from NF membrane softening facilities
Level of Water Utility Control	Very high level of control
Membrane Cleaning Solutions	Site specific, but generally can be addressed through pretreatment or separation of concentrated streams for sewer discharge
Proven Technology	Well-proven, but not known to be used for desalting membrane concentrate

Regulatory Issues

Depending on the specific application, an NPDES permit may be required. If the ultimate destination of the rapid infiltration water is recharge of a surface water, an NPDES permit must be obtained.

If a groundwater is the final destination of the membrane concentrate, a Class V well permit must be obtained. However, obtaining a Class V well permit is contingent on the recharge water having a lower concentration of every constituent compared to the groundwater, which is rarely the case for most typical membrane concentrates. Consequently, the chances of obtaining a Class V permit for rapid infiltration of membrane concentrate are minimal.

Cost Considerations

Costs associated with rapid infiltration may include acquisition of land, construction of the basins, conveyance of concentrate to the disposal site, recovery pumping, and maintenance of the basins.

Capital Cost

Construction of the basins involves earthwork to form a berm and prevent lateral movement of the concentrate. In addition, an impermeable liner is sometimes included for soils with extremely high permeability to further reduce lateral movement of the membrane concentrate. Capital costs for conveyance of concentrate to the disposal site include pipeline and pumping facilities.

O&M Cost

Maintenance of the basins typically involves coordinating which basins are online and receiving water and which basins are offline for a resting period to restore aerobic conditions in the underlying soil. Periodic cleaning of the basins may be required to remove accumulated sediment from the rapid infiltration process. Operational costs include power for the pumps and miscellaneous maintenance for the pumps and pipeline.

Cost of Lost Water

Infiltrated water is much more likely to be recoverable with rapid infiltration than with deep well injection.

Economic Risk Factors

The major economic risk factors are plugging of the infiltration basin, greater-than-expected impacts on drinking water aquifers, and regulatory changes.

Human Health and Ecological Risk Factors

It is assumed that limited public exposures to the ponds would occur and that health and safety plans would be in place for workers. Design and operation requirements would be targeted to limit adverse impacts to groundwater that may impact downgradient water supplies and/or surface waters.

Ecological risk factors are similar to those described for evaporation ponds, except that risks to aquatic birds are expected to be lower because of lower average concentrations (less evapoconcentration). The duration of exposure is also less than for evaporation ponds because of the required rest periods.

Applicability to Other Salt Streams and Overall Basin Salt Management

Rapid infiltration may be applicable to other salt streams but is subject to the difficult criterion that all constituents must be at lower concentrations than the receiving aquifer.

Use of rapid infiltration basins for concentrate generally would not benefit overall basin management, because infiltrated salts are not contained, controlled, or removed from the basin and may impact downgradient users.

Conclusions

Rapid infiltration is a potential low-cost method of disposal, but regulatory and technical constraints are significant. This disposal method is not likely to be a viable alternative for most membrane facilities.

CHAPTER 3

BENEFICIAL, INNOVATIVE, AND NONTRADITIONAL USES OF CONCENTRATE

The disposal options described in Chapter 2 are generally well understood but are based primarily on the premise of disposal, rather than beneficial reuse. The major focus of this project is to explore potential beneficial and nontraditional uses of concentrate. The focus of this chapter is the beneficial use of concentrate as a liquid. These beneficial and nontraditional uses include oil well field injection, solar ponds, land application and irrigation (including halophyte irrigation), ZLD and near-ZLD, aquaculture, salt marsh discharge, wetlands treatment, and other potential beneficial uses.

Although a traditional method of disposal, irrigation (land application) is included in this section because it can be a beneficial use, is infrequently used, and its limitations and opportunities have not been adequately described in the existing concentrate disposal literature. ZLD and near-ZLD are included in this section because they are also infrequently used but hold considerable potential for increasing the available volume of high-quality water and are closely linked to separated salts recovery, which is discussed in Chapter 4.

OIL WELL FIELD INJECTION

Oil well field injection of concentrate is a potential disposal option for several U.S. states. Beneficial use results from the potential for concentrates to aid recovery of oil and gas resources. Concentrate may be a resource for oil and gas operators, providing a source of additional “make-up” water that can be used to extract more energy resources (Mace et al., 2004).

Injection of concentrate into abandoned oil and gas wells is not a beneficial use and should be considered a variation of ordinary deep well injection. Laguna County, CA, has successfully permitted injection of brine and concentrate into an abandoned oil well, and the City of Los Angeles is investigating a similar approach (CH2M HILL, 2004).

As oil or gas is extracted, reservoir pressure gradients begin to decline, eventually reaching the point where it is no longer economical to continue production unless the pressure gradient or driving force can be restored (Morales and Smith, 2004). Primary recovery is oil or gas extraction using the preexisting pressure in the reservoir, and secondary recovery or pressure maintenance refers to the input of fluids or gas to allow continued oil or gas extraction (Morales and Smith, 2004). Injection of concentrate could be a tool to restore a driving force for energy resource recovery.

Typical primary oil recovery leaves considerable reserves in the reservoir (~50%) after pressure has been depleted, although recoveries approach 70% for the East Texas field (D. Burnett, Texas A&M, personal communication). Brine solutions are routinely used in oil and gas production for oil well pressure maintenance and/or in a secondary recovery process known as “water flooding” (Burnett and Veil, 2004). Water flooding is a well-known technology in the oil industry where water is injected into the reservoir, sweeping the remaining oil through the reservoir to producing wells (T. Smith, SAWS, personal communication).

All water flooding operations require an independent source of water. At the outset of a water flood when only oil is being produced, all the water used for injection must come from a source other than the formation. As the injected water begins to emerge from production wells, it (the produced water) is then conditioned and reinjected. This cycling continues as long as it is economical to lift both water and oil to the surface and the cost of managing the excess water does not exceed revenue from petroleum sales (D. Burnett, Texas A&M, personal communication).

The concept of concentrate injection into oil and gas reservoirs has been best developed in Texas, although it is not yet practiced anywhere in the state. Texas A&M University has an ongoing program examining the issues associated with injecting concentrate from desalination of produced water into oil- and gas-producing zones (Burnett and Veil, 2004). The Texas Water Development Board and the Texas Bureau of Economic Geology also investigated the current regulatory framework that controls both produced water injection and municipal brine injection (Mace et al., 2004).

Implementation Issues

Oil well field injection applies where formation pressures have been reduced from past oil and gas production (Mace et al., 2004). Technical issues for injection of concentrate are similar to those of water flood oil recovery operations and include maintenance of injectivity, recoverability of oil, and prevention of the formation of precipitates (Burnett and Veil, 2004). Other issues include isolation from drinking water aquifers (USDW) and compatibility with clay mineralogy.

Isolation from Drinking Water Aquifers

Similar to ordinary deep well injection (Chapter 2), the formation must be covered by a sufficient thickness of low-permeability strata so as to ensure containment of injected concentrate (Burnett and Veil, 2004). Formation pressures are often lower than the deepest drinking water source, minimizing the potential for movement of injected fluids from oil and gas formations into drinking water aquifers (Mace et al., 2004).

Formation Damage

Obstructions or barriers that develop near the well bore and reduce permeability are generally referred to as formation damage (Burnett and Veil, 2004). The formation of scale or precipitates and deflocculation and migration of clays destabilized by the injection of concentrate could lead to decreases in reservoir production or injection rate (Mace et al., 2004). “Water sensitivity” is the term used to assess the response of clay particles in the formation (Mace et al., 2004). Clay swelling, emulsion block, water block, solids (suspended solids), and other factors may also result in formation damage (Burnett and Veil, 2004). Emulsion block is a condition where an emulsion of water and oil inhibits the movement of oil and water around the well point. Water block is a condition where water surrounds the well point, preventing the flow of oil or gas to the well point.

Brine compatibility with produced water will likely be a minor problem, as well as brine compatibility with the formation. Concentrate from RO desalination has already undergone pretreatment (to avoid membrane plugging). The high level of pretreatment (filtration) that occurs with the production of desalting membrane concentrate is favorable for injection

(Burnett and Veil, 2004). However, the high scaling potential of concentrate must be carefully considered.

Oilfield brines commonly exceed the TDS of seawater, whereas brackish groundwater RO reject may only be 15,000 TDS. Injected concentrate may actually constitute an improvement in water quality in the receiving formation (Mace et al. 2004); however, the lower salinity may result in the potential for clay instability.

Groundwater chemical models such as PHREEQC can be used for formations with a TDS of less than 50,000 mg/L to assess the compatibility of the concentrate and the receiving formation and determine the need for pretreatment. A model such as SOLMINEQ is recommended for higher-salinity waters. Modeling results can reveal if pretreatment or operational solutions (injection rate, progressive mixing, buffers, etc.) are needed to prevent formation damage such as clogging. Modeling results for major formations in Texas suggest that precipitation would not be an issue, though in some cases antiscalants would be needed (Mace et al., 2004).

Property and Mineral Rights Issues

Essentially all water flood operations for secondary recovery occur in unitized reservoirs. Injection of concentrate would therefore not likely result in property or mineral rights issues (D. Burnett, Texas A&M, personal communication).

Injectivity

The capacity of a formation to accept injected water is determined by the physical characteristics (porosity, permeability, and compressibility) of the reservoir and pressure requirements (admissible surface pressure, well depth, and head loss) (Mace et al., 2004). Single well injection rates in Texas may range from 10 to 470 gal/min (gpm), although various techniques could be used to increase these rates (Mace et al., 2004).

The injection rates of most Class I injection wells outside of those in Florida are comparatively low, and any sizable volume of concentrate would likely require numerous injection wells and a sizable area over which to site the wells (M. Mickley, personal communication).

Capacity and Sustainability

Approximately 60 billion barrels have been removed from Texas formations since the end of the 19th century (Mace et al., 2004). If one assumes a typical 4-MGD plant (producing 1 MGD of concentrate, or 8.7 million barrels/year) injecting all concentrate, approximately 56 such plants could inject all of their concentrate for 125 years to replace this volume. This simplistic calculation assumes disposal rather than oil recovery as the primary objective. Therefore, there is considerable capacity, but even in Texas the capacity is finite. The life of a pressure maintenance application would need to be compared to the life of the desalination facility (M. Mickley, personal communication).

Geographical and Climatic Relevance

Texas has particularly favorable conditions because oil and gas fields are found in many parts of the state and there is extensive experience among oil and gas producers in reinjecting substantial volumes of produced waters into these formations (Mace et al., 2004). Oklahoma, California, and Wyoming also have oil- and gas-producing areas where this approach could be employed. The available oil and gas fields are also near brackish groundwater sources as well as the Gulf of Mexico which growing communities will increasingly need to draw upon for desalination (Mace et al., 2004). More than 31,000 active permitted injection wells are found in Texas (the vast majority are Class II), through which more than 228 billion gal of water are injected annually (Mace et al., 2004). More than 300,000 oil and gas wells are found in Texas (Burnett and Veil, 2004). Oil well field injection may be preferable to oceanic discharge even for coastal areas, especially where sensitive bays and estuaries may be impacted by concentrate (Mace et al., 2004).

Figure 3-1 illustrates the location and extent of major oil and gas reservoirs in Texas, Figure 3-2 illustrates the location of Class II injection wells in Texas, Figure 3-3 illustrates the extent of oil and gas wells in southern California, and Figure 3-4 illustrates the extent of oil and gas fields in Kansas.

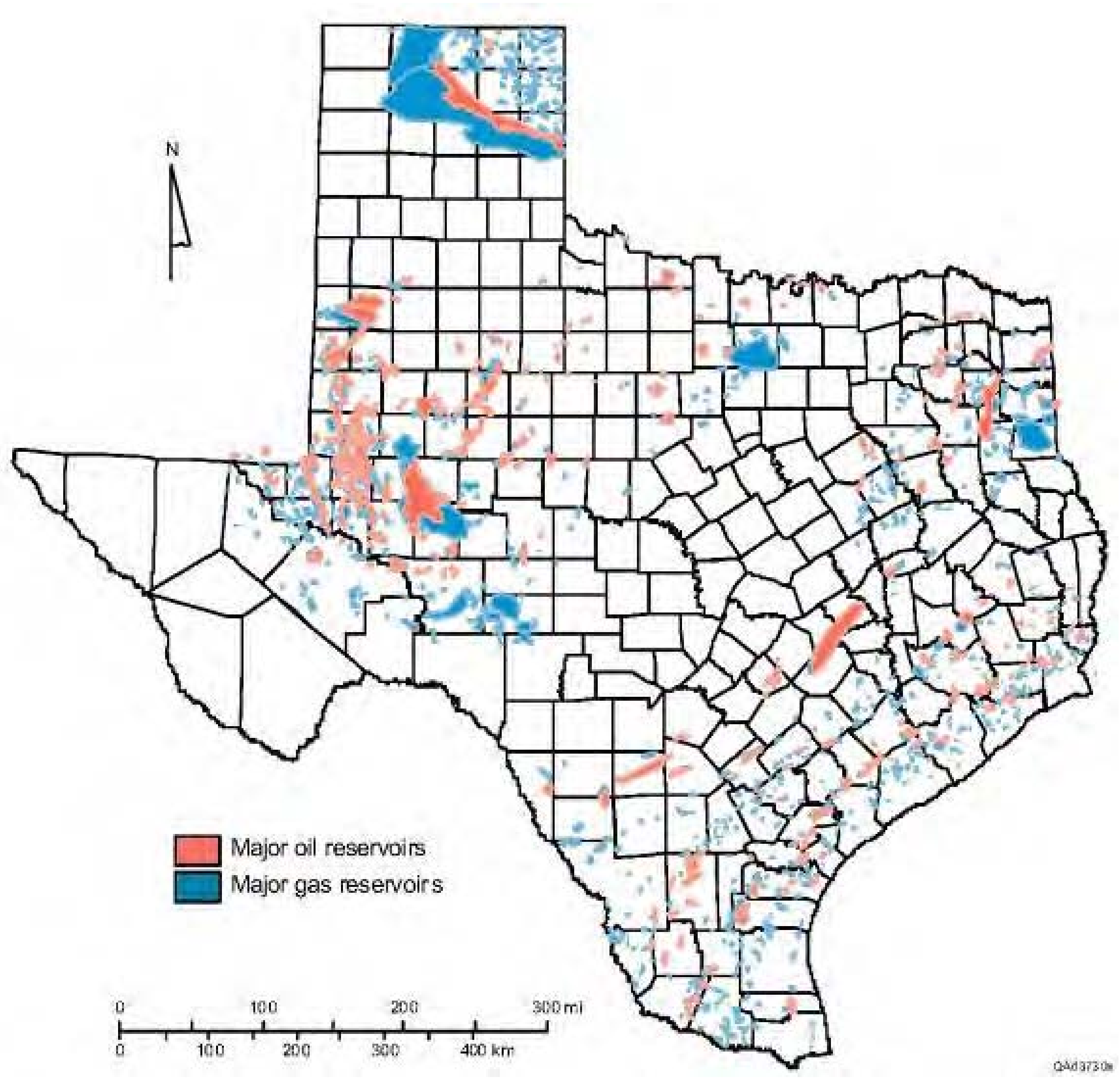


FIGURE 3-1
Location of Major Oil and Gas Reservoirs in Texas.
Source: courtesy of Texas Bureau of Economic Geology.

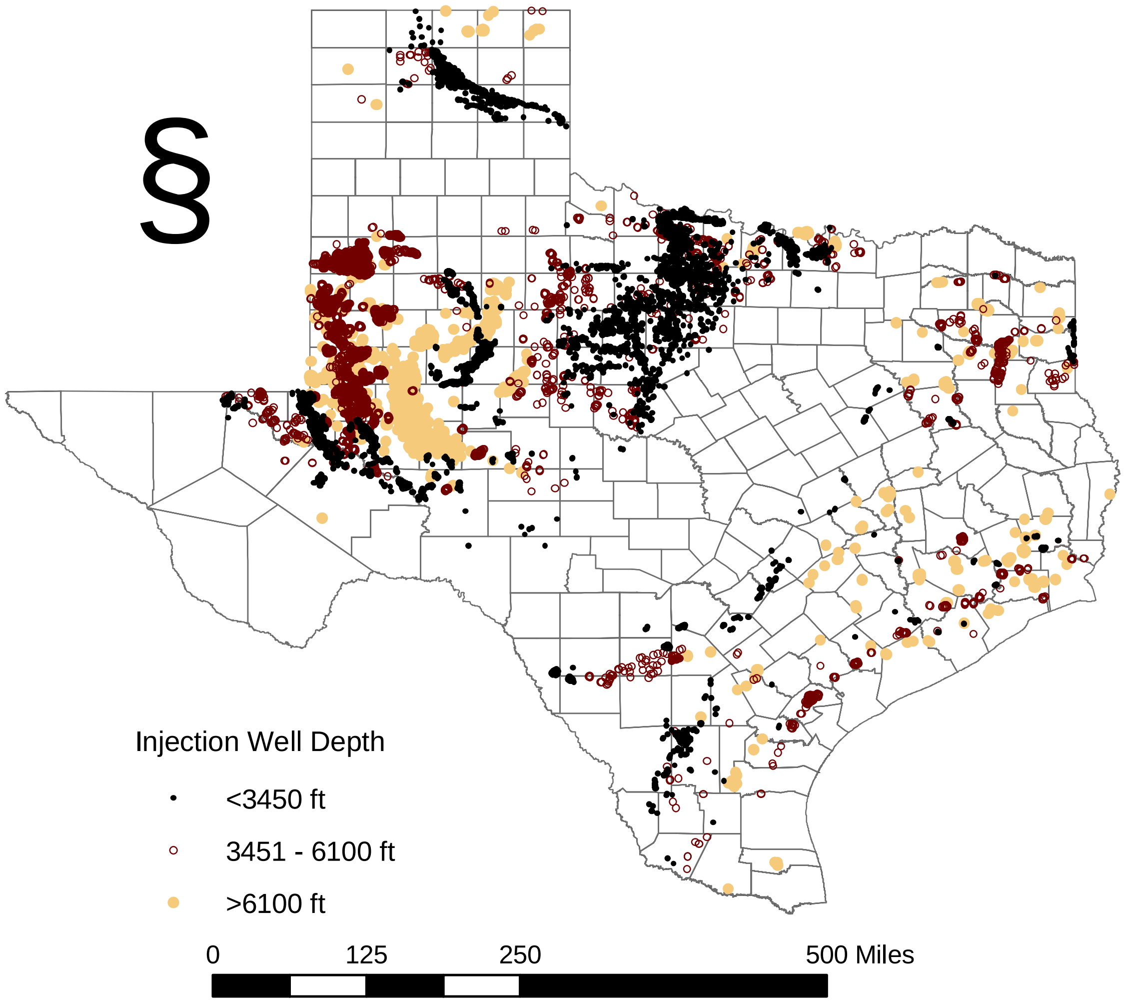


FIGURE 3-2
Location of Class II Injection Wells in Texas with Corresponding Completion Depths.
Source: courtesy of Texas Bureau of Economic Geology; data from the Railroad Commission of Texas.

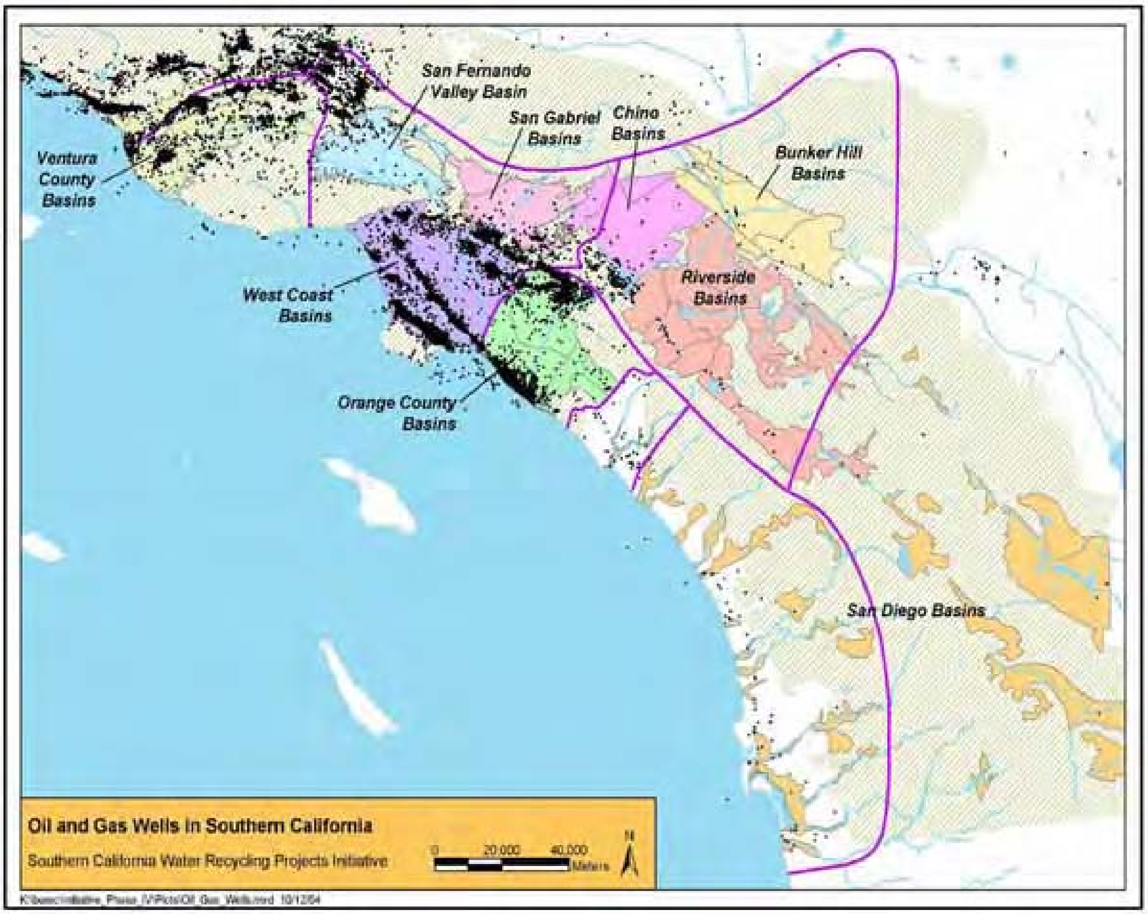


FIGURE 3-3
Oil and Gas Wells in Southern California.
Source: CH2M HILL (2005).

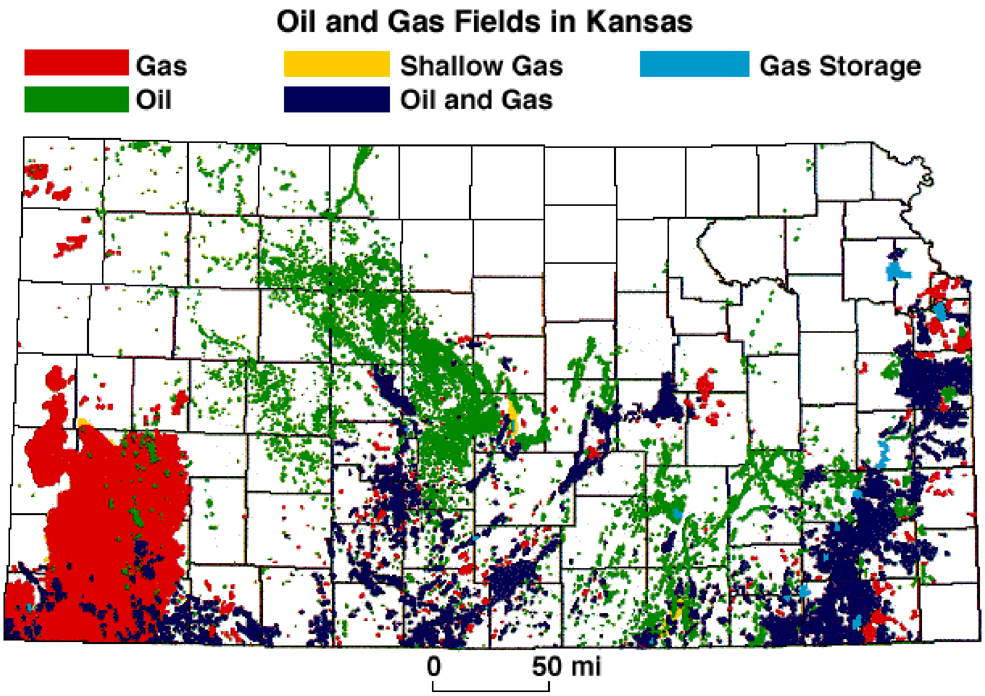


FIGURE 3-4
Oil and Gas Fields of Kansas.
Source: Kansas Geological Survey, 2005 (http://www.kgs.ku.edu/PRS/petro/ogSheetMap.html).

Other Issues

Other significant implementation issues for oil well field injection are summarized in Table 3-1.

TABLE 3-1
Summary of Other Implementation Issues for Oil Well Field Injection

Parameter	Discussion
Level of Water Utility Control	High if the water utility owns and controls the injection well, but in many cases will require long-term agreements with oil and gas field operators
Membrane Cleaning Solutions	Inclusion of membrane cleaning solutions would be site specific, and regulatory and technical issues such as compatibility with the formation would need to be addressed
Proven Technology	Produced water reinjection and water flood oil recovery is a well-established and well-understood technology; injection of concentrate for secondary oil recovery cannot yet be considered proven, but appears promising

Regulatory Issues

Implementation of oil and gas well field injection is primarily driven by state-level interpretations of USEPA rules on deep well injection. The similarity of concentrate to the commonly reinjected produced water offers some hope of flexibility. Under current Texas regulations, concentrate injection would require a Class I permit, which would result in expensive well construction requirements and 1 to 3 years to permit even for a nonhazardous material (Mace et al., 2004). In contrast, the permitting of produced water disposal through a less costly Class II well can be accomplished in 30–45 days and for a $250–400 fee (Mace et al., 2004). It is currently not allowable to inject desalting concentrate into a Class II well for disposal, but it appears that it would be possible to permit the injection of concentrate into a Class II well for secondary oil recovery (Mace et al., 2004), at least in Texas. Interpretations among states on the type of well required vary (Table 3-2) and to some extent depend on the purpose of injection (secondary recovery of oil and gas versus disposal). Injection of concentrate into a Class V well would be considerably less costly in terms of permitting, construction, and operating costs than a Class I well (Burnett and Veil, 2004).

The key regulatory factors are (1) classification of the concentrate, (2) location of the injection zone relative to USDW (Burnett and Veil, 2004), and (3) a transition at some point in the future from secondary recovery to concentrate disposal, when oil recovery is no longer economically feasible. If concentrate is considered hazardous or injected below a USDW, the injection well would automatically be a Class I well (Burnett and Veil, 2004). If injected into or above a USDW, it could be permitted as a Class V well (Burnett and Veil, 2004) if all constituents in the concentrate were less than the USDW; however, this is unlikely to occur. The City of El Paso, TX, is moving forward with construction of a Class V well constructed to Class I standards. If injected below a USDW, it would be a Class I hazardous or nonhazardous well, depending on the classification of the concentrate (Burnett and Veil, 2004). (Texas has no nonhazardous Class I category.) Table 3-2 suggests that several states may have some flexibility in at least considering the injection of concentrate through a Class II well for enhanced oil and gas recovery.

Various paths may lead to easing the permitting difficulty for this application in Texas (Mace et al., 2004), including the following:

- Nonhazardous Class I: Texas would need to adopt USEPA requirements, which are less stringent than current rules. The injection zone would need to be below any source of drinking water (USDW) within 0.25 mi of well bore (Burnett and Veil, 2004).
- Class II: This classification is applicable to produced water disposal. It could potentially be applied where concentrate is used as “make-up” water as part of enhanced oil recovery operations (Burnett and Veil, 2004).
- Class V: may be possible as a function of the concentrate and formation; a special subclass of Class V is being considered by USEPA.
- Dual permitted wells: permit a Class II well also as a Class I well.

Although there is some flexibility at the state level in interpreting current rules, USEPA is unlikely to change rules any time soon to accommodate desalination concentrate disposal (Mace et al., 2004).

TABLE 3-2

Possible Regulatory Requirements for Injection of RO Concentrate

	Purpose of Injection[a]		
State	**Enhanced Oil and Gas Recovery**	**Disposal**	**Reference**[b]
California	Class II well	If nonhazardous, Class II would be considered, otherwise Class I	Michael Stetner, California Division of Oil, Gas, and Geothermal Resources, Oct. 6, 2003
New Mexico	Class II well	Class I or II, depending on characteristics of concentrate	Roger Anderson, New Mexico Oil Conservation Division, Oct. 2, 2003
Oklahoma	Class II well	Class I nonhazardous well	Tim Baker, Oklahoma Corporation Commission, Oct. 6, 2003; Hillary Young, Oklahoma Dept. Environ. Quality, Oct. 6, 2003
Texas	Railroad Commission (regulates oil and gas activities) would confer with Texas Commission on Environmental Quality; wells could be Class I or Class II[c]		Fernando De Leon, Railroad Commission of Texas, Oct. 6, 2003
Utah	Class II well	Class V well	Dan Jarvis, Utah Division of Oil, Gas, and Mining, Oct. 2, 2003
USEPA	Not certain, but probably could be Class II well	Not certain; would depend on characteristics of concentrate and location of injection zone relative to a USDW	Bruce Kobelski, USEPA Office of Groundwater and Drinking Water, Oct. 2–3, 2003

Source: Burnett and Veil (2004).

[a] Assumes the source water is saline groundwater.

[b] Informal opinions that do not necessarily represent official agency policy.

[c] As per the previous discussion, under current regulations, a Class I well would be required for concentrate disposal regardless of the objective.

Cost Issues

It has been estimated that oil well field injection may reduce operating costs of a desalting facility by 30% (Burnett and Veil, 2004). Capital and O&M cost considerations are described in this chapter.

Capital Cost

Classification as a Class I hazardous well has a significant impact on costs. Oil well field impacts are likely to require additional testing and analysis beyond that of ordinary deep well injection, but much of these costs could potentially be borne by the petroleum company. Pretreatment may be required to ensure compatibility with the formation, and capital costs for this infrastructure would need to be determined.

As described earlier in this report, for traditional deep well injection of concentrate, major cost considerations for oil well field injection would likely include well depth and diameter, pretreatment, pump size and pressure, and the extent of monitoring needed, such as number of monitoring wells. Considerable economies of scale would be expected for larger plants. Capital costs would largely be driven by drilling, reaming, cementing, and testing rather than well materials. Produced water injection wells are often small diameter and low capacity, typically less than 20 gpm. RO disposal will require larger-diameter wells, which would have a near-linear impact on costs. Insufficient information is available to develop a cost model, but the information presented for ordinary deep well injection in Chapter 2 is a reasonable approximation.

Similar to ordinary deep well injection, the permitting process for an injection well in many cases will require extensive geologic investigations and permit applications. The permitting process can be expedited by drilling a test well that is completed to Class I standards, unless regulatory flexibility for oil well field injection can be obtained.

The flow rate of membrane concentrate determines the number of wells required to dispose of the concentrate into the site-specific geology. Data obtained by operating the test well provide the permeability of the injection strata and reservoir geometry, which is then used with the concentrate flow rate to determine the number of wells required. Where enhanced oil recovery is an objective, additional modeling will be required.

O&M Cost

Similar to ordinary deep well injection, operating costs would primarily be electrical costs for pumping, with comparatively minor costs for chemicals and operating labor. Monitoring and testing for formation damage with respect to oil or gas recovery may result in additional costs compared to ordinary deep well injection, but it is likely that much if not all of these costs may be borne by the entity engaged in recovery of the oil or gas. Like ordinary deep well injection, pretreatment costs may be incurred depending on the compatibility between membrane concentrate and the geologic strata of the injection zone. The membrane concentrate may require pH adjustment or other conditioning to prevent precipitation of constituents in the injection layer. Potential adverse effects on oil or gas recovery may result in increased pretreatment costs. To prevent a total loss in capital investment, possible chemical reactions between the membrane concentrate and the geologic strata must be thoroughly analyzed.

Cost of Lost Water

Similar to ordinary deep well injection, once concentrate is injected into a deep well, it is unlikely to be economically recoverable for another use (Sandia, 2003). Assuming 1 MGD concentrate flow from a 5-MGD plant, the “lost” water would be 1 MGD, with an annual value of more than $640,000/year (assuming a total water cost of $1.75/1000 gal).

Economic Risk Factors

The economic risks of concentrate injection are relatively low, unless permits change. For example, if a Class II well was allowed, at some point justification for classification as a Class II well would no longer exist because oil recovery would no longer be profitable.

Human Health and Ecological Risk Factors

As with deep well injection, exposure pathways to human or ecological receptors occur only if the injected concentrate migrates to a drinking water supply or surface water. Therefore, oil and gas well field injection of concentrate would likely result in very low human health and ecological risks if appropriate assessments are done and there are no failures such as those described for deep well injection in Chapter 2.

For decades, produced waters have been reinjected into these formations without adverse human health or ecological effects. However, accidental salt discharge could occur if, for example, there were improperly abandoned wells nearby, and injected brines could rise to the surface as pressures rise in the formation (Burnett and Veil, 2004). Evaluation of the potential hazard for use of the process for a specific application may consider distance to potential exposure points and concentrate characteristics.

Applicability to Other Salt Streams and Overall Basin Salt Management

Any salt stream could potentially be injected, depending on chemical and physical characteristics. As with concentrate, the presence of hazardous constituents and compatibility with the formation would be critical.

In addition to the potential benefits of secondary oil recovery, oil and gas well field injection of concentrate would permanently remove salt from the surface environment and, therefore, it clearly benefits overall basin salt management (D. Burnett, Texas A&M, personal communication). Injection of 1 MGD of concentrate with 12,000 mg/L of TDS removes more than 18,000 tons/year of salt from the surface environment, where it could cause considerable harm.

Conclusions

While formation hydraulic capacity is often a limiting factor, injection of concentrate into oil and gas well fields may be technically feasible at some locations. Although the concept has been best developed in Texas, even there it has not yet been done. A clear beneficial use can result when concentrate is used to aid secondary recovery of oil and gas resources. Injection of concentrate is very similar to the well-proven practice of produced water injection. In addition to formation hydraulic capacity, other potentially limiting factors include regulatory constraints, technical constraints such as compatibility with the formation to avoid plugging, and conveyance issues from the source of concentrate to the oil field.

There may be some regulatory flexibility in some states regarding the classification of concentrate injection wells as Class II rather than Class I, at least where they are used for secondary recovery. At least under current Texas regulations, a discharger of concentrate to a Class II well would need to make provisions for alternate disposal when concentrate injection can no longer be justified for secondary oil recovery. In terms of sustainability, it should be recognized that although the capacity of oil and gas well fields to accept concentrate is large in a number of U.S. states, it is finite.

SOLAR PONDS

Solar ponds collect and store solar energy that can be productively used. The Israelis first worked on this technology as a renewable energy source more than 30 years ago (Morales and Smith, 2004). Salt gradients can be used to inhibit convection, preventing accumulated heat from being dissipated. The recent rise in fossil fuel prices could make this source of energy increasingly attractive, and membrane concentrate could be used as source water for solar ponds. These ponds can be a reliable source of heat for process heating, crop drying, space heating, aquaculture applications, desalination, and generation of electricity (Lu et al., 2001; 2004). They are more efficient for supplying energy to medium- or low-temperature thermal applications than for electric power generation (Lu et al., 2001). Solar ponds do not necessarily constitute a concentrate disposal method (CASS, 2005) but nevertheless are a potential beneficial use for concentrate. Concentrate could potentially be used as the source of salts for a solar pond (Lu et al., 2004); however, no literature is known in which an actual solar pond was constructed and operated using RO concentrate (Hou, 2004).

Several U.S. organizations, in consultation with the Israelis (the leaders in solar pond technology), built a 0.75-acre salt gradient solar pond on the grounds of a food cannery in El Paso, TX, which was operated from 1985 through 2003. Unfortunately, because of a lack of funding, the University of Texas—El Paso (UTEP) facility was decommissioned, and no other solar pond facilities are known to be in operation in the United States, but some solar ponds are currently in operation in Italy (H. Lu, UTEP, personal communication).

Solar ponds consist of three layers: an upper, low-salinity zone (upper convective zone) that is relatively cool, a middle or main gradient zone, with increasing salinity and temperature, and a lower zone of very high salinity and temperature. Convection currents are suppressed in both the middle and lower zones of the pond (UTEP, 2005), although the lower zone can either be convecting or temperature stratified (Lu et al., 2001). The very high salt concentrations in the lower layer generally prevent convection, and the lack of movement in the lower zone also prevents convection in the middle zone (UTEP, 2005). The middle zone is transparent, allowing solar energy to reach the bottom layer, but it also acts as an insulator, allowing temperatures in the lowest zone to rise to very high levels (Lu et al., 2004). Accumulated heat in the lowest zone can be either stored in place for later use or recovered through the use of a heat exchanger (Lu et al., 2004). A schematic of a solar pond highlighting the function of the three layers is provided in Figure 3-5.

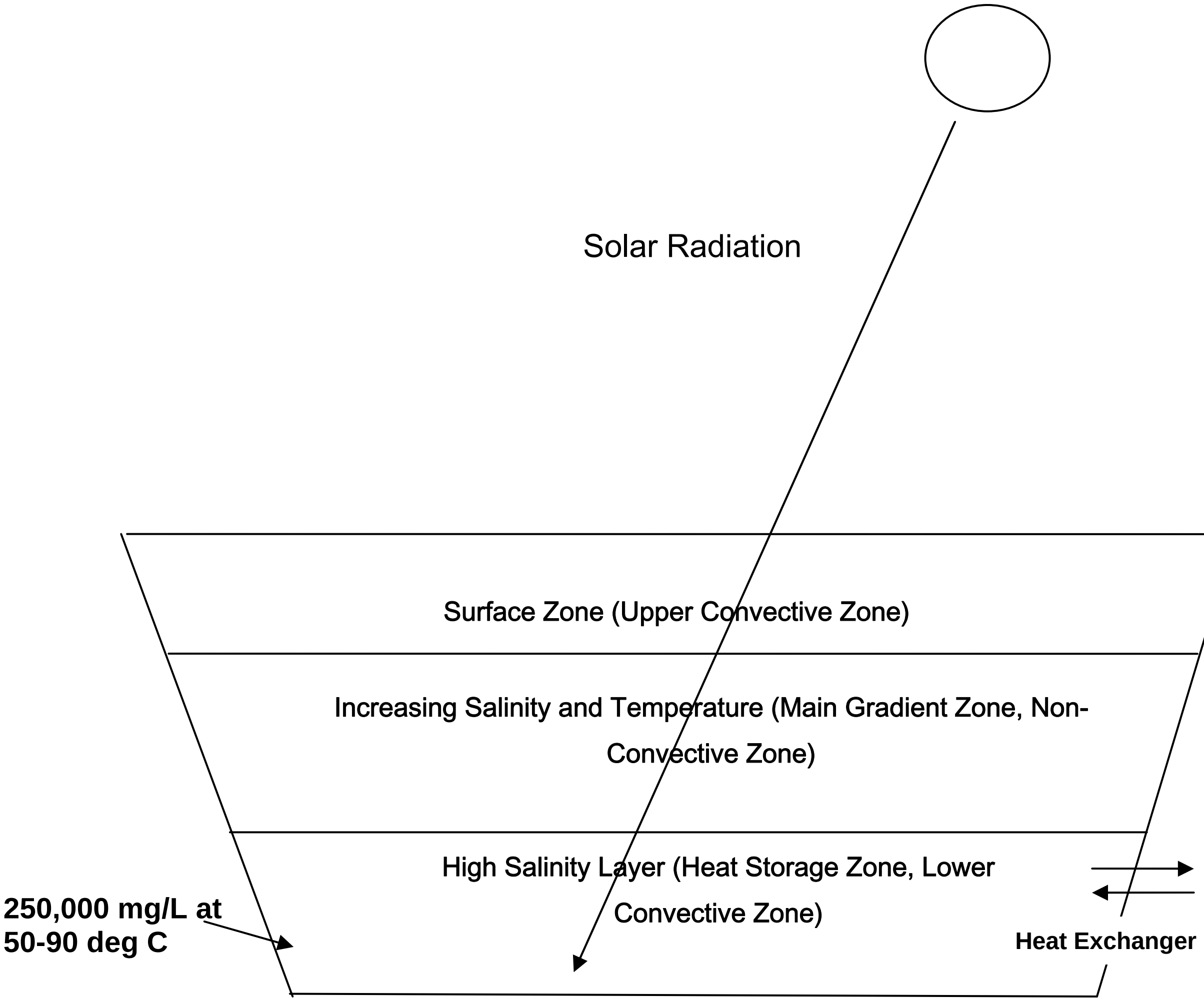


FIGURE 3-5
Solar Pond Schematic.
Source: adapted from http://www.ece.utep.edu/research/Energy/Pond/pond.html.

Temperatures in the lower layer can reach nearly the boiling point of pure water (100ºC, 212ºF) (UTEP, 2005), but the reliable operating range of the UTEP facility was 50–90ºC (Lu et al., 2001). Typical temperatures in the storage zone are 70ºC in winter and 90ºC in early fall (Lu et al., 2004). Stored heat from the bottom brine layer is obtained through the use of a heat exchanger (NRC, 2004). The UTEP solar pond relied primarily on NaCl as the salt, had a 0.75-acre surface area, and upper, middle-gradient, and lower convective zone depths of 0.5, 1.2, and 1.35 m, respectively (Lu et al., 2004). The lower convective zone concentration was about 311,000 mg/L of TDS, and the upper convective zone was normally maintained at 10,000 to 41,000 mg/L of TDS (Lu et al., 2001).

[General caveat: The following discussion of solar ponds is largely based on research work conducted at UTEP and is based on a single water with simple chemistry (primarily NaCl). Any variation in chemistry (e.g., a typical membrane concentrate) could provide very different results.]

Implementation Issues

Storage zone salinity must be 200,000 mg/L of TDS or higher, which is higher than the discharge from RO facilities (NRC, 2004). Since essentially all concentrates are considerably less concentrated than this, evaporation ponds may be required as a concentration step to provide sufficient salinity for solar pond operation (NRC, 2004). Additional research on salt concentration technologies and a greater understanding of life-cycle economics may be required for utilities to consider incorporating solar ponds (NRC, 2004).

Establishing and Maintaining the Gradient

Initial establishment of the gradient zone is neither trivial nor rapid. A number of months are likely required for establishing the gradient, and if the gradient is lost, the lengthy process of establishment must begin again (T. Hinkebein, Sandia, personal communication). For more reliable, accurate, and rapid establishment of the gradient zone, UTEP developed a scanning injection technique where a diffuser is moved up and down within a preset region during each stage (Lu et al., 2004). Once the gradient zone is established, fresh or brackish water to establish the surface zone (upper convective zone) is placed above the gradient zone through a floating diffuser until the design pond depth is reached (Lu et al., 2004).

Maintenance of the correct gradient within the pond requires a high level of management; it cannot act as a passive system (H. Lu, UTEP, personal communication). Based on the level of management skill and monitoring required, it could be viewed as more similar to the operation of an activated sludge system than to an evaporation pond.

- The gradient zone must have adequate thickness and clarity.
- The gradient zone can erode either through convection in the upper zone or upward diffusion of salts from the storage zone.
- Gradient zone maintenance may consist of scanning injection, brine extraction, or freshwater addition to the surface zone (Lu et al., 2004).
- Heat may need to be removed from the storage zone to prevent boiling, which disrupts the gradient zone (Lu et al., 2001).
- Reducing the density of the surface zone by replacing brine with lower-salinity water may be required to maintain the gradient (Lu et al., 2002).
- Wind action can result in loss of heat and potentially loss of the gradient (CASS, 2005).

Maintaining Pond Clarity

Clarity is also critical for maximum transmission of solar energy to the storage zone (Lu et al., 2004). The UTEP facility maintained the surface and gradient zones at a pH of 3 to 4 through the addition of hydrochloric acid (HCl) (Lu et al., 2004). Studies at Arizona State University (ASU) have found that RO brine from the Scottsdale Water Campus was actually similar to an artificial algal growth medium in terms of promoting algal growth (Hou, 2004). Control of algae in the ASU studies was only achieved through pH control, as traditional methods (potassium permanganate, copper sulfate, Cutrine-Plus, and barley straw pellets) failed (Hou, 2004).

Monitoring

Data must be collected and regularly analyzed on pond temperature, salinity, and clarity (Lu et al., 2004). At the El Paso pond, they found that changes in parameters other than temperature were typically slow enough that weekly increments were sufficient (Lu et al., 2004), and temperature was recorded daily. Temperature and salinity were measured together at 5-cm intervals, the minimum interval of small convective zones in the gradient zone that would indicate breakdown of the gradient (Lu et al., 2004). The location of boundaries between layers, boundary movement, temperature, and salinity profiles at boundaries are critical (Lu et al., 2004).

Monitoring the overall salt inventory of a solar pond project is also important for planning and budgeting salinity gradient modification, salt recycling, and leak detection. Salt inventory includes analysis of the salts contained in each zone of the pond, total salt in the solar pond, and the quantity of salt in any supporting evaporation ponds (Lu et al., 2004).

Periodic Disposal of Accumulated Salts

Some salts will exceed solubility limits in the heat storage zone and will precipitate. Design of the pond will need to allow for accumulation of these salts. Proper operation of the pond requires that the depth not exceed certain limits, and planning for removal of excess salts about every 10 years is recommended (H. Lu, UTEP, personal communication). Greater salt storage volume results in a longer start-up time before desired temperatures are reached (H. Lu, UTEP, personal communication). Salts removed from the facility would need to be disposed of in a landfill unless salt separation and beneficial reuse technologies were implemented.

Heat Extraction

Heat accumulated in the storage zone is extracted in one of two ways: (1) by pumping the heated brine from the pond to an external heat exchanger, or (2) by pumping a heat exchange fluid through a heat exchanger which is submerged in the lower convective zone of the pond (Lu et al., 2001). The UTEP facility found that the first approach (brine circulation) was most efficient and trouble-free (Lu et al., 2001; 2004).

Construction Requirements

Construction of these ponds requires an abundance of inexpensive salt, flat land, and easy access to water, essentially the same considerations as previously described in Chapter 2 for evaporation ponds. Pond dimensions based on the UTEP facility suggest allowing for 10 years of salt storage, a 1.2-m lower convective zone, a 1.5-m gradient zone, and a 0.4- to 0.5-m upper convective zone, plus freeboard (H. Lu, UTEP, personal communication). Increasing the thickness of the storage zone reduces diurnal fluctuations in temperature but increases the start-up time to reach operating temperatures (Lu et al., 2001). The UTEP facility, with a 1.2-m gradient zone and a 1.35-m storage zone, experienced a 1ºC/day increase in temperature during startup (Lu et al., 2001).

Concentrate could potentially provide the source of salt. Studies with RO concentrate from the Scottsdale Water Campus found that concentrating the 6000-mg/L TDS brine to the >200,000 mg/L needed for a solar pond resulted in precipitation of $CaCO_3$ and other salts and that these salts would need to be removed to avoid an increase in the reflectivity and energy loss of the pond (Hou, 2004). The nature and extent of problems and required pretreatment associated with increasing the TDS of concentrate to that required to establish a solar pond will vary with concentrate chemistry.

Coupling Solar Ponds with Thermal Desalination

Solar pond-powered desalination is a promising technology and has been studied at UTEP since 1987 (Lu et al., 2001). It may be one of the most effective potential uses for a solar pond. One approach would be to utilize more traditional membrane technology as a first step to accomplish 80% or more recovery, followed by solar-powered thermal desalination of the concentrate (H. Lu, UTEP, personal communication). High levels of potable water recovery can be achieved with modest energy costs.

A system approach has been evaluated that includes a small multieffect, multistage flash (MEMS) distillation unit and a brine concentration and recovery system (BCRS) (Lu et al., 2001; Swift et al., 2002). The concept is to reach zero discharge desalination, where reject streams are concentrated to near NaCl saturation and subsequently are used as feedstock for additional solar ponds (Lu et al., 2001). The BCRS uses thermal energy from the pond and produces a near-slurry salt discharge that can be returned to the solar pond (Lu et al., 2001). The MEMS unit produced a very high-quality distillate (2 to 3 mg/L of TDS), and the surface water from the solar pond was successfully used as a cooling water source to reduce energy costs (Lu et al., 2001; 2002). Tests at UTEP found that 10–26% of the volume of the brine feed to the BCRS could be recovered as freshwater, and there were no problems with scaling (Swift et al., 2002). The BCRS requires both thermal energy from the solar pond and electrical energy from another source for fans, pumps, and other equipment (Swift et al., 2002).

Figures 3-6 and 3-7 show example applications of the integrated application of conventional RO or ED or thermal desalination with a solar pond, MEMS, and BCRS technologies to result in a zero discharge system. In these examples, a 2000-mg/L brackish water supply is assumed, producing a concentrate flow of 15,000 mg/L. The concentrate flow provides a makeup water source to replace water volume lost to evaporation. Water from the surface layer of the solar pond can be used as a feed source for the MEMS process, powered by thermal energy from the storage layer of the pond, ultimately producing additional high-quality product water. The reject from the MEMS process (250,000 mg/L of TDS) can be further concentrated in the BCRS process, driven by energy from the pond, and also produces high-quality product water, with a slurry that can be used to maintain or expand the solar pond system or from which separated salts can potentially be recovered.

A number of water treatment functions could be powered by a solar pond, including preheating water for RO, other source heat, or electricity generation to operate RO equipment (CASS, 2005)

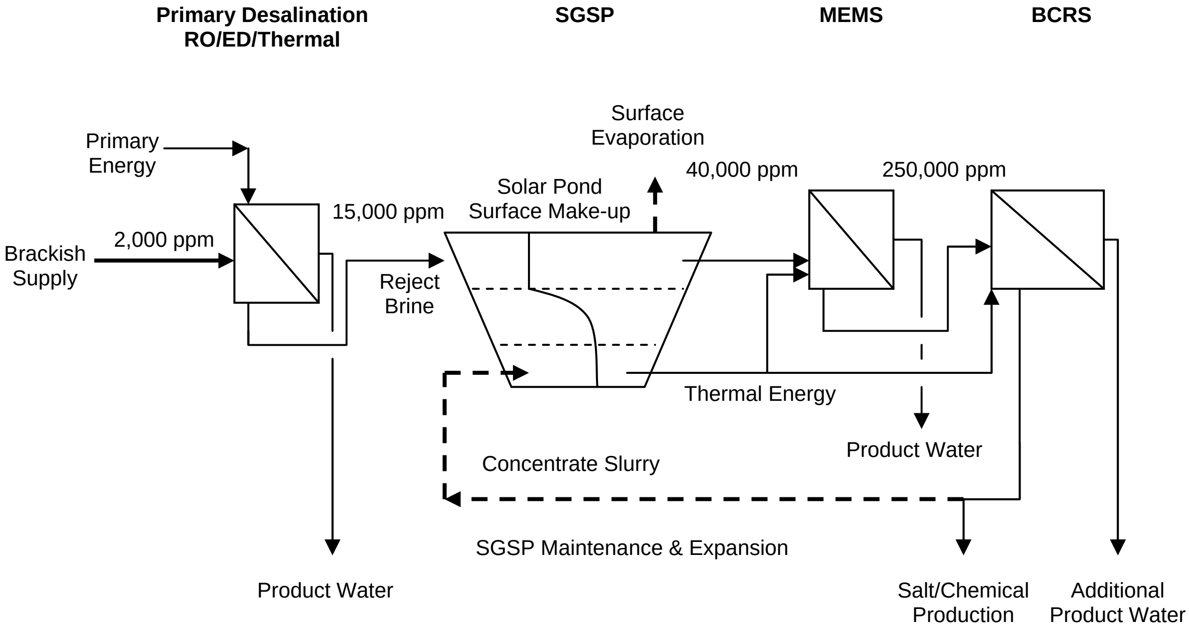


FIGURE 3-6
Solar Pond-Based Zero Discharge System.
Source: Lu et al. (2002).

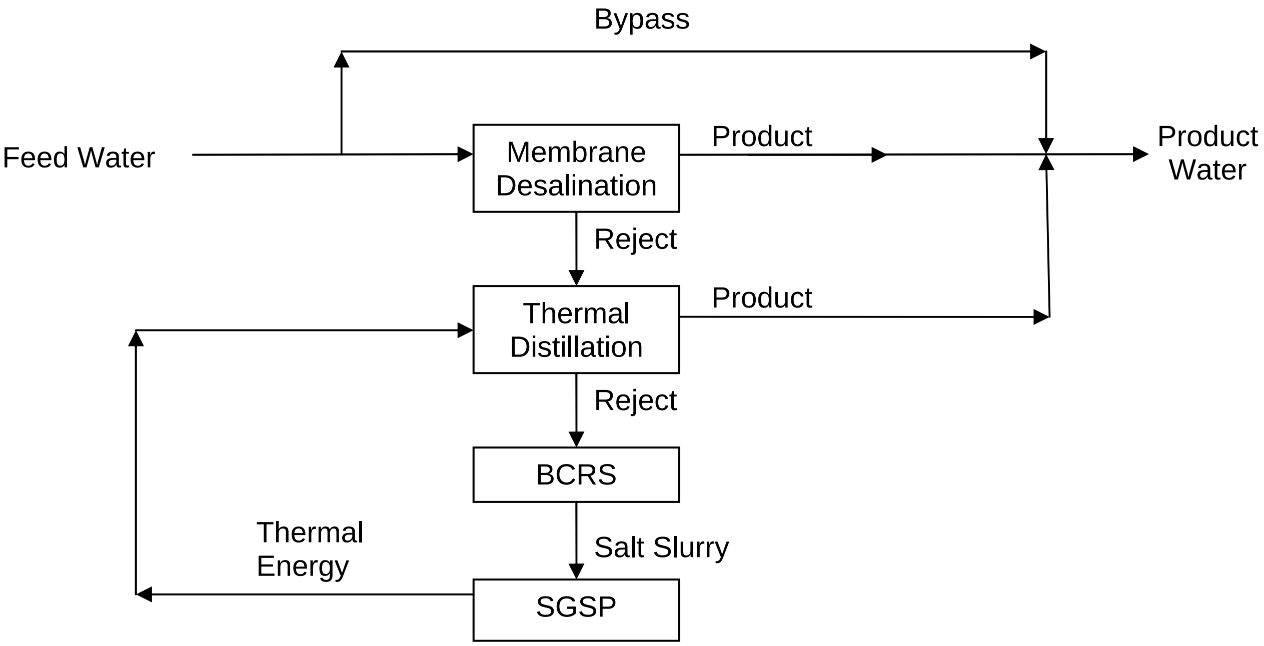


FIGURE 3-7
Flow Schematic for UTEP Solar Pond-Based ZLD System.
Source: Lu et al. (2002).

Other Issues

Other significant implementation issues for surface water discharge are summarized in Table 3-3.

TABLE 3-3

Summary of Other Implementation Issues for Surface Water Discharge

Parameter	Discussion
Geographical and Climatic Relevance	Areas with high levels of solar radiation and limited precipitation, like much of the southwestern United States, most of the Middle East, and North Africa (Lu et al., 2001), would be favored; even in climates that experience freezing temperatures, solar ponds can continue to provide usable energy; the UTEP solar pond still had water at 154ºF 7 ft below a layer of ice (UTEP, 2005)
Level of Water Utility Control	Very high, assuming the pond is located on utility property
Membrane Cleaning Solutions	Issues would be site specific, and ecological risk and nuisance factors would likely be most important
Proven Technology	Not proven for concentrates, but some design issues are well understood; relatively cheap energy in recent years has limited its development; however, recent rises in energy costs could increase interest; developing solar pond technology was identified as important by Sandia (2003)
Pond Clarity	Maintenance of clarity in all zones of the pond is an important operational challenge
Land Area Requirements	Not well-defined

Regulatory Issues

Regulatory issues would be expected to be essentially the same as described for evaporation ponds. Solar ponds would need to be lined to prevent seepage into the groundwater, or the ponds would be considered a Class V injection well, and permitting a solar pond as a Class V injection well would be extremely difficult. Given proper lining, however, permitting a solar pond would likely be a relatively simple process involving specific state and local regulations. Ecological impacts on wildlife are likely to be an increasing concern, especially where selenium, arsenic, or other constituents of concern are found at high concentrations in the surface layer.

Periodic disposal of precipitated salt and sludge from the bottom of the solar pond would likely require landfill disposal. If the material fails a toxicity characteristic leaching procedure test, it would have to be disposed of in a type D hazardous waste landfill (AWWA, 2004). If technically and economically feasible, separated salts recovery (Chapter 4) may provide a means of recovering some costs.

Cost Issues

The major benefit of a solar pond is collection and storage of usable energy in the form of heat. The best use of this heat energy is likely as part of a ZLD desalination system, with recovery of additional high-quality product water and the potential for recovery of separated salts. A solar pond is an elaborate and expensive evaporation pond unless energy is derived. The ultimate sink for water in the concentrate is evaporation, and the ultimate sink for salts is periodic collection and disposal of precipitated salts accumulated in the pond, the same as for evaporation ponds. Therefore, a key cost consideration is the value of the energy that can be derived from the pond. Economies of scale are considerable, and larger ponds are likely more economically feasible (Lu et al., 2004).

The components of cost would be generally similar to those previously described for evaporation ponds (Chapter 2), but with a few key differences. These differences would include deeper water depths, larger berms, equipment required to monitor and adjust gradients, and the installation of piping to allow circulation of water through the pond to collect heat for beneficial use. High corrosion resistance of pipe materials would be required because of the extreme salinity. The other major difference between solar pond costs and evaporation pond costs is the income stream or cost reduction associated with the heat generated by the pond.

The most important factors affecting the cost of a solar pond are the liner, leak detection required, heat exchanger, and monitoring. Depending on the applicable regulations, leak detection may be required. Climate, concentrate volume and salinity, and land costs will be important site-specific considerations. A concentration step will be required at least for initial establishment of the pond, with brackish groundwater RO at 3000–40,000 mg/L and 150,000–300,000 mg/L required.

Some have proposed that solar pond technology could be developed as part of an integrated system, to provide greater levels of product water recovery with low energy costs as well as a means of concentrate management. A summary of the economic analysis developed by UTEP (Lu et al., 2002) for 1- and 10-MGD RO plants is shown in Table 3-4. Table 3-5 shows a summary of costs for a solar pond as part of a ZLD system (MEMS-BCRS). The costs for the solar pond in this example assume a \$4/m^2 pond liner cost. The cost models do not include costs of periodic disposal of brine solids, estimated to be required approximately every 10 years (H. Lu, UTEP, personal communication).

TABLE 3-4

Summary of Estimated Costs for Solar Pond Coupled Reverse Osmosis Plants

RO Plant Capacity	1 MGD	10 MGD
Solar Pond Size (acres)	52	469
Total Capital Cost	$4,721,687	$31,898,783
Total Annual O&M Cost	$933,493	$6,594,301
Total Water Cost ($/kgal)	$2.78	$1.95

Source: Lu et al. (2002).

TABLE 3-5

Estimated Water Costs with Solar Pond: ZLD System

Plant Capacity	1 MGD	5 MGD	10 MGD
Solar Pond Size (acres)	45	226	451
Total Capital Cost	$1,773,932	$8,890,049	$17,790,294
Annual O&M Cost	$175,432	$870,965	$1,724,278
Total Water Costs ($/kgal)	$4.01	$3.72	$3.61

Source: Swift et al. (2002).

O&M Cost

Cost components include the frequency of cleanout, disposal of separated salts, seepage monitoring, repair of dikes or liner, pipe, flow control devices, acids or other chemicals used to control the growth of algae, and maintenance of the heat exchanger. Monitoring data analysis and gradient management will be a significant part of O&M costs, but these costs have not been established. Periodic replacement of RO membranes for the plant at the front end of a solar pond system would also be required.

Similar to evaporation ponds, recovery of separated salts may be a potential option to reduce operating costs. Waterfowl management may be required to control ecological risk, and this will represent an ongoing cost. Landfill costs are incurred during periodic maintenance of the solar ponds. Salt sludge must be disposed of in either a municipal landfill or an approved RCRA landfill, depending on the makeup of the salt sludge. Disposal of salt sludge in a RCRA-approved landfill will increase costs due to the liner and leak detection system required.

The water balance is driven by the relative rates of evaporation from the UCZ and concentrate flow, and this will determine the volume of concentrate that can be accepted by the pond as makeup water.

Cost of Lost Water

Evaporation losses represent a local loss of the water resource (Sandia, 2003) that is balanced by the value of energy recovered. On a national scale, most of the evaporated water is likely to fall back as precipitation within the continental United States, but it may fall on areas with much less acute water supply issues. On a local watershed basis, assuming a 1-MGD concentrate flow from a 5-MGD plant, the “lost” water would be 1 MGD, with an annual value of more than $640,000/year (assuming $1.75/1000 gal).

The total water recovery from a solar pond-RO-MEMS-BCRS plant is estimated at 96% at 1 MGD and 97% at 10 MGD.

Economic Risk Factors

The major economic risk factor is less-than-expected energy costs, which would mean a less-than-expected value of the energy derived from the pond.

Human Health and Ecological Risk Factors

Human health and ecological risk factors for solar ponds are essentially the same as described previously for evaporation ponds (Chapter 2).

Applicability to Other Salt Streams and Overall Basin Salt Management

Limiting factors regarding the use of solar ponds for other salt streams are ecological risk and the need for approximately 200,000 mg/L of influent TDS for initial establishment of the pond. A preconcentration or evaporation step may be required for some streams. Salts are not removed from the basin and will ultimately require landfill disposal or recovery or reuse. Other salt streams could also be used as makeup water for ongoing operations to be added to the surface layer.

Conclusions

Using concentrate as a feedstock for a solar pond is a potential beneficial use, assuming heat energy is used for a useful purpose. No desalination facility in the United States currently uses this technology, but it could become increasingly attractive as energy costs rise, if technical issues can be resolved. These technical challenges are considerable, including major startup and control challenges. Maintaining the gradient of the gradient zone in the pond is critically important and requires a high level of management and monitoring. Similarly, maintaining pond clarity would also be a challenge, as algal growth is likely to be a problem. Moreover, solar ponds do not constitute final disposal of concentrate salts, and some combination of landfilling or separated salt recovery will eventually be required.

LAND APPLICATION AND IRRIGATION

Irrigation provides a potential beneficial use of membrane concentrate as a supplemental or sole water source for landscape or selected agricultural plants. In addition to reuse of membrane concentrate, irrigation systems may also achieve conservation of potable water by irrigating land with membrane concentrate instead of potable water, or along with a reduced rate of potable water. One approach that may be used is to discharge to a canal or other irrigation conveyance, where concentrate is blended with freshwater prior to land application (WDTF, 2003a).

Irrigation or land application can be considered a liquid-concentrating, volume-reducing technology. Evaporation provides a sink for a portion of the water, but maintaining salt balance in the soil to grow plants requires leaching of excess salts from the root zone. Irrigation is typically used to dispose of low-TDS membrane concentrate streams such as those from NF softening plants and some RO plants producing a lower-salinity concentrate.

Crop irrigation is not likely to be a viable option for many facilities because of the high salinity of concentrate relative to plant tolerance thresholds, as well as concerns over potential groundwater quality impacts (NRC, 2004). Irrigation for concentrate reuse is generally most feasible for smaller systems (AWWA, 2004).

For the purposes of this discussion, irrigation applications are divided into three categories that will be defined as follows:

- Landscape irrigation
- Agricultural irrigation
- Halophyte irrigation

Landscape Irrigation

Membrane concentrate has been used to irrigate various plants. These areas are generally dominated by turf grasses, but shrubs, trees, and other plants may also be components of the plant system. These plant systems are designed primarily to provide some combination of aesthetics, erosion control, and/or recreation.

Agricultural Irrigation

Agricultural irrigation can be defined as plants (crops) that are irrigated and regularly harvested for their economic value. Concentrate is less commonly used for common agricultural crops because of generally lower levels of crop salt tolerance. For the purpose of this report, irrigation of trees to grow wood products (silviculture) is discussed under this section.

Halophyte Irrigation

Halophytes can be loosely defined as plants with an unusually high tolerance to salinity. The definition of a “halophyte” is vague, because it is difficult to define an appropriate lower limit for salt tolerance (Glenn and Brown, 1999). Irrigation of especially the more salt-tolerant halophytes could make land application and irrigation of concentrates a more feasible option for more water utilities. Riley et al. (1998) made the case that halophytes could be irrigated with concentrate in southern Arizona at low leaching fractions (5%) for decades and that impacts on groundwater quality would not exceed those of conventional agriculture. This is because the halophytes tolerate a much greater accumulation of salts in the root zone, and these salts are unlikely to leave the root zone in such an arid climate unless they are actively leached.

Aronson (1989) lists 1560 different halophytic plant species. Most halophytes are deep-rooting perennials (Biosalinity, 2005). It should be noted that Aronson’s list is limited to plants with potential use for food, fuel, forage, or soil stabilization (Glenn and Brown, 1999).

Halophyte irrigation is one of the areas recommended for additional research and development effort by the AWWA subcommittee on concentrate management (AWWA, 2004). Halophyte applications include landscaping, wildlife habitat, dust barriers, windbreaks, livestock grazing, and production of grains, oilseeds, and fodder (Ahuja and Howe, 2005). Internationally, the United Arab Emirates has extensively investigated halophyte systems for landscaping, crop, and livestock production, golf course irrigation, landscaping, and creation of nature preserves (Child, 2005). Halophytes can be planted in strips surrounding agricultural areas to control lateral flows of saline groundwater away from the agricultural site (Biosalinity, 2005).

Implementation Issues

There are a wide range of implementation issues associated with land application and irrigation, including overall irrigation strategy, concentrate chemical characteristics, hydraulic and nutrient loading, site selection, crop selection, drainage, leaching and groundwater impacts, distribution technique, opportunities for blending irrigation water sources, ultimate fate of concentrate constituents, seasonal storage requirements and seasonal alternatives for discharge, and other factors. These issues are discussed in the following sections.

Irrigation Strategies To Utilize High-Salinity Water

Two management strategies have been devised to allow maximum utilization of high-salinity waters, and these are cyclic reuse and series design.

Cyclic Reuse (Irrigation with High-Salinity Water Periodically or Seasonally): Approaches have been developed that allow use of higher-salinity water during periods of plant growth where there is little impact on crop growth or where higher-salinity water is used on crops with greater salt tolerance in a crop rotation (Grattan, 2005). Water of a lesser salinity is used at all other times. The bulk of the research in this area has been conducted with agricultural drainage water in California's San Joaquin Valley.

Prerequisites for this approach include the following (Grattan, 2005):

- High level of active irrigation and soils management, including attention to the potential problem of soil dispersion when following lower-quality irrigation water (high SAR, high salinity) with higher-quality irrigation water (low SAR, low salinity)
- Net downward movement of soluble salts through the root zone
- Good soil conditions and proper drainage
- Use of viable plants acceptable to growers (G. Bañuelos, personal communication)

Series Design (Irrigation of Crop Sequences Based on Salt Tolerance): A number of authors have described collection of and irrigation with agricultural drainage water on a series of increasingly salt-tolerant crops to reduce water volume (Rhoades et al., 1989). Implementation of this approach requires a relatively impermeable layer near the surface to protect groundwater and allow collection of a large percentage of the applied water. This lithology is present in western portions of California's San Joaquin Valley. Use of impermeable membranes in constructed cells can result in the same functionality, but for most applications it is likely to be cost-prohibitive. The concept is to first irrigate the least-salt-tolerant crop with the best-available water, then to collect the drainage water and irrigate a more-salt-tolerant crop, and continue the process as long as is feasible (Grattan, 2005). The last crops to be irrigated are halophytes. With each increment, a volume reduction due to evapotranspiration is achieved, and drainage water salinity is increased (Grattan, 2005). Models developed for reuse of highly saline agricultural drainage water can be adapted for concentrate reuse. Fields at the end of the sequential approach can reach soil salinity levels (electrical conductivity of the soil saturation extract [ECe]) exceeding 40 dS/m.

A 640-acre site at the Red Rock Ranch in the Westlands Water District in western Fresno County, CA, has been the site of extensive research and development of an Integrated Farm Drainage Management system concept (Diener, 2005). The first field in the sequence is irrigated with normal irrigation water, and drainage water is collected, blended with tailwater (excess water from surface irrigation), and used to irrigate salt tolerant grasses. Drainage from the second field is collected, blended with tailwater, and again used to irrigate salt-tolerant grasses in a third field. Drainage water from the third field is used to irrigate halophytes. Drainage from the halophyte field is conveyed to an on-farm solar evaporator to achieve ZLD. The solar evaporator is still in the developmental stage, but the pilot study includes spray nozzles, 2-in. aggregate on a 2% slope, and stepwise increases in salt concentration (Begaliev et al., 2005). Figure 3-8 illustrates the general concept.

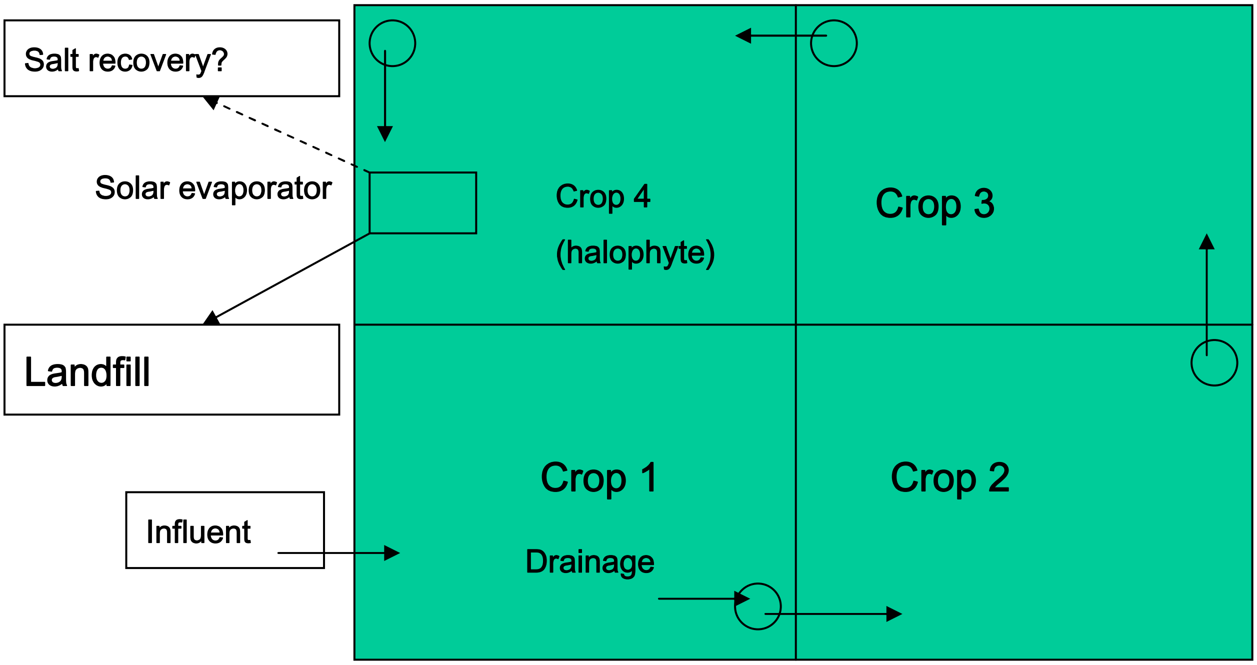


FIGURE 3-8
Concept for Multiple Crop Irrigation of Drainage Water.

Prerequisites are the same as those listed previously for the cyclic approach, with the following additions:

- An impermeable layer below the root zone to force lateral movement and facilitate drainage water collection
- A final treatment step, such as careful design and construction of an evaporation basin or solar concentrator, is needed to remove the last increment of water from the drainage from the halophyte cell.
- Residual salt constituents may be recovered or disposed of in a landfill.

There is also the potential to reduce drainage volumes by managing the system to allow for crop uptake from a shallow water table through controlled drainage (Ayars et al., 2005), but this approach probably requires additional research and development. Also, shallow groundwater quality must be suitable for uptake by the crop in question.

Strategies To Manage Conservative Constituents in Concentrate

Conservative constituents in the membrane concentrate can be managed in one of three ways, as shown in Figure 3-9.

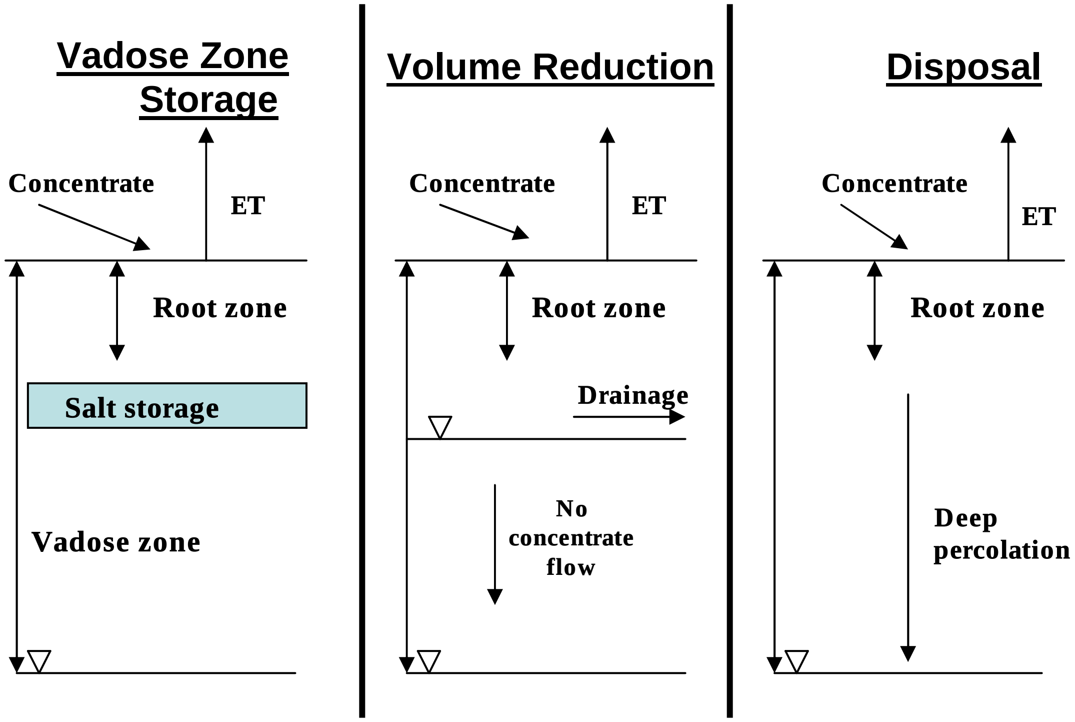


FIGURE 3-9
Salt Management Concepts with Land Application.

Vadose Zone Storage: This approach depends on evapotranspiration of the water by the irrigated plants and storage of the salts below the root zone and above the groundwater. It requires controlled, limited leaching, an arid environment, and a deep vadose zone. This technique is commonly employed on golf courses, public parks, and roadway medians (CH2M HILL, 2004). This approach may be feasible with good management for a number of years in an arid environment with a deep water table. Critical issues with regard to this approach include the maintenance of salt balance in the root zone, the rates of unsaturated and saturated flow, potential formation of slowly permeable caliche and gypsum layers, native and operational soil chemistry, preferential flow, aquitards, and lateral groundwater flow. There are several sparingly soluble salts in RO concentrates that could precipitate, including calcium sulfate ($CaSO_4$), barium sulfate ($BaSO_4$), strontium sulfate ($SrSO_4$), silicon dioxide (SiO_2), calcium fluoride (CaF_2), and calcium carbonate ($CaCO_3$). Modeling can be used to determine reasonable site life for this approach. Riley et al. (1998) suggest that for southern Arizona, sites should be selected out of the floodplain, in areas where the soil (vadose zone) is very deep, and that irrigation should be managed to minimize deep leaching and preferential flow. As an example, Riley et al. (1998) calculate that if a low leaching fraction (3–5%) were used for halophyte irrigation, it would require 100 years of irrigation for percolation to reach 42 m, 50% of the depth to the local water table.

Volume Reduction: In this approach, concentrate volume is further reduced in the root zone through evapotranspiration; the more-concentrated percolate is recaptured in a subsurface drainage system. The costs of handling concentrate are directly related to the volume; therefore, reductions in volume can be of considerable value. For protection of groundwater, hydrogeology and management of the site need to facilitate recapture by the drainage system. A natural condition favorable to recapture would be, for example, slowly permeable subsoil layers underlying subsurface drainage. Design and operational features might include perimeter subsurface drains or maintenance of on-site shallow groundwater gradients generally toward the site. Note that in either case there is significant potential to capture shallow groundwater other than percolate from applied water. Therefore, this potential must be considered during feasibility evaluation of the system, evaluated as part of site characterization, and then considered during system design. The flow from the drainage system may require additional treatment, depending on its next use or disposal pathway. Examples of next steps include the following:

- Further volume reduction by using the drainage to irrigate increasingly more salt-tolerant crops, including halophytes
- Diversion to evaporation ponds or a ZLD (brine concentrator) system

Disposal: A land application site can be used purely for disposal if the underlying aquifer is of poor quality (i.e., >10,000 mg/L of TDS). In this case, relatively little in the way of advanced site design or operations is required.

Characteristics of Concentrate (Irrigation Water Quality Assessment)

Irrigation water quality assessment requires consideration of a number of factors, including salinity, sodicity or SAR, and the concentration of specific constituents. Certain constituents of saline waters, such as boron and selenium, can be especially problematic. Blending is an option to increase the range of plants that can be irrigated with highly saline concentrates and may help make irrigation more sustainable in terms of soil quality. The combination of high hardness and alkalinity can result in the formation of solids (e.g., $CaCO_3$) that can occlude soil pores and restrict infiltration rates (Mickley, 2004a).

Salinity: As a result of the typical salinity range of RO and EDR concentrates, NF concentrate is more likely to be feasible to use directly (without dilution) for irrigation of typical agricultural crops. Irrigation using RO and EDR concentrates (e.g., 5000 to 10,000 mg/L of TDS for brackish groundwater RO) is more likely to require dilution to be feasible (Mickley, 2004a).

The availability of water to plants is determined by the total water potential, which is the sum of the matric and osmotic potential (Pratt and Suarez, 1990). In other words, plants find it increasingly difficult to extract water as soils become drier and as soil solution salinity increases. Irrigation water salinity impacts are best assessed with a good understanding of a number of factors, including the following (Pratt and Suarez, 1990):

- Salt tolerance of the vegetation to be used
- Leaching fraction (how much excess water will be applied to prevent the accumulation of soluble salts beyond specific crop tolerance limits)
- Irrigation method (sprinkle, drip, or flood) and duration of use of low-quality water (G. Bañuelos, personal communication)
- Soil characteristics
- Climate
- Expertise of the irrigation system operator (ability to achieve the designed leaching fraction)
- Decrease in yield or crop growth that can be economically tolerated
- Range of expected salinity of the resulting soil pore water

The maximum TDS level that can be treated by a given plant also depends on whether the plant will be grown for landscape or agricultural purposes. For agricultural production, water and soil salinity that limit crop yield to less than 90% of maximum is generally considered an undue hardship for the farming operation (Dickey, 2000). For landscape plants grown for ground cover and aesthetic value, soil salinity levels resulting in 50% of the maximum "relative crop yield" correspond to the point at which plant aesthetics are unacceptable (Bernstein et al., 1972). Some horticultural and ground cover species will have unacceptable visual damage, such as leaf edge or tip burn, that will appear long before 50% yield reduction occurs. This will be especially true where elements like chlorine or boron are present in concentrate in excessive amounts (see discussion below under Sprinkling Hazard). For turf grasses, soil salinity thresholds are established to produce acceptable quality turf rather than acceptable growth (Harivandi et al., 1992).

If the TDS for a given membrane concentrate is in excess of the highest value that can be treated by a landscape or agricultural plant for a given location and soil condition, irrigation is not a feasible alternative for disposing of membrane concentrate without blending. However, if a suitable plant is identified for the concentrate quality, geographical location, and soil condition, irrigation may be a viable alternative for disposing of membrane concentrate if the economics are favorable.

SAR: Sodium, Calcium, and Magnesium: Of particular concern regarding beneficial use of membrane concentrate through irrigation are the relative concentrations of sodium, calcium, and magnesium in the concentrate stream. When bulk salinity levels are low (see below), a high concentration of sodium relative to calcium and magnesium can adversely affect the permeability characteristics of soil. High sodium concentrations, relative to calcium and magnesium, tend to cause dispersion of aggregates composed of many individual clay particles. When this happens, the free clay particles tend to move with the water, plugging pore space and sealing the soil. Soils with higher percentages of clay (especially clays prone to shrinking and swelling with changing moisture content) are most vulnerable. Consequently, the U.S. Department of Agriculture developed a parameter to measure this effect, called the sodium adsorption ratio (SAR). SAR is defined as follows:

$$SAR = \frac{Na}{\left(\frac{Ca + Mg}{2}\right)^{\frac{1}{2}}}$$

where: Na = concentration of sodium (meq/L)
Ca = calcium (meq/L)
Mg = magnesium (meq/L)

SAR values greater than 9 (Ayers and Wescot, 1985) may adversely affect soil permeability or result in sodium toxicity to certain plants. Sensitive plants may be affected at a SAR of 3 to 9. Posttreatment or blending with higher-quality water would likely be required for concentrate with a SAR value greater than 9 to lower the SAR to an acceptable value. Treatment may be accomplished by the addition of gypsum to the irrigation water or the soil to increase the concentration of calcium and, in effect, lower the SAR. Note again that the SAR is unlikely to be a problem so long as bulk salt concentration is also high (see below).

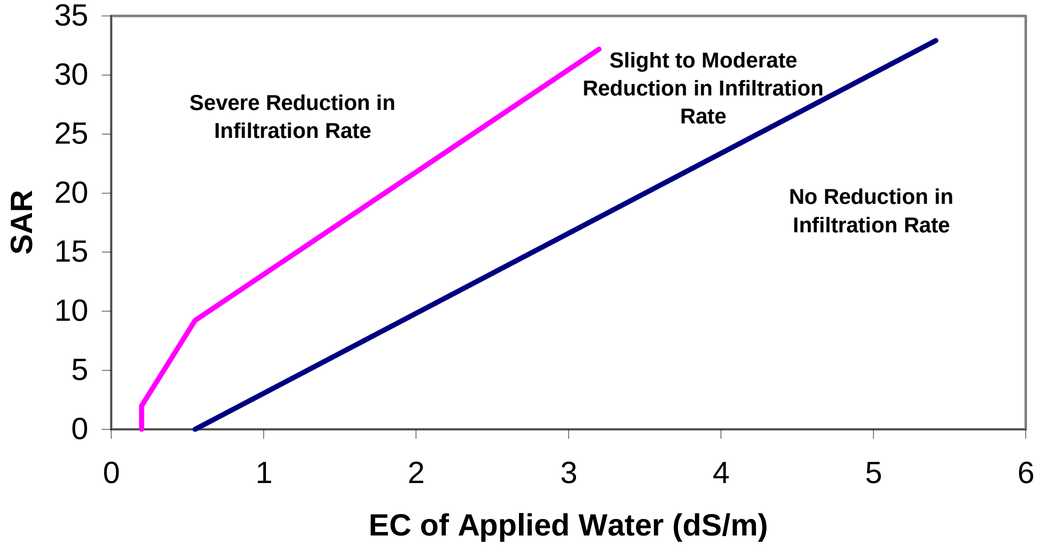


FIGURE 3-10
Relative Infiltration Hazard of Irrigation Waters Based on SAR and Salinity (dS/m = mmho/cm).

If soluble calcium and magnesium are reduced, the proportion of soluble sodium increases, increasing the tendency of soils to disperse and lose permeability. High alkalinity can result in the precipitation of calcium and magnesium carbonate, increasing the relative concentration of sodium in the soil solution and on exchange sites. The end result is that the actual hazard from excess sodium is underestimated by the SAR. To predict a potential water infiltration problem, the SAR is sometimes used with a modification to account for this effect. The adjusted sodium adsorption ratio (SAR_{adj}, or adj R_{Na}) accounts for the changes in calcium solubility in the soil water (Ayers and Wescott, 1985; Suarez, 1981).

$$SAR_{adj} = \frac{Na^{+}}{\sqrt{\frac{Ca_{x}^{2+} + Mg^{2+}}{2}}}$$

Interrelationship between SAR and Salinity: A higher SAR can be tolerated as the irrigation water salinity (TDS) increases. As a general rule, waters with a SAR below 3 are considered safe regardless of irrigation water salinity. Other factors, such as soil properties, irrigation management, climate, salt tolerance of the plants, and cultural practices all interact with SAR and irrigation water salinity to influence soil permeability. The general relationship between salinity and SAR is shown in Figure 3-10.

High irrigation water SAR values, especially when combined with relative low salinity, can lead to high levels of exchangeable sodium, soil dispersion, and reduced infiltration. Rainfall is typically low in salinity (<0.6 dS/m), resulting in considerable potential for dispersion of surface soils if the level of exchangeable soil sodium is high (Pratt and Suarez, 1990), or even at lower exchangeable sodium levels (Shainberg et al., 1980).

It is important to note that in addition to the critical interrelationship with irrigation water salinity, the impact of irrigation water SAR on soil permeability varies with soil mineralogy, salinity, organic matter, and pH (Pratt and Suarez, 1990). For example, in some tropical soils with high organic matter and oxide minerals, there may be little or no decrease in soil permeability even if the soil is saturated with sodium and irrigation water salinity is very low (Pratt and Suarez, 1990). The standard values and relationships described in this report are generally derived from data from the southwestern United States, primarily from studies conducted in arid areas of California, and are therefore generally applicable in this area and similar regions of the world.

Sodium and Chlorine Sprinkling Hazard: When plants are sprinkler irrigated, especially during the heat of the day, high sodium and chloride concentrations can cause foliar damage to sensitive species. Maas (1990) suggested that damage to very sensitive plant species can occur at concentrations above 5 meq/L of sodium or chloride (115 mg/L of sodium or 180 mg/L of chloride), and limitations for sprinkling moderately tolerant species become severe above 20 meq/L (460 mg/L of sodium or 710 mg/L of chloride). The standards provided by Ayers and Wescot (1985) are even more conservative, suggesting that 3 meq/L of either sodium or chlorine may cause damage to sensitive crops.

Pratt and Suarez (1990) also provided additional guidance on crop salt tolerance and irrigation water quality assessments. They suggested that 5 meq/L may be a usable threshold for sprinkler irrigation of salt-sensitive plants, but they went on to suggest that with the current state of knowledge, limits or guidelines for sprinkler irrigation were really too arbitrary to be useful, at least in part because temperature, wind, humidity, time of day, frequency and duration of irrigation, and other factors strongly influence the severity of crop impacts. Therefore, the relative hazard and required management tools should be assessed on a case-by-case basis, ideally supplemented by pilot tests before full-scale implementation. Many extension publications still use the 3-meq/L standard as a guideline.

Options to decrease the potential damage caused by high-sodium, high-chloride, or high-boron irrigation water include the following:

- Blend with a higher-quality (low-chloride, low-sodium, low-boron) water, such as treated wastewater, before it is used for irrigation
- Select plants that are not sensitive to sprinkler irrigation impacts
- Irrigate at night to reduce absorption
- Irrigate sequentially, completing an irrigation cycle with low-chloride, low-sodium water that rinses other water off of leaves before they dry between irrigation events.
- Avoid applications to juvenile plants, which are typically more sensitive than mature plants
- Switch to surface or subsurface irrigation methods such as furrow or drip

Sodium in Soil Water and Effects on Plants: Excessive levels of sodium can be directly toxic to some plants. Generally, adverse effects are limited to woody plants. However, even some turf grass species are susceptible (Harivandi, 2005).

Chloride in Soil Water and Effects on Plants: Chlorine is an essential plant nutrient, but chloride levels in excess of the very small amounts needed by plants can damage foliage of sensitive plants, even with surface applications. Most plants are able to tolerate high soil chloride relatively well, but many woody species are relatively sensitive to high levels of chlorine in the soil water (Pratt and Suarez, 1990). Strawberries and avocados are sensitive to chloride.

Boron: Boron is both an essential plant nutrient and a toxicant, depending on concentration (Keren and Bingham, 1985). The window of acceptable concentrations is small, with only a few milligrams per liter difference between insufficient and excessive concentrations (Grattan, 2005). Excessive boron can build up in soils and can be toxic to sensitive plant species. Sensitive plants can begin to suffer at 0.7 mg/L of boron, with levels above 3 mg/L severely limiting the use of irrigation water for many crops (Ayers and Wescot, 1985). Soil solution concentrations exceeding 2–4 mg/L are likely to limit the growth of Kentucky bluegrass turf (Maas, 1990). If boron is allowed to build up in the soil, it typically requires two to three times as much infiltrating water to reduce boron levels as would be required to leach chloride (Pratt and Suarez, 1990). Boron can be a key limitation to the reuse of drainage water (Grattan, 2005), as described previously.

pH: If the irrigation water has a pH of 9 or more, it may have a direct adverse impact on soil infiltration (Suarez et al., 1984) and increase boron solubility.

Precipitation of Major Salts in Irrigation Piping and Corrosion: Salts in the concentrate can precipitate in the irrigation system, plugging spray nozzles or drip emitters (CASS, 2005) and causing corrosion of irrigation equipment. Acidification to control scaling is commonly recommended.

Manganese, Iron, and Sulfide: Manganese, iron, and hydrogen sulfide can form deposits that plug distribution systems, especially in drip irrigation systems using groundwater. Surface irrigation systems (sprinkle or flood) and wastewater reuse systems are less likely to experience problems. Manganese and iron can pose problems with concentrations as low as 0.1 mg/L. Chlorination and filtration will likely eliminate any potential problems with iron. The relative hazards for various concentrations are provided in Table 3-6.

TABLE 3-6

Thresholds for Minor Constituents of Potential Concern in Drip Irrigation Systems

Potential Problem	**Concn (mg/L) Causing Degree of Restriction on Use**		
	None	**Slight to Moderate**	**Severe**
Manganese	<0.1	0.1–1.5	>1.5
Iron	<0.1	0.1–1.5	>1.5
Hydrogen Sulfide	<0.5	0.5–2.0	>2.0

Source: Ayers and Wescot (1985).

Selenium and Molybdenum: Yields of most plants will be reduced by levels of selenium as low as a few milligrams per liter, unless there is adequate sulfate present to reduce uptake of selenate. Selenium-laden agricultural drainage waters are a major problem in the western United States because of ecological risks such water may pose to wetlands and wildlife (especially waterfowl), particularly when the water is further concentrated through evapoconcentration in storage ponds (Ohlendorf and Santolo, 1994). High selenium and molybdenum levels in agricultural drainage waters used for irrigation of forage crops in California can also be of concern for livestock (Benes et al., 2005; Whiston and Powell, 1987). Bioconcentration of selenium through aquatic and/or terrestrial food webs is a major ecological concern where selenium-laden waters are present.

Sulfate: Concentrate with high levels of sulfate can pose a problem if used to irrigate forages that accumulate sulfate and that are fed to ruminant animals (Grattan, 2005). However, elevated sulfate reduces uptake of selenium (as selenate) by plants (Vickerman et al., 2002).

Other Trace Elements: A number of trace elements could potentially be at sufficient concentrations to limit concentrate irrigation. Limits appropriate to protect sensitive crops have been provided by Pratt and Suarez (1990).

Pretreatment

Pretreatment requirements depend on the type of vegetation irrigated, the degree of public contact, and the method of application. Typically, concentrate is aerated to increase the DO concentration before conveyance to a detention pond. Increased levels of DO help prevent stagnation and algal growth. Additional pretreatment may be required if there is anticipation of substantial public contact with irrigation water, such as may be the case for some landscaping applications.

High levels of sodium could potentially be mitigated with injection of a gypsum ($CaSO_4$) slurry or calcium chloride ($CaCl_2$), increasing the proportion of calcium in the water. The potential for plugging in the distribution system would need to be carefully considered in the design, since gypsum is only sparingly soluble and many concentrates are already supersaturated or near saturation with $CaSO_4$.

In lieu of posttreatment of membrane concentrate to decrease the SAR, a soil amendment may be added to the irrigation site to offset sodium buildup. Appropriate soil amendments high in calcium and magnesium include gypsum, calcium chloride, calcium nitrate, and agricultural lime. In agricultural applications, the addition of a soil amendment to offset a high-SAR membrane concentrate may be more economical than posttreating the concentrate before irrigation. For landscape irrigation, a membrane concentrate with a high SAR will require pretreatment before application.

The primary role of gypsum ($CaSO_4 \bullet 2H_2O$) is to provide soluble calcium to balance the high level of sodium in the irrigation water. It also provides a secondary "benefit" by increasing soluble salts, decreasing the dispersing effect of high sodium. Calcium chloride ($CaCl_2 \bullet 2H_2O$) can be used as a substitute for gypsum. Calcium chloride is much more soluble than gypsum, reacts much more quickly with the soil, and can be easily injected. Calcium chloride is more costly than gypsum. Injection avoids nuisance problems with dust associated with dry gypsum applications and may be useful where gypsum cannot practically be mixed into the soil during tillage. The potential for $CaCO_3$ scale formation in the distribution system will increase if calcium chloride is injected, and the rate to be used should be modeled along with updated overall water chemistry to more fully assess the hazard.

Land Requirements

Land requirements for reuse of membrane concentrate through irrigation depend on the plants being irrigated, storage requirements, and buffer zones. The portion of land required solely for irrigation can be calculated by the following expression:

$$\text{Irrigated Area} = \frac{1{,}118 \cdot Q}{\text{HLR}}$$

where: Q = concentrate flow rate (MGD)
HLR = annual liquid hydraulic loading rate (ft/year)

Land requirements for storage of irrigation water depend on many different factors, including annual concentrate flow rate, annual hydraulic loading rate, length of growing season, precipitation, and evapotranspiration. The 10-year average hydrology (precipitation and evapotranspiration) is typically used to size storage facilities for irrigation applications. Taking into account these factors and timing of seasonal discharges (e.g., to sewer or surface water), the required storage volume for irrigation water can be determined. The storage volume can then be used to determine storage land requirements based on storage pond depth and freeboard.

Factors affecting the hydraulic loading rate include precipitation, evapotranspiration, percolation, and runoff. Runoff from a facility irrigated with brine is not generally allowed and can be prevented by a combination of application rate control or construction of a berm or underground collection system around the perimeter of the irrigation site. Assuming runoff is not allowed, the following water balance equation expresses the relationship between the various hydrologic pathways:

Precipitation + Hydraulic Loading Rate (irrigation) = Evapotranspiration + Leaching

The rate of precipitation is specific to the climate of a given area. The evapotranspiration rate is dependent upon the vegetation, which will be discussed later.

For example, a typical RO membrane facility that delivers a 1.5-MGD flow may produce 0.375 MGD of concentrate flow, assuming 80% efficiency. Assuming an HLR of 2 ft/year, the irrigated portion of this system would require 210 acres. Land area requirements for various concentrate flows and hydraulic loading rates are shown in Figures 3-11 and 3-12.

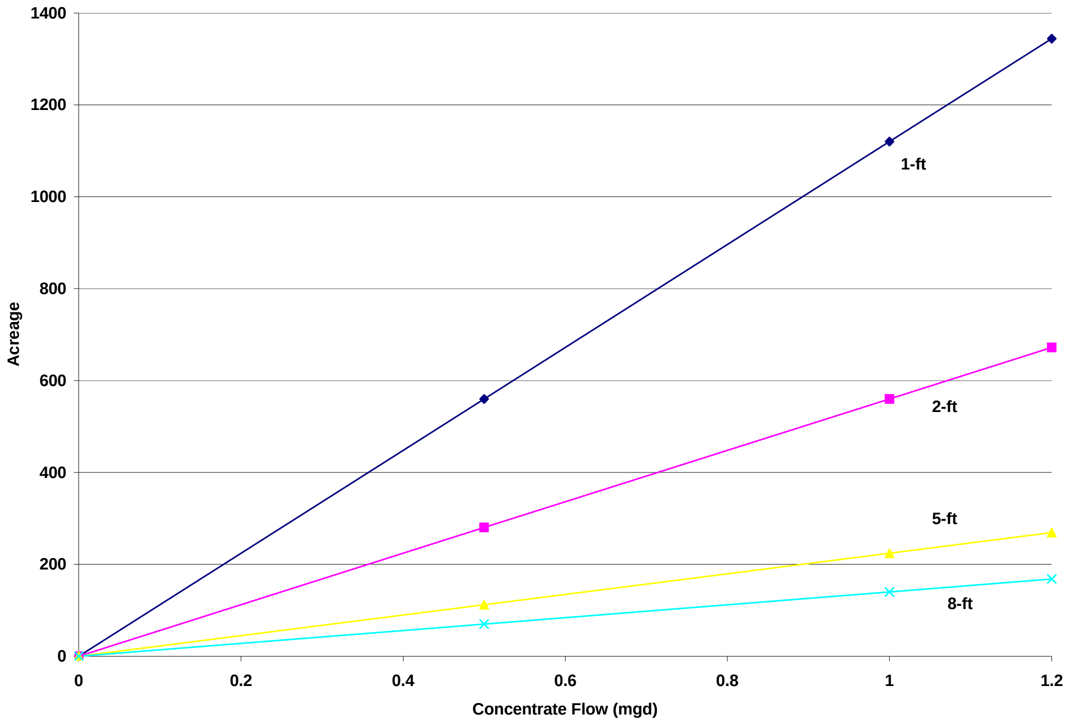


FIGURE 3-11
Acreage Requirements for 0.5- to 1.2-MGD Concentrate Flows Based on Hydraulic Loading.
Source: adapted from Mickley (2004a).

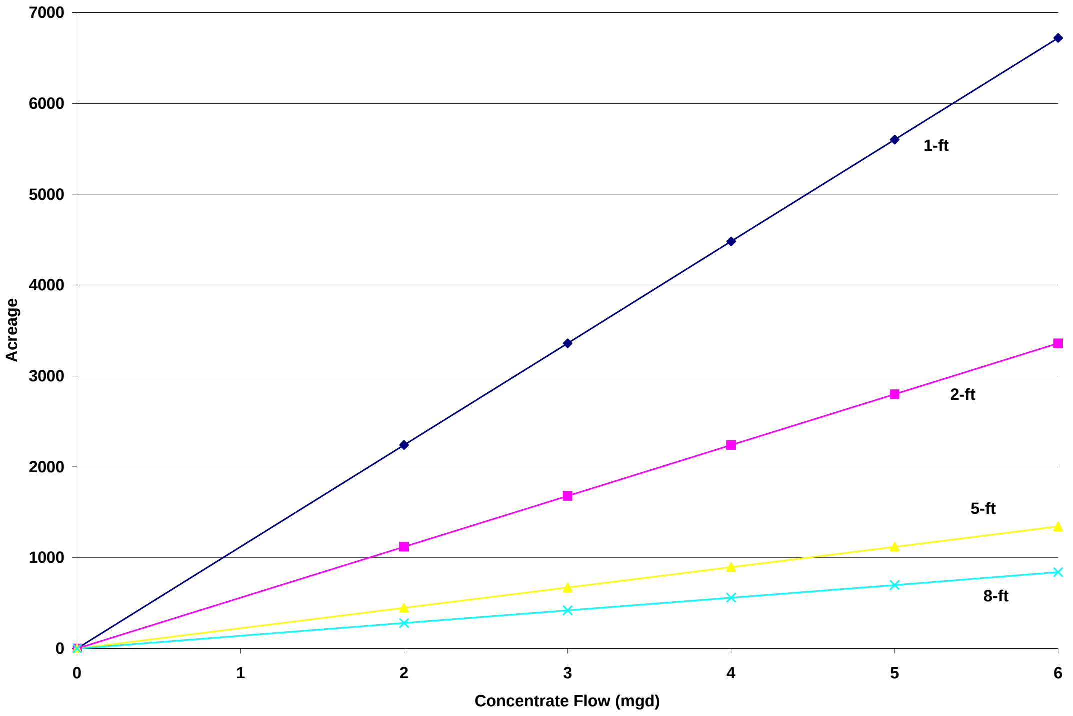


FIGURE 3-12
Acreage Requirements for 2- to 6-MGD Concentrate Flows Based on Hydraulic Loading.
Source: adapted from Mickley (2004a).

Seasonality and Alternate Disposal

The hydraulic loading rate must be adjusted according to seasonal variations in precipitation and evapotranspiration in accordance with the water balance. Fluctuation in hydraulic loading rates between seasons may be mitigated by installation of detention ponds before irrigation, which will detain excess water when the rate of membrane concentrate production periodically exceeds the allowable hydraulic loading rate. Typically, 10-year hydrology is used to determine the allowable hydraulic loading rate and the required detention volume according to the water balance. The typical pattern in evapotranspiration (ET) is shown in Figure 3-13 in comparison to an example concentrate discharge. Values for ET are for a grass crop in the Mojave Desert area of California.

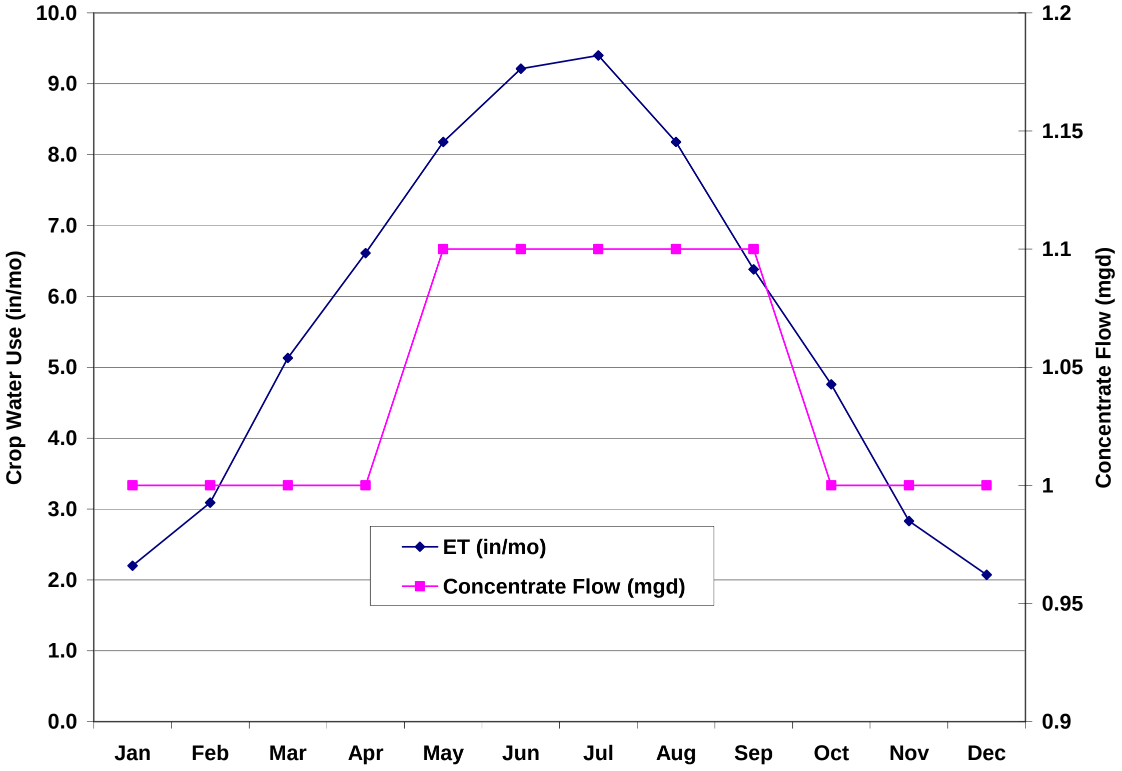


FIGURE 3-13
Crop Water Demand Relative to Concentrate Flow.

The capacity to use concentrate for irrigation varies with time, while concentrate flow may be relatively constant. The figure highlights the fact that each system must include flexibility or an ability to regulate flows (variable irrigated acreage, storage, alternate discharge, overirrigation, and deficit irrigation) required to balance supply with demand. It should be noted that in some communities like Scottsdale, AZ, peak concentrate production occurs during the winter, rather than the summer (CASS, 2005), because the city's RO units operate when wastewater plant effluent is not utilized for golf course irrigation.

Crop water demand varies throughout the year and among years. Even in arid climates, wet periods occasionally occur and reduce irrigation demand. It may be possible for discharge permits to provide seasonal flexibility. For example, in the Pacific Northwest west of the Cascade Mountains, wet winter weather leads to high stream flows and increased capacity to assimilate concentrate discharges. Direct surface water discharge is allowed when stream flow exceeds a specified threshold. This period coincides with seasonally low evapotranspiration and corresponding hydraulic loading rates.

Leaching

Leaching of salts and specific ions (sodium, chloride, and boron) is the universal method of managing concentrations in soil. All irrigation systems require a positive leaching fraction to remove excess salts that accumulate as water is evapotranspired and salts are left behind. Leaching is simply application of slightly more water (commonly an additional 15 to 20%) than the plants use (i.e., take up in their roots and transpire). A larger leaching fraction is needed as applied water salinity increases. Leaching fractions in landscape irrigation are typically somewhat conservative (large enough to remove excess salts, including specific ions like boron). The amount of leaching required to maintain favorable rooting conditions depends on the salinity of applied water, the climate, and the plants being irrigated. Even with the use of halophytes, some net leaching of excess salt is required.

Depending on soil and groundwater characteristics, the leachate has the potential to degrade groundwater (NRC, 2004). Degradation of groundwater quality, especially due to salinity, is common in southern California and influences decisions about managing brines and reclaimed water (CH2M HILL, 2004). Site design and operation must account for this potential and avoid the impact. As mentioned previously, drainage systems may be used to influence subsurface flow and fate of leachate. However, the irrigation practices should be evaluated first to determine the potential for avoiding impacts without resorting to artificial subsurface drainage.

The leaching requirement is best calculated based on a root-zone average approach, as described by Ayers and Wescot (1985). Published threshold values for average root zone soil salinity, above which yield losses are expected, are used in the calculation.

The pattern of root zone salinity response may vary depending on the level of salt tolerance. When pickleweed (*Salicornia bigelovii)* was irrigated with water at 40,000 mg/L of TDS, at rates that ranged from 50 to 250% of pan evaporation, Glenn et al. (1997) found that all treatments resulted in a 0.35 leaching fraction. Increased irrigation rates reduced average soil salinity, which increased plant growth and water uptake. It is important to note that the response of *Salicornia bigelovii* found by Glenn et al. (1997) may not be repeated in other plants because of limits on the ability to increase leaf area and use the additional water and because of nutrient limitations to plant growth. Understanding interactions that allow *Salicornia* to respond so well to increased water supply is important if this response is to be used as a means of predicting other species or system responses (J. Richards, University of California, Davis, personal communication).

In any case, detailed analyses for individual sites should take into account site- and application-specific factors. The goal of such analyses is to determine the required leaching fraction for the given site. Note that soils and drainage conditions may vary significantly within a site and that the most sensitive areas on a site may determine its requirements.

Nutrient Loading

Nutrient loading is frequently an important design consideration, after hydraulic and salt loading have been addressed. In some cases, the contribution of excess nitrogen and phosphorus to eutrophication of surface water bodies is also a concern. The major limiting factor is often nitrogen, and the concern is adverse impacts to groundwater from nitrate leaching. Typically, nitrogen levels in concentrate are relatively low except where concentrate is derived from treatment of wastewater effluents, but regulatory agencies will require a nitrogen management plan for most land application sites. Nutrient loading from the concentrate, commercial fertilizers, and any other soil amendments should be compared with crop needs and soil loading limits.

Nutrients are removed in plant tissue during harvest. This removal, or the lack thereof in an unharvested system, must be accounted for when calculating loading limits.

Phosphorus loading from land application systems is increasingly being regulated. Systems perennially receiving concentrate derived from treatment of wastewater effluents need to be planned, monitored, and managed to avoid overloading with phosphorus. Either sustainable levels of phosphorus application to a site may be determined and applied, or fields may be rotated out of application before phosphorus levels become too elevated.

Several key ratios influence the performance of plant–soil systems. These include nitrogen/phosphorus, carbon/nitrogen, and water use efficiency (carbon/water). The balance of these factors must also be considered in addition to salts in concentrate.

Blending with Freshwater

In some cases there may be an opportunity to blend concentrate with lower-salinity freshwater to increase the range of crops on which concentrate can be used. Large-scale blending of irrigation flows to meet salinity targets has been implemented at Owens Dry Lake using in-line eddy current sensors (Appendix B).

For example, an inland facility desalinating brackish groundwater (2276-mg/L TDS feedwater) with a 5× concentration factor (80% efficiency) would produce a concentrate with TDS of 11,380 mg/L (eddy current, ~17.8 dS/m). Unless blended with higher-quality water, this level of salinity would only be appropriate for halophytic plants such as salt grass. Figure 3-14 shows a typical range of TDS for RO concentrate and plant tolerance limits assuming typical leaching fractions. It also shows how blending can potentially make irrigation feasible for a wider range of crops.

Bermuda grass is a relatively salt-tolerant turf species, with a soil salinity threshold of 6.9 dS/m. Assuming a typical leaching fraction of 15–20%, this soil salinity would be sustainable with an irrigation water salinity of approximately 2900 mg/L (4.6 dS/m), with no loss in crop yield. If an alternative water source were available with TDS of 500 mg/L (0.78 dS/m), the 11,380-mg/L concentrate could be blended at a ratio of 22% concentrate, 78% freshwater to meet crop needs on a sustainable basis with no loss in crop growth or yield. Figure 3-15 presents graphically the fraction of 11,380-mg/L TDS concentrate as a percentage of total irrigation flow that could be used to irrigate Bermuda grass for various levels of crop yield and freshwater salinity.

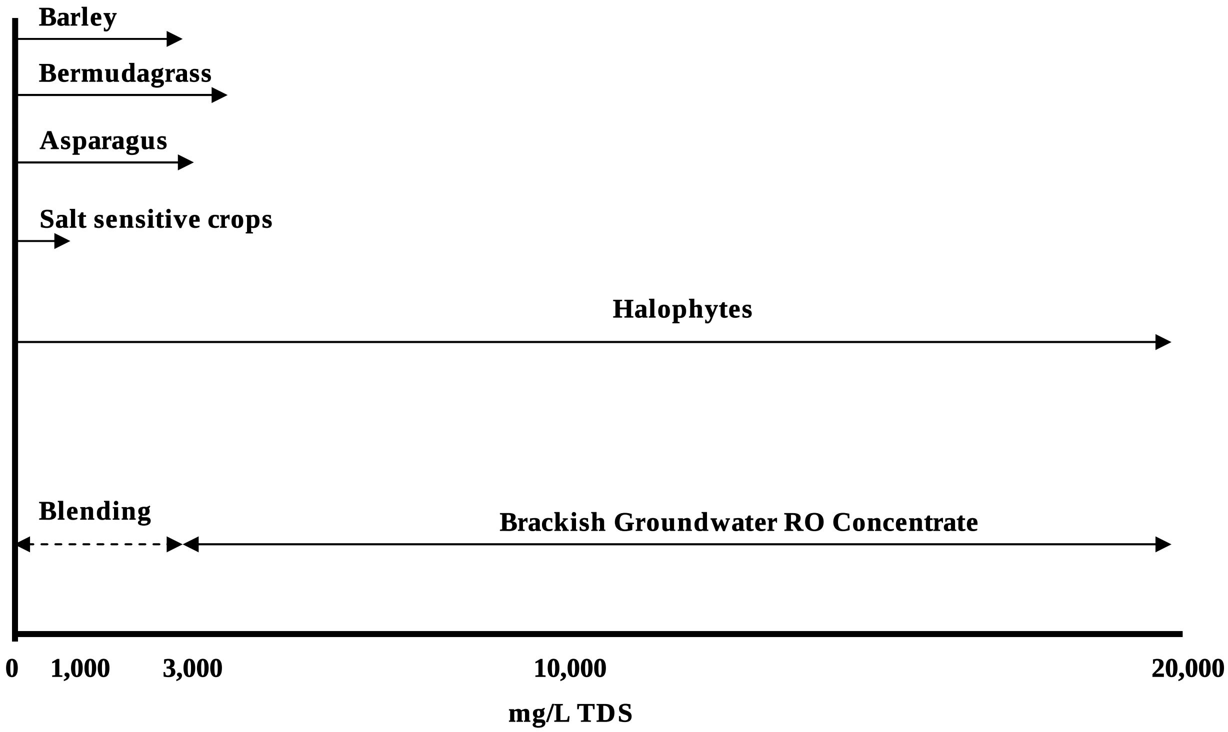


FIGURE 3-14
Salinity Range of RO Concentrate and Selected Plants.

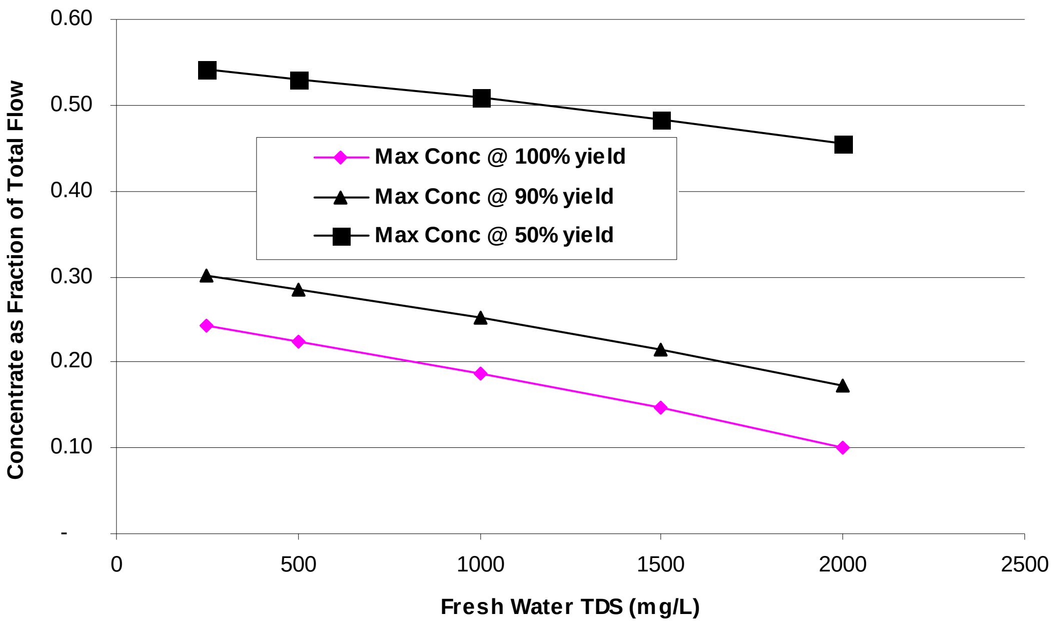


FIGURE 3-15
Concentrate as a Fraction of Total Irrigation Flow for Bermudagrass.
Note: Threshold soil salinity is 6.9 dS/m ECe, the slope is a 6.4% decrease in relative yield per dS/m increase in soil salinity. Assumes 15–20% leaching fraction, root zone average ECe of 150% of irrigation water EC, 640 mg/L of TDS per ds/m, and 11,380-mg/L concentrate.

Figure 3-16 illustrates blending requirements for alfalfa, a much more salt-sensitive crop than Bermuda grass. A reduction in yield to 50% of normal would not be economically viable and is not shown. The example of 11,380-mg/L TDS concentrate could comprise nearly 9% of the irrigation water supply for alfalfa if blended with 500-mg/L freshwater, and 90% of normal crop yield could be obtained. If blended with 1500-mg/L TDS freshwater, concentrate would be limited to only about 4% of the flow to maintain at least 90% of normal yield.

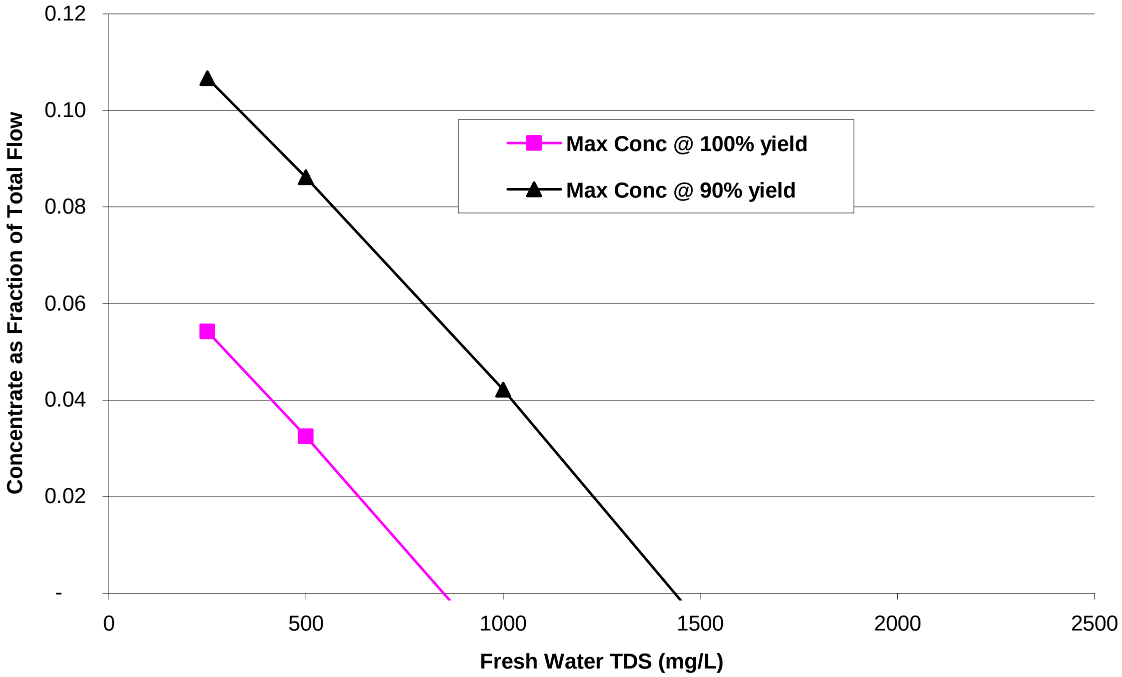


FIGURE 3-16
Concentrate as a Fraction of Total Irrigation Flow for Alfalfa.
Note: Threshold soil salinity is 2.0 dS/m ECe, the slope is a 7.3% decrease in relative yield per dS/m increase in soil salinity. Assumes 15–20% leaching fraction, root zone average ECe of 150% of irrigation water ECw, 640-mg/L TDS per ds/m, and 11,380-mg/L concentrate.

Irrigation Methods

Innovative irrigation system designs (e.g., drip and subsurface drip) can be used to allow irrigation of saline waters on plants or soils where it would otherwise be infeasible. Irrigation methods include surface or flood irrigation (poor efficiency), sprinkler (foliar effects), and drip (efficient, but filtration and water treatment are critical). RO and EDR concentrates are normally low in TSS (<1 mg/L), so filtration is not needed, but scaling (precipitation) is a significant concern. Important characteristics of these systems are described in Table 3-7. Important considerations such as the potential for foliar toxicity were discussed previously.

TABLE 3-7

Distribution Systems and Conditions of Use[a]

Distribution System	Suitability and Conditions of Use				
	Crops	**Topography**	**Soil**	**Water**	**Application Efficiency, %[e]**
Sprinkler Systems					
Portable hand move	Orchards, pasture, grain, alfalfa, vineyards, low-growing vegetable and field crops	Max grade: 20%	Min IR[b]: 0.10 in./h WHC[c]: 3.0 in.	Quantity: NR[d] Quality: high-TDS water can cause leaf burn	70–80
Wheel roll	All crops less than 3 ft high	Max grade: 15%	Min IR: 0.10 in./h WHC: 3.0 in.	Quantity: NR Quality: see above	70–80
Solid set	NR	NR	Min IR: 0.05 in./h	Quantity: NR Quality: see above	70–80
Center pivot or traveling lateral	All crops except trees	Max grade: 15%	Min IR: 0.30 in./h WHC: 2.0 in.	Quantity: large flows required Quality: see above	70–80
Traveling gun	Pasture, grain, alfalfa, field crops, vegetables	Max grade: 15%	Min IR: 0.30 in./h WHC: 2.0 in.	Quantity: 100 to 1000 gal/min per unit Quality: see above	70–80
Surface Systems					
Narrow-graded border up to 15 ft wide	Pasture, grain, alfalfa, orchards	Max grade: 7% Cross slope: 0.2%	Min IR: 0.3 in./h Max IR: 6.0 in./h	Quantity: moderate flows required	65–85
Wide-graded border up to 100 ft wide	Pasture, grain, alfalfa, orchards	Max grade: 0.5–1% Cross slope: 0.2%	Min IR: 0.3 in./h Max IR: 6.0 in./h Depth: sufficient for required grading	Quantity: large flows required	65–85
Level border	Grain, field crops, rice, orchards	Max grade: level Cross slope: 0.2%	Min IR: 0.1 in/hr Max IR: 6.0 in/hr Depth: sufficient for required grading	Quantity: moderate flows required	75–90
Straight furrows	Vegetables, row crops, orchards, vineyards	Max grade: 3% Cross slope: 10% (erosion hazard)	Min IR: 0.1 in./h Max IR: NR if furrow length is adjusted to intake Depth: sufficient for required grading	Quantity: moderate flows required	70–85

TABLE 3-7

Distribution Systems and Conditions of Use[a]

Distribution System	Suitability and Conditions of Use				
	Crops	**Topography**	**Soil**	**Water**	**Application Efficiency, %[e]**
Graded-contour furrows	Vegetables, row crops, orchards, vineyards	Max grade: 8% undulating Cross slope: 10% (erosion hazard)	Min IR: 0.1 in/hr Max IR: NR if furrow length is adjusted to intake Depth: sufficient for required grading Noncracking soils required	Quantity: moderate flows required	70-85
Drip systems	Orchards, vineyards, vegetables, nursery plants	NR	Min IR: 0.02 in./h	Quantity: NR	70–85

[a] Source of data: Smith et al. (1984).
[b] Infiltration rate.
[c] WHC, water holding capacity.
[d] NR, no restriction.
[e] Irrigation application efficiency is the combined efficiency, considering both application and distribution, which is equal to the volume of water stored in the root zone divided by the volume delivered to application devices.

Site Selection

Irrigation as a means for membrane concentrate reuse is attractive if the application areas are sufficiently close to the membrane facility and the soil is capable of supporting the selected vegetation. A list of site selection criteria is included in Table 3-8.

TABLE 3-8
Site Selection Factors and Criteria[a]

Factor	Criterion
Soil	
Texture	Loamy soils are preferred, but sandy to clayey soils may be acceptable
Drainage	Well-drained soil is preferred
Depth	5 to 6 ft or more throughout sites is preferred
Groundwater	
Depth to groundwater	A minimum of 5 ft is preferred[b]
Groundwater control	Control (e.g., artificial drainage) may be necessary if the water table is less than 10 ft from the surface
Groundwater movement	Velocity and direction of movement must be determined
Slopes	Slopes of up to 20% are acceptable with or without terracing
Underground formations	Formations should be mapped and analyzed with respect to interference with groundwater or percolating water movement
Isolation	Moderate isolation from public is preferred; the degree of isolation depends on wastewater characteristics, method of application, and vegetation
Distance from source	An appropriate distance is a matter of economics

[a] Adapted from *Membrane Concentrate Disposal* (AwwaRF, 1993).
[b] The 5-ft minimum may be reasonable if the groundwater is nonpotable; however, if groundwater protection is a consideration, much deeper depths would likely be required.

In instances where no suitable existing application is available, a plot of land may be acquired to grow plants that are suitable for the soil, climate, and membrane concentrate quality. A dedicated site may entail considerable capital for purchase but would ensure long-term access. Permits will go to the landowner and utility jointly. It is typically not easy for a utility to accept landowner management under their permit, or for a landowner to accept liability of permit. However, with the right incentives and agreements, it can be done.

Drainage

Tile drainage may be required to protect groundwater; however, with some concentrates scaling and blockage of the drains can be a problem (Mickley, 2004a). It should be noted that tile drains do not provide complete capture of applied water: a significant fraction will percolate past even closely spaced drains. Drains collect water in a saturated zone, so that not all of the water saturating the soil will necessarily be from the irrigation source; some could be groundwater recharged to the site from another source. A drainage system can be used to capture excess water and allow it to be irrigated again, as described previously. If most of the water captured is percolated irrigation water, then the drainage water will be significantly higher in salinity than the applied water as a result of evapotranspiration. For reuse of the collected drainage, crops even more salt tolerant than the initial crops irrigated would be required.

Surface Runoff Control

Reuse permits typically require control of surface runoff. This may be accomplished with perimeter berms or trenches to ensure control of stormwater and tailwater.

Vegetation Selection

Selection of appropriate vegetation for irrigation with membrane concentrate depends on many application-specific factors, including concentrate quality and quantity, flexibility to blend concentrate with lower-salinity water sources, geographical location, soil composition, site setting (e.g., urban, residential), and land availability. In addition, a decision must be made whether to use the membrane concentrate to irrigate landscape areas such as golf courses, parks, or medians or whether to produce an agricultural product.

Irrigation of concentrate on landscape areas (e.g., airports, highway medians and borders, golf courses, parks, and recreational areas) has a number of advantages, including the lack of human food chain issues and land acquisition costs (Mickley, 2004a).

Figure 3-17 shows the relationship of salt tolerance by plant species and typical ranges of concentrate salinity. The actual range for brackish groundwater RO concentrate actually extends significantly higher, up to 40,000 mg/L, as described in Chapter 1.

The figure shows that there are a number of plant systems that could beneficially and directly (without blending) use the concentrate from softening NF plants, but only the more salt-tolerant plants are capable of utilizing concentrate from brackish groundwater RO plants without dilution. In addition, it should be noted that concentrate from some brackish groundwater RO plants may have a TDS concentration exceeding that shown in the figure. Direct (undiluted) irrigation of concentrate in the 10,000- to 40,000-mg/L range would require use of only the most salt-tolerant halophytic plants, and sustained irrigation even of halophytes is probably limited to less than 20,000 mg/L, as described in a subsequent section.

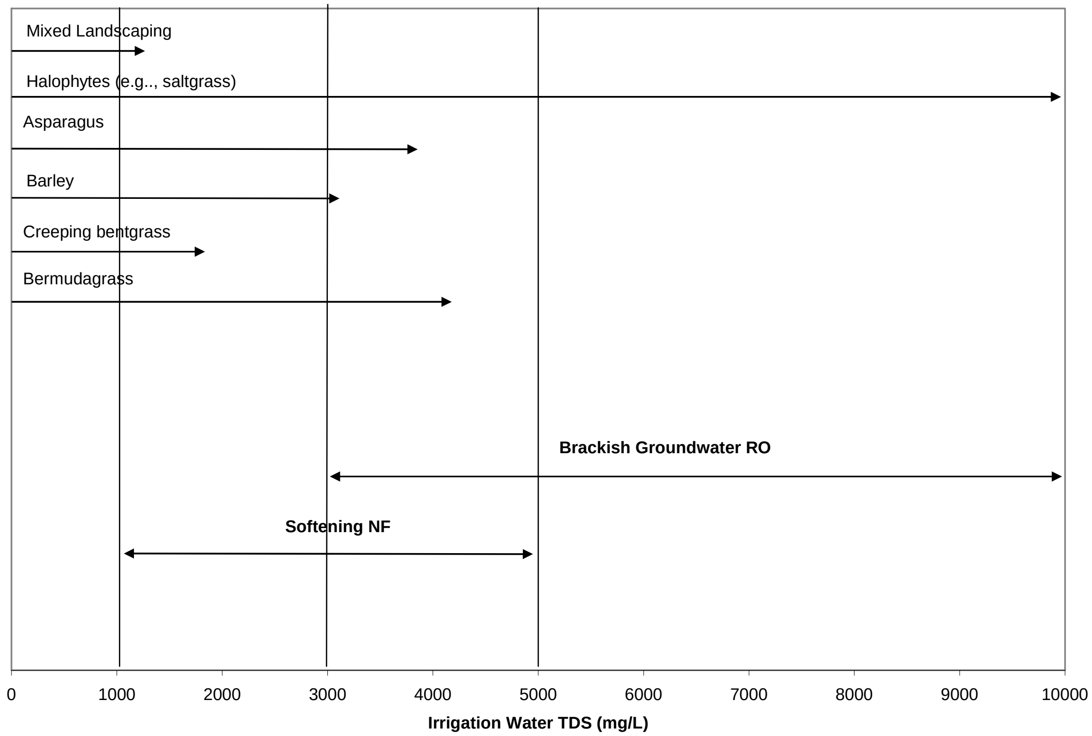


FIGURE 3-17
Salt Tolerance Ranges of Selected Plants and Concentrate Salinity Ranges.

Turf Grass Applications. The comparatively continuous nature of turf grass growth compared to many other plant species makes it a good candidate for reuse projects where there typically is relatively continuous flow (Harivandi, 2005). The length of the growing season for turf grass varies considerably for different climatic regions. A summary of salt tolerance for turf grass species used in various parts of the United States is provided in Table 3-9. Values in the table assume fair quality growth and are not based on a yield threshold.

TABLE 3-9

Relative Tolerances of Turf Grass Species to Soil Salinity (Soil ECe)

Sensitive (<3 dS/m,[a] 1280 mg/L[b])	**Moderately Sensitive (3–6 dS/m, 1280–2560 mg/L)**	**Moderately Tolerant (6–10 dS/m, 2560–4267 mg/L)**	**Tolerant (>10 dS/m, >4267 mg/L)**
Annual bluegrass	Annual ryegrass	Perennial ryegrass	Alkali grass
Colonial bentgrass	Creeping bentgrass	Tall fescue	Bermuda grass
Kentucky bluegrass	Fine-leaf fescues	Zoysiag rasses	Seashore paspalum
Rough bluegrass	Buffalo grass		St. Augustine grass

Source: adapted from Harivandi (1999)

[a] Soil ECe.

[b] Irrigation water TDS assuming 640 mg/L per dS/m and 15–20% leaching fraction.

Irrigation of large urban landscapes dominated by turf grasses can typically be achieved with a maximum concentrate stream TDS of up to 2000 mg/L (~3.13 dS/m), depending on various characteristics of the landscape, such as turf species, soil quality, and level of management. A vast majority of membrane concentrate streams exceed 2000 mg/L of TDS. Therefore, urban landscape irrigation is typically not a feasible alternative for membrane concentrate reuse without blending. Only in a few applications, such as NF softening with a low-TDS feedwater, could urban landscape irrigation be a viable option for beneficial reuse of concentrate without significant blending with lower-salinity water. Uniform application is often a problem, as many turf grass systems do not have a sufficient density of sprinklers to achieve uniform application (J. Richards, University of California, Davis, personal communication).

Landscaping, Nonturf Grass: In some areas there may be a demand for water for landscaped areas where turf grasses are not dominant. There is a wide range of salt sensitivity among these landscaping plants. Threshold values for soil ECe are available for some species based on the acceptability of a maximum 50% decrement in plant growth. A partial list of species commonly used in California and their maximum soil salinity tolerances are provided in Table 3-10.

TABLE 3-10

Common Study Area Landscaping Species and Salt Tolerance Thresholds

Common Name	Scientific Name	Max. Soil EC_e (dS/m)[a]	Max. Irrigation TDS (mg/L)[b]
Iceplant	(Various)	>10	>4267
Oleander	*Nerium oleander*	6–8	2560–3413
Hibiscus	*Hibiscus rosa-sinensis*	3–4	1280–1707
Rose	*Rosa* sp.	2–3	853–1280

Source: Maas (1990).

[a] Soil ECe.

[b] Irrigation water TDS assuming 640 mg/L per dS/m and 15–20% leaching fraction.

A reasonable maximum soil EC_e value for general planning purposes, assuming a diverse mix of woody species, vines, and groundcover as well as some turf grass, is 3.0 dS/m. Assuming a typical 15–20% leaching fraction, this would mean an irrigation water salinity of approximately 1280 mg/L. Therefore, the only type of membrane concentrate that could be applied to general landscaping without dilution would be a low-TDS softening NF water. This somewhat low value will limit the opportunities for landscape reuse of many concentrates without significant blending with freshwater. The exception is where it is known that the dominant species in the areas to receive concentrate have significant salt tolerance (e.g., iceplant, oleander, bougainvillea, Bermuda grass). Landscaped areas dominated by such salt-tolerant landscape plants could be irrigated with higher-salinity water.

Halophytes: Plants capable of tolerating significantly elevated salinity are called halophytes. Moderately salt-tolerant plants include some crop plants, such as sugar beet, date palm, and barley, that can be irrigated with water approaching 5000 mg/L (Ayers and Wescot, 1985). In contrast, highly salt-tolerant halophytes, such as *Salicornia bigelovii*, can produce significant biomass and seed when the soil solution exceeds 70,000 mg/L (roughly twice that of seawater) (Glenn et al., 1991; 1997 as cited in Glenn and Brown, 1999). *Salicornia* has been found to be capable of maintaining an ET rate equal to ETo with irrigation of 29 dS/m (~18,000 mg/L of TDS) and more than 25 mg/L of boron (Grattan, 2005).

Near Phoenix, plots of old-man saltbush (*Atriplex nummularia*) and seashore paspalum (*Paspalum vaginatum*) have been irrigated with cooling tower blowdown and storm drainage water (4300 and 1700 mg/L of TDS, respectively), with very low leaching rates of less than 3% (Glenn et al., 1995, as cited in Riley et al., 1998). In this case, root zone salinity should climb to relatively high levels over time, potentially stressing even a halophyte.

Species found to be productive in trials using seawater (~40,000 mg/L of TDS) include a succulent, annual plant (*Salicornia bigelovii*), a perennial grass (*Distichlis palmeri*), a prostrate, rhizomatous plant with succulent leaves (*Batis maritima*), and several species of desert saltbush (*Atriplex* spp.) (Glenn and O'Leary, 1985, as cited in Glenn and Brown, 1999).

Halophytic trees and shrubs include acacia, causarina, eucalyptus, melaluca, prosopis, and tamarix (Biosalinity, 2005). Uses include cooking, heating, and timber (Biosalinity, 2005).

In general, although relatively high yields of some halophytes have been obtained using seawater levels of salinity (~40,000 mg/L of TDS), optimal growth for even the most salt-tolerant halophytes is obtained more in the range of 11,000 to 19,000 mg/L of TDS (Glenn and O'Leary, 1985; Yeo and Flowers, 1986, as cited in Glenn and Brown, 1999). Seawater irrigation studies often employ very high leaching fractions. As the great depth of applied water required to achieve this leaching is not practical or economically viable, Miyamoto (1996) found that with more typical irrigation management (e.g., 50% depletion of the plant available water between irrigations), 20,000 mg/L (soil solution salinity) was optimal, with an associated irrigation water salinity maximum of about 10,000 mg/L (as cited in Glenn and Brown, 1999).

Other Issues

Other significant implementation issues for land application and irrigation are summarized in Table 3-11.

TABLE 3-11

Summary of Other Implementation Issues for Land Application and Irrigation

Parameter	Discussion
Geographical and Climatic Relevance	Some irrigation is practiced in most parts of the United States, but the greatest demand for irrigation will be in arid to semiarid regions of the Southwest; it may be an option where conventional approaches (sewer discharge, surface water discharge, evaporation ponds, and deep well injection) are not available or feasible
Level of Water Utility Control	Typically low, unless a dedicated irrigation site is owned and operated by the utility; otherwise, utility operations must be coordinated leases developed with local farmers, golf courses, parks departments, departments of transportation, etc.
Membrane Cleaning Solutions	The soil is generally an excellent medium to allow degradation, sorption, volatilization, or neutralization of many cleaning solutions, but site-specific evaluations are required
Proven Technology	Irrigation of concentrates is rare, but soil and plant management and design issues associated with irrigating saline water are well understood Halophyte irrigation has been evaluated in numerous research and demonstration projects, but no full-scale projects using RO concentrate have been identified to date

Regulatory Issues

Permitting required for land application of membrane concentrate is dependent upon site, feedwater, and concentrate water characteristics.

Protection of groundwater quality (from deep percolation) and surface water quality (from runoff) are the key concerns and require close scrutiny before implementation of a concentrate land application project (Mickley, 2004a). Both federal and state requirements need to be considered, including those protecting groundwater and public health (AWWA, 2004). The concentrations and management of drinking water pollutants (e.g., arsenic, nitrate) and crop-specific issues will likely be addressed by state agencies.

Discharges to surface water and groundwater are recognized as a potential result of land application. While land application looks like agriculture (which usually requires no permit), an irrigation source tied into a municipal or industrial waste stream almost always triggers a water quality permitting requirement, and there are usually specific requirements for permitting such a site. Many states have permitting processes that serve this purpose. However, when a federal water is involved, or where no state process is in place, a federal permit may be required.

If a surface water supplies the membrane treatment facility, additional permits from the health department or another agency may be required. This health-related permitting authority relates to the potential for concentration of pathogens during membrane treatment. Additional state or local regulations pertaining to land reuse of membrane concentrate may be applicable and should be fully investigated.

An argument against requirement for a permit can be attempted on the grounds that runoff and percolation from a site will never occur. This is a difficult claim to substantiate, however, so that permitting the facility may prove the more straightforward approach (Mickley, 2004a). In some cases, measures to prevent runoff allow for the avoidance of water quality permitting (Mickley, 2004a).

In Oregon, the nondegradation of groundwater must be demonstrated; waivers of the requirement are possible for situations where it can be shown that groundwater will not be used beneficially. These regulations have their roots in the CWA but presume that degradation of groundwater is impairing that resource for a future, if not a current, beneficial use.

Sensitivity about adding TDS to groundwater systems is growing in California, where protection of beneficial uses is required. Soon, several pipelines will be installed in southern California to transport membrane concentrate to bodies of saltwater such as the ocean. The driver is the protection of groundwater for downgradient water users. Property values are very high in this region, so that the opportunity cost of undeveloped land (for lack of a permissible wastewater discharge) is therefore very high. California has generally addressed this issue on a case-by-case basis but can be aggressive about protecting beneficial uses. In addition, the SDWA established a wellhead protection program residing at the state level to protect the area around wellheads from specific contaminants. Consequently, depending on the location of area wells and the land application site, state or local wellhead protection programs may limit reuse options.

Cost Considerations

Factors affecting the cost of irrigation systems include volume and quality of membrane concentrate, distance to reuse site(s), land uses (urban, residential), application area (landscaping, agriculture), geographical location, storage requirements, and land costs.

The volume of membrane concentrate impacts the amount of land required for reuse. The greater the volume of membrane concentrate, the more land area required for reuse. In general, land application is only cost-effective for small volumes of concentrate due to the large land areas required (M. Mickley, personal communication). The quality of membrane concentrate affects the type of vegetation that can be used for reuse as well as the pretreatment required. Use of a relatively high TDS membrane concentrate will likely require use of halophytes rather than agricultural plants. Halophytes can increase costs because they are not usually salable and provide no income to offset capital and operations costs associated with managing membrane concentrate. Beneficial reuse of halophytic plants in forage rations for animals has been done and could be used to offset costs.

If dilution is feasible, it may increase the potential for reuse, but land area required will be proportionately larger as the fraction of membrane concentrate increases.

The irrigation equipment is another cost component that must be considered in accurately estimating cost for land application by irrigation. Three types of irrigation systems are most common: sprinkler systems, surface systems (e.g., flood), and drip systems. Costs for these systems can vary considerably depending on the location and characteristics of the site. Generally, mechanized or automated systems have relatively high capital and low labor costs compared with the manually moved sprinkler systems or manually operated surface systems.

Distance to the reuse site(s) affects operating and capital costs of reuse facilities. The greater the distance to the reuse site, the more costly the conveyance (capital, O&M, and pumping costs) to the site.

Use of land between the treatment facility and the reuse site can impact the capital and operational costs of a reuse facility. Urban land use increases the cost for new conveyance infrastructure, due to installation of facilities below paved roadways and coordination of construction activities in an urban setting. Maintenance cost increases for similar reasons.

The type of application area can also affect the cost of land application of membrane concentrate. Application areas that can sustain high loading rates decrease the amount of land required for reuse as well as the infrastructure required to apply the membrane concentrate. Also, the topography of an application area can impact the cost of land application. If topographic variations are pronounced, costs to regrade the site to minimize runoff and comply with applicable regulations may be significant.

Geographical location can have a significant impact on the economics of land application. The geographical location affects the length of the growing season and amount of precipitation and available plant species. Each of these factors impacts the basic design criteria of land (e.g., required acreage) and infrastructure required for land application of membrane concentrate.

Capital Cost

Facility characteristics determining capital cost include concentrate flow rate, concentrate chemical characteristics, conveyance, land purchase and preparation, distribution system piping, pumping requirements, need for wet weather storage, and drainage requirements (Mickley, 2004a; AWWA, 2004). An underdrain system may constitute approximately 80% of the irrigation system piping cost (Mickley, 2004a). Land costs also impact the ultimate cost for land application. Land application typically requires a fairly large tract(s) of land, depending on the volume of membrane concentrate produced for disposal. Therefore, the cost of land can have a significant impact on the overall feasibility of land application. A detailed procedure and cost model have been provided by Mickley (2004a), and an example derived from this model is provided in Table 3-12.

Costs not included in the model include costs of blending, pretreatment, pipeline to the irrigation site, and monitoring wells (Mickley, 2004a). Monitoring wells are likely to be required in many areas before a permit can be obtained (Conlon, 1989, as cited in Mickley, 2004a). Costs also not shown include other land preparation, planting and establishment, and other start-up costs.

Costs for development of an alternative disposal system (e.g., sewer, surface water discharge) or storage for rainy periods and non-growing season months are highly site specific but may be a major consideration for some sites.

O&M Cost

O&M costs are highly site specific. Major components are likely to include pretreatment, site monitoring, labor for irrigation system operation, irrigation system maintenance, and drainage management. Many of these costs may be borne by a contract farmer accepting the concentrate flow, but others may be borne by the water utility for a dedicated site. It is likely that farmers will not typically accept lower-quality water than they normally use without being paid some kind of premium for the costs of managing the lower-quality water.

Pretreatment costs may include chemical, power, and labor inputs for aeration, pH adjustment, antiscalants, chlorination, and possibly other treatment approaches.

Irrigation system maintenance will vary significantly with the type of irrigation system being used but may include labor for periodic flushing of the distribution system, periodic water treatment events (biofilm and scale control), and repairs of leaks.

TABLE 3-12

Traditional Agricultural Reuse (Irrigation) Capital Costs (in 2001 $)

Variable	Variable Range	Example
A Flow rate (MGD)	1–5	1
B Loading (ft/year)	5–20	5
C Land type (see note)	1, 2, 3, 4	2
D Storage time (days)	1 or 2	1
E Land unit cost ($/acre)	0–10,000	$3000
Land Parameters	**Action**	**Result**
F Land requirement (acres)	(use A; see Fig. 11.1 and 11.2 in Mickley, 2004a)	225
G Land clearing cost ($/acre)	(see note)	$2000
Cost Calculation	**Action**	**Cost**
H Land ($/acre)	F * E	$675,000
I Land clearing (see note) ($/acre)	F * G	$450,000
J Main header, submain, laterals ($)	(use F; see Fig. 11.4 and 11.5 in Mickley, 2004a)	$225,000
K Sprinklers, valves, controls ($)	(use F; see Fig. 11.6 in Mickley, 2004a)	$95,000
L Distribution system materials	J + K	$320,000
M Installed distribution system ($)	1.8 * L	$576,600
N Pump cost ($)	(use A; see Fig. 11.7 in Mickley, 2004a)	$25,000
O Storage tank cost ($)	(use A * D see Fig. 11.8 and 11.9 in Mickley, 2004a)	$230,000
P Underdrain cost ($)	1.44 * J	$324,000
TOTAL	H + I + M + N + O + P	$2,280,000

Source: Mickley (2004a).

Note: Land clearing costs are assumed as follows: (1) brush, $1000; (2) sparsely wooded, $2000; (3) medium wooded, $4000; (4) heavily wooded, $7000.

Monitoring costs may include crop quality testing, soil testing, applied water quality testing, groundwater monitoring, shallow vadose zone monitoring (e.g., with suction lysimeters), and drainage water monitoring.

O&M costs may be at least partially offset by the value of the crop produced. Besides traditional agricultural commodities, there are also potential commercial uses for halophytes, although data on their commercial potential are very limited. More than 50 halophytes show promise as future sources of grain and oil; many others have various other edible or useful plant parts. One possible exception is *Salicornia bigelovii*, a highly salt-tolerant, versatile, coastal marsh species that is being used commercially (Biosalinity, 2005). Its uses include as a green vegetable, edible oil source (from the seed), seed meal for livestock and aquaculture, livestock forage, and even construction materials (Biosalinity, 2005). *Atriplex* sp., another well-known halophyte, can be used as a forage crop (Glenn and Brown, 1999). Biomass yields of halophytes can rival those of conventional crops, even when grown using irrigation water with a salinity equivalent to seawater (Glenn and Brown, 1999), but under field conditions these comparable yields may not be realized (G. Bañuelos, personal communication).

Vegetation of desert areas has significant potential for generation of carbon credits. Due to regulatory and market uncertainty surrounding these credits, this income potential is speculative but potentially significant.

Cost of Lost Water

Evapotranspiration losses resulting from irrigation are hydrologically similar to those of evaporation ponds: evaporated water is lost to the atmosphere and is likely to fall back to the ground as precipitation. However, this precipitation will likely fall outside of the watershed of interest. Therefore, all concentrate diverted to land application or irrigation represents a "loss" of potential potable water. There is also the potential for ZLD approaches to be applied to agricultural drainage, resulting in recovery of a residual of high-quality water. However, substitution of concentrate for potable water that would otherwise be used for irrigation should free potable water for other uses.

Economic Risk Factors

Economic risk factors would include changes in regulatory standards, changes in land use such as conversion for development, and shifting markets for agricultural products. Plant diseases, insect outbreaks, and unusual climatic conditions can unexpectedly reduce the capacity of the land application site to accept concentrate. Plants exposed to reuse water may be under some stress and may as a consequence be more susceptible to insects and disease. Discovery of unanticipated impacts to groundwater may also pose an economic risk.

Human Health and Ecological Risk Factors

The primary feasibility considerations for land application and irrigation of concentrate include the following:

- Maintaining a water quality source that is suitable for the intended crops
- Limiting potential for adverse impacts to groundwater
- Control of runoff that may impact nearby surface water bodies

Protection of groundwater and surface water are considerations for many of the potential disposal options based on potential human and/or ecological exposures. These have been discussed previously.

For land application, additional human health exposure pathways may occur. A first consideration is potential direct exposure to concentrate during application or spraying. Persons who work in the agricultural fields or play in the parks where concentrate is applied could potentially be exposed by inhalation of mists, dermal absorption, and/or incidental ingestion. This contact may occur during irrigation or from contact with plants or soil following irrigation. Human health evaluations typically do not focus on workers, particularly those who are trained to deal with the particular hazards (for example, workers in a sewage treatment plant would be trained in health and safety issues). However, persons working in agricultural fields would not necessarily be aware of precautions that may reduce exposures, and so in this case these agricultural workers are considered general public.

For any specific land application project, several factors should be clarified when evaluating this alternative. For example, these factors may include the characteristics of the concentrate, the mode of application, the potentially exposed individuals (field workers, children in parks), and the frequency and type of activities. The fate of chemicals and pathogens may also be important (risks are much lower if constituents degrade rapidly). In many cases, this analysis may suggest exposures to chemicals or pathogens are minimal or can be easily reduced.

An additional consideration is potential uptake of metals or organic constituents into edible plants. This could be further evaluated but is not likely to be a significant route of exposure. However, selection of the plants to be grown with use of concentrates is important, and it may be prudent to avoid the use of crops that end up in the human food chain.

The use of concentrate for land application poses similar questions as use of biosolids and/or wastewater. The significant benefits from these applications are sometimes hampered by perceived risks. For a specific project, risk analysis may be combined with risk communication to gain acceptance.

Ecological concerns also would be primarily associated with food chain issues, which in turn are a function of specific chemical characteristics of the concentrate and the kinds of plants that are grown. Plants may accumulate problematic constituents in the concentrate, resulting in ecological risk factors that would have to be considered in the design. *Salicornia* is also capable of converting toxic selenate to organic selenium, which can be released to the atmosphere (“phytovolatilization”) (Biosalinity, 2005). The use of evaporation ponds of drainage water for volume reduction or storage ponds for balancing supply and demand of irrigation water may attract ecological receptors, increasing their exposures.

Applicability to Other Salt Streams and Overall Basin Salt Management

Many salt streams could potentially be used for irrigation supply. Crop tolerance to the concentration and composition of the salt stream and impacts to groundwater and surface water quality are major considerations.

Halophytes have been shown to be useful in treating highly saline agricultural drainage waters. Where feasible, the substitution of concentrate for higher-quality water sources leads to a direct cost savings and preservation of resources (Ahuja and Howe, 2005).

Conclusions

Land application and irrigation can be a viable, beneficial use of concentrate, especially for smaller facilities relatively close to agricultural areas producing relatively low-salinity concentrates. Major benefits include volume reduction through evapotranspiration, replacing existing uses of high-quality water for irrigation, and the potential value of irrigated crops and landscapes. Major constraints include the high level of TDS in many concentrates and the potential for adverse impacts on groundwater. Efficient capture of drainage water from agricultural systems is likely a requirement for sustained groundwater protection. Drainage water from these sites will need either (1) subsequent treatment and/or volume reduction through further irrigation on yet more salt-tolerant plants or (2) the use of evaporation ponds or brine concentrators to prepare salts for disposal. The long-term viability of multistep irrigation approaches is not yet established. Halophytic plants increase the range of concentrate salinities that can be land applied, but full-scale systems are not well-proven, and markets for halophyte commodities are not established. A decision tree for land application and irrigation is provided in Figure 3-18.

ZERO LIQUID DISCHARGE

ZLD for concentrates refers to any series of processes that extract essentially all of the water from concentrate. Membrane concentrates can be dried using heat to produce dry salts, with ZLD. Typically, resulting salt solids are landfilled, although there is the potential for separating and recovering specific salts (Chapter 4). High capital and operating costs, especially for energy, render ZLD infeasible for most facilities (AWWA, 2004). To date, ZLD has not been used for drinking water plants in the United States, although use of ZLD technology such as crystallizers may be appropriate where other disposal options are not feasible.

Evaporated water that is very low in salinity (<10 mg/L) can be captured as a distillate and used for a variety of purposes. The very high purity water obtained in this process can bring in substantial revenue for the water utility while reducing costs for end users of the water by eliminating or reducing their need to invest capital and O&M to produce such water (Robinette et al., 2003). Advantages of ZLD include the following (Mickley, 2004a):

- May avoid lengthy permitting process common to other discharge options
- May be easier to gain community acceptance
- No geographic limitations
- Efficient use of water resource

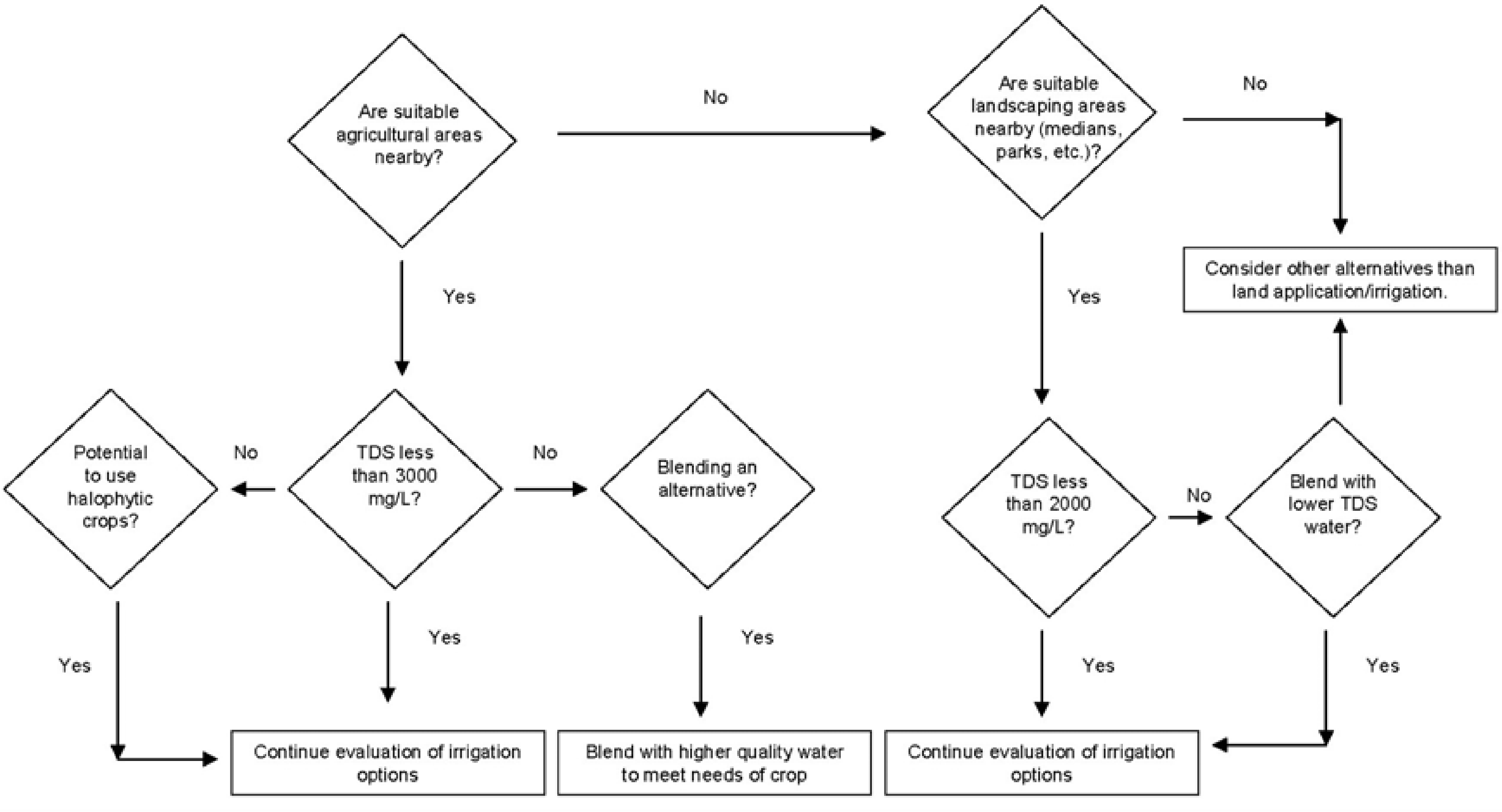


FIGURE 3-18
Decision Tree for Land Application and Irrigation.

In a true ZLD scheme, RO concentrate is concentrated in a brine concentrator (evaporator) whose concentrated blowdown stream is followed by a forced circulation evaporator, or crystallizer, that can produce a total solids level (TDS plus TSS) of 40–50%, which is suitable for dewatering. Mechanical evaporation can treat membrane concentrate by converting the water component to steam, leaving behind a wet salt to be landfilled. Many different options for mechanical evaporation equipment exist:

- Vapor compression evaporator
- Vertical tube falling film brine concentrator
- Horizontal tube spray film brine concentrator
- Forced circulation crystallizer

These can be configured as single-effect evaporation or can be combined in series to provide multiple effect evaporation. The most common approach to achieve complete evaporation of membrane reject streams is a vertical tube falling film brine concentrator followed by a forced circulation crystallizer (CH2M HILL, 2004). Since this arrangement of evaporation equipment is typically the most economical among the distillate-recovering systems, it will be the focus of further discussion for mechanical evaporation of membrane concentrate. Brine concentrators typically use a seeded slurry process, allowing a concentration factor of as much as 40 to 1 without scaling problems in the evaporator (Mickley, 2004a). When used together with a crystallizer, this process can achieve ZLD of RO concentrate under all climatic conditions (Mickley, 2004a).

DewVaporation

DewVaporation is a technology developed by Arizona State University professor James Beckman. Studies are being done with the City of Phoenix by L'Eau LLC and Dr. Beckman. The DewVaporation technique is related to the humidification and dehumidification desalination technique but does not use water as a major heat source or sink. Rather, DewVaporation uses air as a carrier gas to evaporate water from saline feeds, and dew forms pure condensate at constant atmospheric pressure in a single heat-transferring tower. This project is a follow-on project based on previously funded research work. The technology has only been demonstrated at flows up to 10,000 gpd (CASS, 2005).

A 10,000-gpd DewVaporation pilot plant will be installed and operated at the 23rd Avenue Wastewater Treatment Plant in Phoenix, AZ. RO concentrate will be the feedwater for the DewVaporation unit. The 5000-ppm TDS RO effluent will be concentrated to more than 200,000 mg/L of TDS, thereby reducing the brine stream volume to 2% of the RO effluent (98% recovery). The DewVaporation operating cost is \$3.50/1000 gal when using natural gas as a heat source (compared to \$12/1000 gal for vapor compression evaporators). In this pilot study, concentrate volume will be even further reduced, resulting in wet salt solids being generated for disposal, at the same DewVaporation cost (compared to \$30/1000 gal for industrial crystallizers) (http://www.usbr.gov/pmts/water/newsletters/03win.html). (For more information contact Henry Day, City of Phoenix, or Dr. Jim Beckman, ASU; phone (480) 965-4395 or (480) 770-6023; e-mail: jim.beckman@asu.edu or james.beckman@leau.org.)

Other Technologies

The “high-efficiency reverse osmosis” (HERO) process is a proprietary desalination process developed to provide higher product recovery (i.e., >90%) and lower concentrate flows. Higher recovery is accomplished through an ion exchange pretreatment step to remove hardness ions (i.e., calcium and magnesium) and RO operation at a high pH to reduce silica scaling. The HERO process has some application in the further concentrate RO blowdown and has been most successfully employed in ZLD and near-ZLD industrial wastewater applications as pretreatment for a brine concentrator or crystallizer. A study conducted for the Southern Nevada Water Authority concluded that pretreatment steps such as HERO and other chemical pretreatment systems to increase water recovery were not cost-effective for their groundwater (Black and Veatch, 2004) (Appendix E).

Other proprietary products offer improved RO or membrane performance in certain, specific applications. An example is the V-SEP process (vibratory shear enhanced process), which is said to improve a membrane's fouling resistance.

Implementation Issues

Falling film vertical tube evaporators, or "brine concentrators," are often used for volume reduction of concentrates. Brine concentrators are used in some industrial applications and much less frequently in municipal ZLD and near-ZLD applications. Brine concentrators are designed to operate in a "seeded slurry" mode, where calcium sulfate is added to the recycle to provide nucleation sites for the precipitation of scale to prevent scaling of heat transfer surfaces. When further concentrating brackish water RO or seawater RO reject (e.g., 10,000 to 85,000 mg/L of TDS), a brine concentrator can usually achieve 160,000 to 200,000 mg/L (total solids, including dissolved and precipitated solids) and sometimes even higher concentrations.

A schematic of a falling film brine concentrator followed by a forced circulation crystallizer is presented in Figure 3-19. The flow diagram is described below (CH2M HILL, 2004).

1. Concentrate is preheated in a heat exchanger.

2. Hot feed combines with the brine slurry in the sump. The brine slurry is constantly circulated from the sump to a flood box at the top of a bundle of heat transfer tubes. Calcium sulfate crystals (seeds) in the brine slurry act as precipitation nuclei for precipitating calcium sulfate and often silica, which would otherwise scale the heat transfer surfaces.

3. Some of the brine evaporates as it flows in a falling film around the inside periphery of the tubes, down the length of the tubes, and back into the sump.

4. The water vapor passes through mist eliminators and enters the vapor compressor, which heats it. Compressed vapor flows to the outside of the heat transfer tubes, where it condenses, releasing the heat of vaporization. Mechanical compressors are used in most applications. The mechanical vapor compressor is responsible for about 80% of the 70- to 90-kilowatt-hour (kWh) power usage per 1000 gal of brine concentrator feed. A thermal system (or steam-driven vapor compressor) can be economical if waste steam is available. However, mechanical vapor compressors cannot be retrofitted to steam-driven compressors, and vice versa.

5. Heat from the compressed vapor is transferred to the cooler brine falling inside the tubes, causing some of the brine to evaporate. As the compressed vapor releases heat, it condenses as product water. This condensate is highly pure, with a TDS content of 5–10 mg/L, making it an excellent water source for boiler makeup, cooling makeup, and

process use. There may be the potential to negotiate the sale of this low-TDS product to private facilities at a premium over typical water rates.

6. This high-purity distillate is pumped back through the heat exchanger, where it gives up heat to the incoming membrane reject. Total product water recovery across the brine concentrator can be up to 95% of feed. The distillate can be used for cooling tower makeup or process water or sold for other uses, as discussed above. In some cases, it may be posttreated and used as drinking water.

7. Some of the brine slurry is blown down from the sump to control the brine total solids content to between 200,000 and 300,000 mg/L. Blowdown is sent to a crystallizer feed tank and then on to the forced circulation crystallizer or to an evaporation pond.

8. The concentrated brine is recirculated through a heat exchanger under pressure to prevent boiling and subsequent scale formation in the tubes.

9. The pressurized brine then enters a separator chamber (vapor head) operating at a slightly lower pressure or partial vacuum, resulting in flash evaporation of water and formation of insoluble salt crystals in the brine.

10. The vapor passes through mist eliminators and enters the vapor compressor, which heats it. Compressed vapor flows to the outside of the heat transfer tubes, heating the recirculated brine flowing inside the tubes. Mechanical compressors are used in most zero liquid discharge applications. The mechanical vapor compressor is responsible for about 80% of the 250-kWh power usage per 1000 gallons of forced circulation crystallizer feed.

11. A portion of the brine and crystal liquor is wasted to separate the insoluble salt from the liquor. Typically, salt crystals are separated from the liquor with a centrifuge or filter press. Salt can be landfilled, and centrate or filtrate can be returned to the forced circulation crystallizer feed tank.

12. The high-quality crystallizer distillate is blended with evaporator condensate and reused.

Total product water recovery across the crystallizer can be a high percentage of the water content of the feed to the crystallizer. The condensate can be delivered as drinking water or sold separately to a power plant as discussed previously.

Due to the highly specialized nature of mechanical evaporation equipment, the suppliers of this equipment should be contacted for guidance regarding the specific sizing and materials of construction for a given application.

Size and Complexity

Besides cost, the primary obstacle in implementing mechanical evaporation for the disposal of membrane concentrate is the size and complexity of the equipment. For example, a falling film brine concentrator for a 1.3-MGD concentrate stream is approximately 100 ft in height. The total space requirement to treat 1 MGD of concentrate is a volume of approximately 140 by 100 by 100 ft (Mickley, 2004a). In addition to the large size of mechanical evaporation equipment, evaporators and crystallizers are relatively complex to operate compared to other methods of membrane concentrate disposal. An option for decreasing the amount of mechanical equipment involved is to replace the forced circulation crystallizer with evaporation ponds. The falling film brine concentrator would be used to reduce the volume of the membrane concentrate prior to evaporation. The 200,000- to 300,000-mg/L TDS brine would then be pumped to an evaporation pond for additional volume reduction. The conclusions of a ZLD study for the Southern Nevada Water Authority were that the most cost-effective approach would be RO, followed by a thermal brine concentrator, followed by discharge to an evaporation pond (Black and Veatch, 2004) (Appendix E).

High-Quality Product Water Recovery

The product water quality from ZLD treatment of concentrate is less than 10 mg/L of TDS (Mickley, 2004a). Recovery rates depend on the feed water, but 90–98% recovery is typical (Mickley, 2004a).

Solids Disposal and Reuse

ZLD processes may produce solid product for landfilling (AWWA, 2004). (See also Chapter 4.)

Near-ZLD

Utilities may elect to use one of a number of technologies to reduce the volume of concentrate short of ZLD. The experience of Sherman, TX, is provided in Appendix F as a case study. Most technologies that reduce concentrate volume have the production of potable water as a benefit. Volume reduction has been identified as a key research priority (NRC, 2004).

Other Issues

Other significant implementation issues for ZLD are summarized in Table 3-13.

TABLE 3-13

Summary of Other Implementation Issues for ZLD

Parameter	Discussion
Geographical and Climatic Relevance	No climatic limitations, but due to the very high power requirements may be somewhat more applicable where power costs are low and the costs of other disposal options are high
Level of Water Utility Control	Very high level of control
Membrane Cleaning Solutions	Can be coprocessed with RO reject stream as long as composition does not conflict with manufacturer’s feed requirements
Proven Technology	Well-proven technologies in industry, but lower-cost alternatives for water utilities are still being researched; as of 2001, approximately 75 brine concentrators were in operation in the United States and overseas, about 12 of which were being used for RO concentrates in industry (Mickley, 2004a); these systems have proven to be highly reliable, with some in the southwest United States operating for 28 years (Mickley, 2004a)

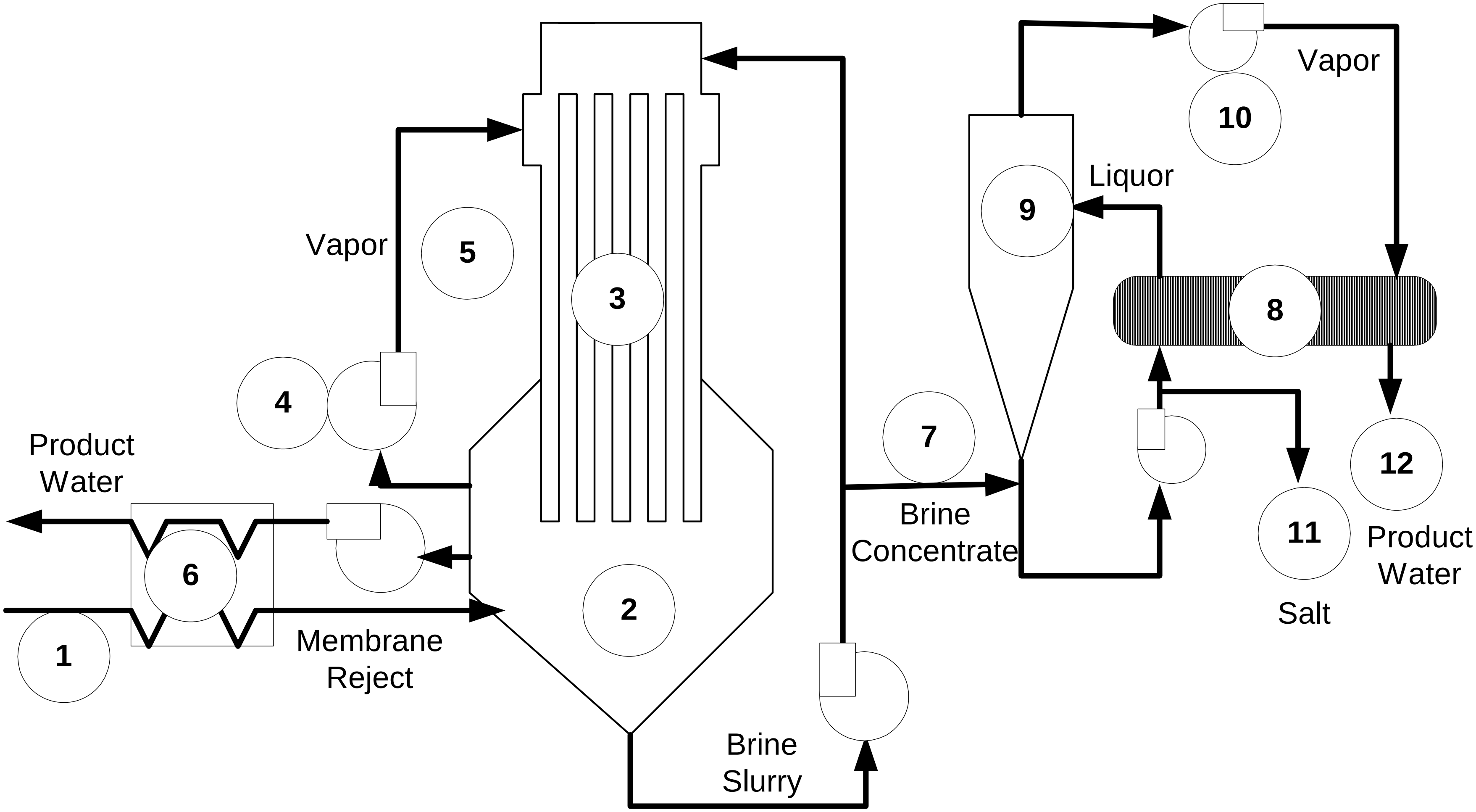


FIGURE 3-19
Typical Schematic of a Vertical Tube Falling Film–Vapor Compression Evaporator and Forced Circulation Crystallizer.
Source: adapted from CH2M HILL (2004).

Regulatory Issues

Permit requirements are minimal for operation of mechanical evaporation equipment for membrane concentrate disposal. Depending on the zoning regulations and height of the falling film brine concentrator, a variance to allow a structure in excess of the regulated maximum height may be required. State and local agencies should be contacted for other regulations that may apply. Issues associated with solids disposal at a landfill are essentially the same as those previously described in Chapter 2 for evaporation pond residuals.

The high energy requirement of ZLD systems raises the specter of future limits on carbon emissions because of their role in global warming concerns.

Cost Considerations

The primary drawback for implementing mechanical evaporation for membrane concentrate disposal is the relatively high expense. Mechanical evaporation equipment is both capital and operational cost-intensive. Current ZLD technology increases desalination costs roughly 300–800%, varying with the size and location of the facility (Sandia, 2003).

Capital Cost

Costs for brine concentrators and crystallizers vary widely with the characteristics of the feedwater (Mickley, 2004a). Equipment manufacturers should be contacted for capital cost of mechanical evaporation equipment, because the materials of construction of the mechanical evaporation equipment are sensitive to membrane concentrate quality. The falling film brine concentrator has a higher capital cost than the forced circulation crystallizer of comparable hydraulic capacity, but the high capital cost can be offset by lower operation and maintenance costs for falling film evaporators.

A preliminary cost model from Mickley (2004a) assuming currently available technology was used for the example case of a 1-MGD plant shown in Table 3-14.

Several brine treatment options for concentrate derived from brackish groundwater were evaluated for the Southern Nevada Water Authority. These options included direct discharge to evaporation ponds, thermal treatment (brine concentrator and crystallizer), and a brine concentrator followed by discharge to evaporation ponds. Brine treatment costs for these options are presented in Table 3-15.

TABLE 3-14

Zero Liquid Discharge Capital Costs (in 2001 $)

Variables	**Variable Range**	**Example**
A Flow rate (MGD)	0–5	1
B Reject level (%)	2–10	5
Calculation		
C Concentrator reject/feed to crystallizer (MGD)	(A * B)/100	0.05
D Feed to crystallizer (gpm)	C * 694	34.7
Costs and Energies (from Figures)		
E Capital cost of installed concentrator ($)	(use A; see Fig. 12.4–12.6 in Mickley, 2004a)	5,300,000
F Capital cost of installed crystallizer	(use D; see Fig. 12.7 in Mickley, 2004a)	2,650,000
G Energy usage of concentrator (kW)	(use A; see Fig. 12.9 and 12.10 in Mickley, 2004a)	3750
H Energy usage for crystallizer (kW)	(use D; see Fig. 12.11 in Mickley, 2004a)	525
Estimated Energy Cost	**Action**	
I Cost of electricity ($/kWh)	Estimate	0.1
Calculations	**Action**	**Result**
J Annualized capital costs of concentrator (20-year life)	E/20	265,000
K Annualized capital costs of crystallizer	F/20	132,500
L Annual energy cost of concentrator	G * I * 8760	3,285,000
M Annual energy cost of crystallizer	H * I * 8760	459,900
Total Capital Costs of Equipment		**$7,950,000**
Total Annual Energy Costs		**$3,744,900**
Total Annual Cost	**J + K + L + M**	**$4,142,400**

Source: Mickley (2004a).

Note: Annual cost of disposal of solid waste is not included.

TABLE 3-15

Estimated Annual Costs for Brine Treatment Alternatives

Brine Treatment Option	Total Product Water, MGD	Feed to Brine Treatment Process, MGD	Capital Cost, $M	Annual Operating Cost, $M	Total Annual Brine Treatment Cost, $ per acre-ft of total product water
Option 1: Ponds	1.89[a]				$3169
Evaporation Pond		1.02	$74.00	$0.26	
Option 2: Thermal	3.00[b]				$1157
Brine Concentrator		1.02	$8.25	$1.84	
Crystallizer		0.06	$4.80	$1.67	
Option 3: Combination	2.94[c]				$889
Brine Concentrator		1.02	$8.25	$1.84	
Evaporation Pond		0.06	$4.09	$0.01	

Source: Black and Veatch (2004)

[a] RO permeate at 63% recovery plus bypass.

[b] RO permeate plus bypass and distillate from BC and crystallizer.

[c] RO permeate plus bypass and BC distillate.

Note: Unit prices for energy included $0.065/kWh for electricity and $6.14/1000 ft^3 for natural gas.

O&M Cost

Operational cost of the mechanical evaporation equipment is almost completely associated with power usage of the large vapor compressors used in the process. It is a design decision whether to pay more capital cost for a more energy-efficient device or to pay less capital and pay more for power. As mentioned previously, the brine concentrator requires 70–90 kWh of power per 1000 gal of brine concentrator feed (CH2M HILL, 2004), and the crystallizer requires 200–250 kWh of power per 1000 gal of crystallizer feed (Mickley, 2004a). Therefore, mechanical evaporation is extremely sensitive to power costs at a given location. A small increase in power costs can dramatically increase the cost to treat a specified volume of membrane concentrate. Power costs are typically 95% of the nonlabor operating cost (Mickley, 2004a). Annualized energy costs for the example facility in Table 3-15 were estimated at $3,744,900.

A reasonable estimate for labor costs for operation of the brine concentrator is 2 to 4 h per 8-h shift, and a similar amount is required for a crystallizer (Mickley, 2004a).

Landfill costs are also incurred for ultimate salt disposal. Salt sludge must be disposed of in either a municipal landfill or a RCRA-approved landfill, depending on the makeup of the salt sludge. Disposal of salt sludge in a RCRA-approved landfill will increase costs, due to the liner and leak detection system requirements. The alternative to landfilling is recovery and reuse of separated salts. Technological progress in this area and markets are discussed in Chapter 4.

Economic Risk Factors

Increasing energy costs are the major risk factor for a ZLD system. Other economic risks include the potential loss of an industry paying a premium for high-quality water recovered in the ZLD process.

Cost of Lost Water

A crucial advantage of ZLD is that essentially all of the water in the feed is recovered, and water recovered from the concentrate is of very high quality. There is no “lost water.” Rather, the high-quality water is valuable to a number of industries, who will be willing to pay a premium that help to offset operational costs of a desalination plant. The value of this high-quality water varies with location, especially with proximity to a suitable industrial application, such as electronics or a high-pressure boiler. The value also is dependent upon the equivalent cost for the end user of obtaining this water from another source. The cost (or value) of distillate or condensate depends heavily on the required purity and ultimate use.

Human Health and Ecological Risk Factors

ZLD may include the use of evaporation ponds and solids disposal or reuse. Human health and ecological impacts may be related to these activities. Energy use and emissions (e.g., carbon dioxide [CO_2] and nitrogen oxides [NO_x]) of disposal alternatives are concerns that need to be considered and require additional research and planning (NRC, 2004). In other words, the total environmental cost should also be considered when evaluating disposal alternatives.

Applicability to Other Salt Streams and Overall Basin Salt Management

ZLD technology is applicable to other salt-containing aqueous streams. Use of ZLD maximizes potable water produced by the facility, minimizes the mass and volume of residuals that must be handled in final disposal, allows salts to be removed, and provides for the potential recovery of separated salts.

Conclusions

ZLD is excessively costly with today’s technology, primarily because of the prohibitive energy requirements for operation. The large footprint required is also a significant disadvantage. Near-ZLD approaches such as those that provide 90% volume reduction may have acceptable costs (NRC, 2004). Reducing the volume of concentrate is a critical factor to reduce the current high cost of ZLD technologies (Sandia, 2003).

AQUACULTURE

Aquaculture is a rapidly growing industry, driven in part by declining ocean fish stocks. Domestic aquaculture in the United States continues to increase, driven also by domestic economic growth, the soft dollar, and restaurant sales (USDA, 2005). Membrane concentrates could potentially be used as a water source for these operations, primarily those producing salt water or estuarine fish species. Aquaculture has been suggested as a mid- to long-term concentrate management technology that should be explored (Sandia, 2003).

There are two general categories of aquaculture, marine (saltwater) and freshwater. The application of concentrate reuse in freshwater aquaculture is obviously quite limited by the elevated salinity in concentrate. Consequently, the focus of the following discussion will relate to saltwater (marine) aquaculture.

It should be recognized when considering aquaculture as a potential option for concentrate that RO concentrate has not been used for aquaculture production in the United States, and no known research is ongoing (K. Fitzsimmons, University of Arizona, personal communication). Moreover, with the exception of brine shrimp, marine aquaculture in the United States to date has generally utilized relatively low-salinity waters (relative to seawater), with a TDS of generally less than 7000 mg/L of TDS (K. Fitzsimmons, personal communication), well below that of many undiluted concentrates.

Aquaculture is being investigated as a beneficial use and as a means of offsetting costs for addressing a saline groundwater problem in Australia. In the Murray Darling region, 30 million L of saline groundwater (16,000 to 17,000 mg/L of TDS) was extracted and pumped 12 km away to protect the Murray River (Flowers and Hutchinson, 2004). Mulloway (*Argyosomus japonicus*) was grown in the groundwater and in seawater that was adjusted to match the salinity of the groundwater. Survival was not affected by using the groundwater and there were no abnormalities of internal organs, but growth was reduced compared to the diluted seawater unless the groundwater was supplemented with potassium. Ultimate disposal of the effluent will apparently be through evaporation ponds, after biological treatment (Flowers and Hutchinson, 2004).

Implementation Issues

Major implementation issues to consider for concentrate disposal include overall salt and water balance, influent toxicity issues, environmental and human health risks, costs, species selection, and effluent regulations.

Salt and Water Balance

Concerns over effluent discharges have led to a trend toward recirculating aquaculture systems which filter culture water and typically only need water to make up for evaporation losses (J. Kaiser, University of Texas Marine Science Institute, personal communication). Most aquaculture facilities will replace upwards of 5–10% by volume of the ponds, tanks, and pipes on a daily basis. The purpose is to control the buildup of nitrogenous wastes, phosphates, pathogens, and suspended solids. Some operations exchange relatively small volumes. For example, the daily water exchange for a shrimp farm in Arizona is approximately 1% of the pond volume and is used to irrigated wheat, sorghum, and olive trees (McIntosh and Fitzsimmons, 2003). A common approach for tolerant species, like tilapia and shrimp, to limit discharges is to only add water as needed to replace evaporation losses and then drain the pond after harvest to begin another cycle (K. Fitzsimmons, University of Arizona, personal communication). Salts and other wastes will accumulate, but the periodic discharge may be easier to manage than continuous discharge.

The recirculation trend will have a negative impact on the applicability of aquaculture as a concentrate disposal alternative. First, the volume of concentrate will be restricted to being less than or equal to the rate of evaporation of the aquaculture system. Second, a recirculating system will have ever-increasing concentrations of constituents which, in time, will reach toxic levels. It is estimated that water use has been reduced from 30,000 L of water/kg of shrimp produced in 1994 to 2500 L of water/kg of shrimp produced in 1998 (Treece and Hamper, 2002).

A shrimp farming operation in Arizona uses 2000-mg/L brackish well water, pumping the flow into cement channel raceways. The shrimp larvae are acclimated from 35,000 mg/L of TDS down to 2000 mg/L of TDS over a 1-month period. The water from the raceways travels through irrigation ditches (generally at 2000–6000 mg/L) where the water in the ditches is siphoned out to irrigate olive trees (T. Smith, SAWS, personal communication).

Effluent Discharge

Pressure from environmental organizations and government regulations to reduce environmental impacts has been considerable. Effluent from freshwater operations can be readily land applied as a beneficial use (McIntosh et al., 2003). Beneficial reuse of the effluent from marine (saltwater) aquaculture systems is much more challenging because of the elevated salinity. One alternative that has been investigated is land application to halophytic plants. Even relatively low-salinity aquacultural effluents may require a salt-tolerant crop (McIntosh and Fitzsimmons, 2003).

Disposal of produced water from CBM operations in Wyoming is a significant issue. Researchers are investigating use of the CBM water for aquaculture (K. Fitzsimmons, University of Arizona, personal communication). Experiments have been conducted using the CBM water, aquacultural effluent, and a commonly used grass crop (crested wheatgrass), a salt-tolerant barley, and a halophyte (*Atriplex canescens*, also known as four wing salt bush) (Wiowode, 2004). The salinity levels in this particular study (40 to 1580 mg/L of TDS) were very low relative to typical RO concentrate. The nutrients in the effluent were as effective in promoting plant growth as inorganic fertilizers. Similarly, effluent from a low-salinity white shrimp (*Litopenaeus vannamei*) farm in Arizona provided 20–31% of the nitrogen requirement for wheat production (McIntosh and Fitzsimmons, 2003).

“Low-salinity” (1380 mg/L of TDS) effluent from a white shrimp operation in Arizona was similarly applied to olive trees (McIntosh et al., 2003). Neither improvements nor adverse impacts were noted on the olive trees, but the authors suggested that relatively high nitrate content of the control likely masked beneficial effects of the effluent. Soil salinity increased significantly for the plots receiving the effluent treatment.

A more applicable study in terms of total salinity levels was conducted by Brown et al. (1999). Effluent from a freshwater tilapia operation was supplemented with sodium chloride to achieve solutions with 500 (freshwater), 10,000 (brackish), and 35,000 (seawater) mg/L and used to irrigated three halophytic plants (*Suaeda esteroa*, *Salicornia bigelovii*, and *Atriplex barclayana*) in a greenhouse. Irrigation was applied to achieve a relatively uniform leaching fraction of 0.3. *Suaeda* and *Salicornia* performed significantly better than *Atriplex* at the higher salinity levels. High rates (94% or more) of removal of nitrogen and phosphorus were achieved. Plant growth was severely restricted with the 35,000-mg/L treatment for all plants, but plants did relatively well with the 10,000-mg/L treatment. The growth of *Salicornia* was actually greater with 10,000 mg/L compared to the freshwater treatment. The authors noted that this type of system might be most applicable as a pretreatment step for coastal discharge, where the underlying aquifer is saline and has a direct connection to the sea.

Influent and effluent water quality parameters for a low-salinity Arizona white shrimp operation are summarized in Table 3-16. These results show a small increase in TDS and significant increases in ammonium (NH_4)-N, nitrate (NO_3)-N, phosphorus, BOD, and TSS, with an average water exchange rate of 1% per day.

TABLE 3-16

An Example of Low-Salinity Shrimp Farm Effluent Quality

Parameter	Influent, mg/L	Effluent, mg/L
TDS	2000	2200
pH	7.69	8.84
NH_4-N	0.02	0.17
NO_3-N	6.7	9.8
TP	0.40	0.74
SRP	0.14	0.33
BOD	1.09	6.40
TSS	4.6	46.8

Source: McIntosh and Fitzsimmons (2003).

Maintenance Issues

Typically, facilities that use ponds apply fertilizers to stimulate phytoplankton and zooplankton communities. There must be the correct proportions of nitrogen and phosphate or blooms of blue-green algae will result. As fish grow larger, up to 3% of body weight/day is supplied in food, resulting in a substantial amount of suspended solids. Corrosion of system components can be a significant issue in salt water systems.

Toxicity Issues

The feasibility of aquaculture as a concentrate disposal alternative is contingent on the ability to match an influent water quality with a species that thrives under those conditions. The water quality parameters required vary considerably by species. However, there are some general water quality guidelines that apply to the vast majority of current aquaculture species. Control of DO, salinity, ammonia, and nitrite is especially important. These values for the example case of marine shrimp are summarized in Table 3-17.

TABLE 3-17

Summary of Desired Aquaculture Water Quality Parameters for Marine Shrimp

Parameter	Desired Range[a]
Boron	0.05–1.0 mg/L
Cadmium	<0.1 mg/L
Calcium	100–500 mg/L
Carbon Dioxide	1–10 mg/L
Chloride	2000–20,000 mg/L
Total Copper	0.0005–0.01 mg/L
Total Iron	0.05–0.5 mg/L
Total Manganese	0.05–0.2 mg/L
NH_3	0.2–10 mg/L
NO_2	<0.23 mg/L
Dissolved Oxygen	5–15 mg/L
pH	7–9
Potassium	100–400 mg/L
Salinity	5000–35,000 mg/L
Sulfate	500–3000 mg/L
Total Suspended Solids	<100 mg/L
Temperature	26–29°C
Total Zinc	0.01–0.05 mg/L

[a] Source: Granville Treece, Texas A&M Univ., personal communication.

In addition to the general water quality guidelines presented above in Table 3-17, major ion toxicity resulting from imbalances (Chapter 1) could also be an issue. The concentration range of up to 35,000 mg/L of TDS suggests concentrates from all but seawater RO could potentially be directly used for marine shrimp.

Water quality tolerance, especially of salinity, is species dependent. The life stage of the species is important, especially for estuarine species where juvenile forms may have a preferred or optimal salinity and, as they mature, the preferences change. In nature, these species preferentially move into more marine habitats with greater or lower salinity.

Species Selection

The organisms that can be utilized in an aquaculture system are variable and numerous. The most likely species for use with concentrate are tilapia and brine shrimp (K. Fitzsimmons, University of Arizona, personal communication).

U.S. imports of tilapia are increasing rapidly ($249 million in 2004), and domestic demand is strong as people become increasingly familiar with this species. Almost all of the imported tilapia is from aquaculture. Similarly, shrimp imports are significant and increasing steadily ($3.7 billion in 2004) (USDA, 2005). Producers of domestically grown shrimp have difficulty competing with producers of imported shrimp because of foreign subsidies, lax environmental rules, cheap labor, and high land cost (T. Smith, SAWS, personal communication). Table 3-18 provides a summary of common marine aquaculture species.

TABLE 3-18

Summary of Possible Aquaculture Species for Commercial Production

Species	Salinity Range, mg/L of TDS	Harvest	Other
Salt-tolerant Tilapia (St. Peter's Fish)	0 to >40,000	12–18 months (1–1.5 lbs.)	Survival above 50°F
Marine Shrimp	2000-50,000	20–23 weeks	Cannot tolerate cold temperatures, growth stops at 24°C
Red Drum	0-40,000	12–18 months	Over 3 lbs has decreased value
Cobia (Ling)	10,000-40,000	12 months	Sporting fish
Hybrid Striped Bass	0-45,000	12–18 months	Freeze tolerant (some winter growth)
Channel Catfish	0-6000	12–18 months	Salinity prevents diseases

Source: Information was supplied by Granville Treece, Texas Sea Grant College Program, Texas A&M, to Tom Smith, SAWS.

Species that have been commercially grown in moderately saline groundwater include red drum, Pacific white shrimp, and tiger prawns (McIntosh and Fitzsimmons, 2003). As of 2003, there were four commercial producers of white shrimp in Arizona (McIntosh and Fitzsimmons, 2003). As of 2000, the farm gate value of marine shrimp exceeded $1 million (Toba and Chew, 2001, as cited in McIntosh and Fitzsimmons, 2003). Tilapia and shrimp other than brine shrimp in the United States are generally produced with water with 6000 to 7000 mg/L of TDS, and brine shrimp in California are produced with water with 50,000 to 60,000 mg/L of TDS (K. Fitzsimmons, University of Arizona, personal communication). Tilapia in Mexico and Ecuador are commonly produced in seawater salinity, and aquacultural operations being developed in the Murray Darling region of Australia commonly use solutions containing 45,000–50,000 mg/L (K. Fitzsimmons, University of Arizona, personal communication).

Brine shrimp (*Artemia* spp.) can be grown over a huge range of salinity (brackish to supersaturated brines), are found throughout the world, and are considered an excellent source of fish food (McCrae, 1996). Brine shrimp are a crucial part of the ecology of the Great Salt Lake in Utah (USGS, 1998). Harvests from Lake Albert, OR, averaged 34,000 lb/year from 1979 to 1995 (McCrae, 1996). The lower limit of salinity is typically driven by the increased presence of predators (McCrae, 1996). Extensive information on the culture and use of brine shrimp can be found in the report by Sorgeloos et al. (1986). Brine shrimp production can be implemented along with an evaporation pond (Ahuja and Howe, 2005).

Bait fish production is a growing business. Since the product is not for human consumption, there is the added benefit of no health effects issues. The market value for this product is typically low. Most bait fish are raised in large freshwater ponds.

Information on oyster production is limited, but it may become evident that oysters can thrive in a wider range of feedwater conditions and are thus applicable to a wider range of concentrate disposal feasibilities. However, it should be recognized that shellfish are noted for bioconcentration of trace metals and organic constituents.

Additional information specific to several aquaculture species can be obtained at the website http://srac.tamu.edu/, including information about 13 different “general” saltwater and freshwater species.

Site Selection

The most critical site selection factor is the need for a warm climate. Sites located away from a coast and other public water resources tend to have fewer regulatory constraints on operations (T. Smith, SAWS, personal communication). Other considerations are a preference for flat areas, transportation and access to markets, options for disposal of effluent, and low-cost land.

Other Issues

Other significant implementation issues for aquaculture are summarized in Table 3-19.

TABLE 3-19

Summary of Other Implementation Issues for Aquaculture

Parameter	Discussion
Geographical and Climatic Relevance	Temperature is an issue for aquaculture feasibility for two primary reasons, salt-tolerant species thrive in warm temperatures and, with the push for recirculating systems, the size of the influent (and indirectly the size of the RO) is dependent on evaporation rates; the net evaporation rate is a key design element as the primary driver for system size; areas with greater net evaporation rates will provide greater volume reductions of concentrate
Level of Water Utility Control	Low; dependent on aquaculture system operator
Membrane Cleaning Solutions	Likely to be a significant concern, requiring pretreatment or separate treatment
Proven Technology	Although there are ongoing research programs with other high-salinity waters, no research appears to have been conducted in the United States on the use of RO concentrate for aquaculture to date

Regulatory Issues

The primary regulatory issue associated with aquaculture is effluent water quality. As the effluent regulations become more stringent, facilities are driven toward operating in a recirculation mode as previously discussed. Aquaculture facility certification is often required with effluent standards for TSS, phosphorus, pH, ammonia, BOD, salinity, and DO. State regulatory requirements for discharge of aquaculture effluent in Texas and many states are stringent, such as those from the Texas Parks and Wildlife Division and the Texas Council on Environmental Quality (TCEQ) (T. Smith, SAWS, personal communication). Human health is also an issue (USDA food standards). Siting constraints due to zoning, aesthetics, odor, land use, and other issues can be problematic.

The Aquaculture Certification Council publishes guidelines for standards for facility certification (http://www/aquaculturecertification.org). These guidelines provide detailed information on effluent management.

It is anticipated that future regulations on effluent will only become more stringent. Consequently, aquaculture as a concentrate disposal alternative may become less feasible in the future.

Cost Considerations

Since there are no known aquaculture operations using RO concentrate, it is not possible to develop a reasonable cost model. General considerations are described below.

Capital Cost Considerations

Infrastructure capital costs for an aquaculture facility will be roughly similar to those of evaporation pond facilities. Additional costs would include pumps and piping for recirculation and effluent disposal and potentially larger berms to allow deeper water depths. Refer to Chapter 2 for information related to evaporation pond costs. Economies of scale tend to be significant.

The primary cost factor with aquaculture is the cost of land. Obviously, this varies considerably from region to region and with proximity to urban development. In general, the capital cost for an aquaculture system may be less than many of the other concentrate disposal alternatives.

One recent example is from a shrimp farming facility in south Texas. The total area of the facility was 50 acres, with primary features of four 5-acre ponds with a settling basin attached to each pond and one common 14.8-acre constructed wetland. This facility had a capital cost estimate of $459,552 (Whetstone et al., 2002).

O&M Cost

Operation and maintenance costs include culture or purchase of juvenile fish, nutrients, food, possible chemical additions to maintain water chemistry in the desired range, marketing and shipping costs, and effluent disposal. Effluent disposal will likely be a major cost consideration. Other costs include maintenance of pumps and piping.

A key consideration potentially offsetting costs is the value of the fish produced; however, aquaculture has historically been a low-margin business enterprise. Consequently, it is of considerable importance that each potential concentrate disposal application be populated with species that are most suitable for the characteristics of the respective concentrate stream that can also be successfully marketed. In other words, it is advantageous to define the waste stream and then select tolerant species for which there is a market. This is in contrast to selecting the species and then pretreating the waste stream to optimal conditions for that species. The added treatment cost will consume the minimal margin available.

Although demand is steadily growing for aquaculture products, markets for aquaculture products are limited and can be easily saturated (T. Smith, SAWS, personal communication). Luxury species, such as lobster and shrimp, may potentially provide the greatest margins.

Cost of Lost Water

The fate of concentrate supplied to an aquaculture operation is evaporation and/or discharge as effluent. Evaporation losses represent a loss to the local watershed. Effluent discharges could potentially be recovered for reuse.

Human Health and Ecological Risk Factors

The use of concentrates in aquaculture facilities can be evaluated on a project-specific basis. As with land application, the first consideration is maintaining water quality that is not toxic to the aquaculture organisms (fish or invertebrates). These target organisms may differ significantly in their sensitivities to a range of general water quality conditions or responses to specific trace contaminants.

Assuming the concentrate can support the growth of the target organism, a secondary consideration is the potential for constituents to accumulate. Subsequent human consumption or ecological receptors higher in the food chain may be more sensitive to selected constituents if present (e.g., mercury). Evaluation of the concentrates for direct toxicity as well as bioaccumulative potential may indicate whether this pathway is a concern.

Fish farm workers will have higher exposures to concentrates than the general public. As with agricultural workers, human health issues may involve the frequency and nature of their potential exposure. It is anticipated that exposures would be limited; however, some recommendations (e.g., washing hands) may be warranted, as pathogens or other constituents may be an issue when surface water is the membrane treatment feedwater.

Conclusions

The primary variables that impact the feasibility of an aquaculture system application for membrane concentrate disposal are existence of a market for the species to be grown, climate, concentrate chemistry and flow rate, land area available, and options for effluent disposal. Marine aquaculture is practical in the United States, but generally with low-salinity water compared to seawater and some concentrates derived from brackish groundwater. No research has been identified on the use of concentrate for aquaculture. In the United States, salt water tilapia for human consumption and brine shrimp as food for other fish are the most likely applications for many concentrates, although a number of other species could potentially be utilized.

WETLAND CREATION AND RESTORATION

Wetlands are shallowly flooded areas dominated by plants adapted to inundation and by soils exhibiting hydric characteristics (Mitsch and Gosselink, 2000). Water in wetlands may be fresh, brackish, or saline, depending upon the water source. Common types of wetlands include marshes, which are dominated by emergent aquatic plants such as rushes, reeds, cattails, sedges, and other herbaceous plants, and swamps, which include woody shrubs and trees adapted to periodic shallow flooding.

Through wetland restoration, creation, and enhancement, ongoing efforts are underway throughout the world to reverse long-term trends of wetland loss and degradation associated with human uses. Wetland *restoration* refers to the return of a wetland from a disturbed or altered condition by human activity to a previous existing condition (Mitsch and Gosselink, 2000). Wetland *creation* refers to the conversion of a persistent upland or shallow water area into a wetland by human activity, and wetland *enhancement* refers to a human activity that increases one or more functions of an existing wetland (Mitsch and Gosselink, 2000). Careful application of membrane (RO) concentrate could potentially be beneficially used to restore or create brackish or saline wetlands such as salt marshes. This section describes two potential concentrate discharges to wetlands: (1) creation of new brackish or salt marshes using concentrate as the primary water source and (2) augmentation of existing brackish or salt marshes with concentrate.

Characteristic Features

Salt marshes may be found along the coast or inland. Along coasts, salt marshes may be associated with estuaries, lagoons, or other forms of coastal lowland or wetland. Salinity in coastal salt marshes is associated with proximity to the ocean and is normally subject to a continuous dynamic tidal influx, depending on the topography and infusion of fresh water from upstream sources. Variables that increase the salinity of coastal marshes include close proximity to tidal inundation, low or infrequent rainfall, presence of tidal creeks and drainage slopes, high soil silt and clay content, presence of salt marsh vegetation, distance to groundwater table, proximity to freshwater inflows, and presence of fossil salt deposits (Mitsch and Gosselink, 2000).

Inland marshes may be saline as a result of the influence of brackish groundwater or a highly evaporative condition that exceeds inflow. For example, prairie wetlands commonly found within continental North America can range from fresh to very saline (LaBaugh, 1989). TDS levels in prairie wetlands and lakes of Nebraska range from less than 100 mg/L to more than 120,000 mg/L. Prairie wetlands generally occur within a geographic range defined by an annual precipitation deficit of 0 to 50 cm (Winter, 1989). Vegetation native to these inland salt marshes has been classified according to a number of schemes, but the commonly used Cowardin wetland classification system employs six salinity classes, three of which encompass the range of salinities found in prairie wetlands: freshwater (<800 µS), oligosaline (800 to 8000 µS), and mesosaline (8000 to 60,000 µS) (Kantrud et al., 1989).

Naturally occurring inland salt marshes are often characterized by open unvegetated areas of sediment in the wetland, which are usually caused by extreme salinity conditions or disturbance of animals seeking salts (MNFI, 2004). Often the fringe areas are populated by halophytes (salt-tolerant plants) and xerohalophytes (salt-tolerant plants specific to arid regions). Depending on geographic location, halophytes and xerohalophytes may or may not be considered exotic plant species in inland salt marsh systems. For example, while inland sites with saline or brine “seeps” may be less likely to support halophytes, these plants may be reintroduced continually to these sites by birds migrating from the extensive salt marshes of the Atlantic coastline regions (MNFI, 2004). Conversely, halophytes and xerohalophytes may be more common as native species to inland salt marshes found in the arid and hyperarid Southwest desert regions.

Inland salt marshes, unlike ocean, estuarine, or riverine salt marshes, may have relatively stable flow characteristics and are more likely to have relatively long turnover rates, similar to water bodies receiving relatively low volumes of new water. Salinity of soils within an inland salt marsh can vary widely within the wetland, with an increase in salinity noted from the center to the fringe through the concentrating effect of evaporation.

Constructed Salt Marshes

Because coastal communities with concentrate management requirements may benefit from the significant dilution afforded by discharge to saline waters, this section focuses on creation or restoration of new wetlands that could be designed as brackish or salt marshes.

Inland salt marsh areas are not limited to arid regions, but rather are found throughout the United States in areas where saline or brackish groundwater reaches the soil surface and where wetland areas are fed by waters passing through salt-laden soil, or where evaporative rates exceed inflow to a given inland water body. Inland salt marsh sites could potentially be created where they have never previously existed to provide aesthetic and habitat benefits or mitigation values. The reasons to construct an inland salt marsh might originate in the need to dispose of concentrate, but they could range broadly enough to include an interest in creating multiple-purpose wetland park facilities. Reasons to implement such a project might range from a municipality seeking concentrate treatment alternatives to private developers seeking wetland or riparian mitigation sites. The feasibility of constructing an inland salt marsh where none previously existed would have to be determined. Constructing an inland salt marsh might be most feasible if it is located adjacent to existing salt marsh areas or where one may have historically occurred to be most consonant with potential local vegetation types, water quality, hydrology, and climate.

A large-scale example of this approach has been created at Owens Dry Lake in California (Dickey et al., 2003; Smesrud et al., 2004; Dahlgren et al., 1997; Richards, 1994). To stabilize dust emissions from a dry lake bed, freshwater blended with highly saline shallow groundwater applied to saline sodic soils now supports extensive stands of native salt marsh vegetation. Appendix B provides additional details on this project.

Implementation Issues

Implementation of a marsh restoration, creation, or enhancement project using membrane concentrate would begin with an assessment of the concentrate quality to determine if significant concentrations of contaminants were present. If contaminant concentrations were found to be below ecotoxicological thresholds or other pertinent water quality criteria, an analysis of the daily and seasonal variability in concentrate supply, as well as a detailed water balance, would be necessary to establish the likely wetland hydroperiod or depth and duration of inundation. This would have to be compared to the salinity and hydroperiod tolerances of the proposed or existing marsh vegetation.

Soils within the wetland or proposed upland construction site would be examined for compatibility with a brackish water source. Engineering or regulatory measures to protect the local groundwater from adverse effects would need to be considered. If the proposed discharge would be to a natural wetland, the occurrence of protected species would need to be determined, and potential positive or negative impacts would need to be assessed. A detailed long-term operation and maintenance plan would need to be prepared.

The feasibility of discharging concentrate into a wetland will require a broad regulatory review of federal, state, and local jurisdictions. Federal regulations to be addressed will likely focus on environmental impact, water quality, wetland dredge and fill, and protected species (i.e., National Environmental Policy Act, NPDES, section 404 of the CWA, and the Endangered Species Act). Related state regulations on wetlands, wildlife, and protection of surface water and groundwater quality would likely be relevant. Local regulations on land use zoning, compatibility, wetland protection, and other ordinances would need to be considered.

While the regulatory review for a wetland project utilizing membrane concentrate is likely to be rigorous, the beneficial aspects of wetland restoration activities can be documented through a demonstration project or by comparison with similar projects.

The assessment of implementation feasibility would require identification of appropriate sites, water quality and hydrologic analyses, assessment of appropriate land uses, and stakeholder identification and contact, as described in the following sections.

Site Identification

Available inland salt marsh areas would first need to be identified and investigated as historical, existing, or preferred future sites. Naturally existing inland salt marsh sites are not distributed uniformly within regions and may be relatively rare and limited in number. The approach might include the following:

- Identification of naturally occurring or man-made salt marsh water bodies located in an area of focus
- Determination if the potential sites are managed, sponsored, or operated as a functioning site or conservation area
- Determination of existing regulatory limitations through contact with the local or regional water board or the discharge permit-issuing agency
- Investigation of selected site soil conditions, percolation and permeability rates, groundwater impacts, and other factors. In cases of hyperarid regions, high desert, the sand dominant soils with high permeability rates may effectively form the area's largest sand filter, which can be a difficult permitting challenge to overcome. Alternatively, clay-dominant soils will tend to prevent exfiltration losses and contain the water surface levels that support high evaporative losses.
- Determination of sites better suited to serve as constructed salt marsh

Each site would be tested and ranked in comparison with the others based on determination of background or intrinsic water quality data and proposed impacts for each selected site. An assessment of the concentrate composition and the marsh's assimilation capacity would be performed to determine the technical and regulatory feasibility of concentrate discharge to the wetland, likely as a land application of industrial wastewater.

Technical Assessment

Assessment activities common to feasibility analysis of any salt marsh implementation concept would likely include the following:

- *Concentrate Characteristics:* Constituent concentrations would need to be assessed and compared to the proposed salt marsh site. In areas that may have a high diffusion rate of water (permeability or other water sources), the opportunity to discharge a higher volume of concentrate may be achieved relative to a site with a low diffusion rate, which would likely be capable of accepting a lower volume of concentrate.
- *Water Budget Analysis:* Inland salt marsh sites do not often experience tidal or flow dynamics within the water body.
- *Ecosystem Analysis:* Arid southwestern regions will primarily have dominant xerohalophyte species rather than halophyte species. Salt tolerance and toxicity of specific constituents should be investigated further based on the species identified at selected sites.
- *Constituent Fate:* The long-term buildup of concentrate constituents needs to be investigated for impact to local flora and fauna as well as groundwater quality impacts.
- *Project Drivers:* (1) comparative costs of traditional discharge methods with that of a constructed salt marsh or the environmental permitting process of discharging to existing marsh; (2) political importance of site and its adopted stakeholders. Does the region want such an entity in their backyard? (3) Can the site be represented as a conservation site and improved by the proposed discharge activities?
- *Funding Resources:* In most cases, funding will likely be provided by private development or a municipal capital program seeking a discharge location.

Functional Uses

The importance of inland salt marshes includes providing habitat for native wildlife and migratory avian species. Wildlife species currently dominate as the primary users and beneficiaries of inland salt marshes. Current human use is limited.

Inland salt marshes are havens for terrestrial wildlife seeking salt sources or salt “licks” and also provide important habitat to a variety of species. For example, avian species use the open (less-vegetated) topography for migratory rest areas, and certain avian species find the lowland areas beneficial as nesting locations. Once identified, inland salt marshes are often highlighted as a local “refuge” or other type of natural resource or conservation site. The uses of inland salt marsh sites need to be practically beneficial when compared against current conditions.

Stakeholders

Private organizations and local nongovernmental organizations (NGOs) may adopt inland salt marsh sites as part of a regional effort in building awareness of local water resources, park development, or refuge delineation set aside for conservation of natural native resources. Other sites may be part of a private or municipal property ownership or jurisdiction and subject to alternative uses, such as mitigation banking, restoration, or constructed wetland as a saline sink or treatment process.

Other Issues

Other significant implementation issues for inland salt marshes are summarized in Table 3-20.

TABLE 3-20
Summary of Other Implementation Issues for Inland Salt Marsh Discharge

Parameter	Discussion
Geographical and Climatic Relevance	Although found throughout the United States, salt marshes would be mostly likely found or created throughout the arid and semiarid West and Great Plains; evaporation can provide volume reduction
Level of Water Utility Control	Relatively low level of control, as discharges would be affected primarily by the hydrology and biology of the system, in addition to likely numerous NGO and regulatory constraints
Membrane Cleaning Solutions	Limitations are site specific, but ecological considerations due to chemical impacts would be paramount; pretreatment may be required
Proven Technology	Concentrate discharge to an inland salt marsh has not been done

Regulatory Issues

Although inland salt marshes have been generally reduced in overall numbers in recent years due to encroachment by human development, remnant areas are increasingly more likely to be designated and protected as wetlands or a wildlife refuge by regulatory agencies. Regional or local communities may also seek protection of inland salt marsh sites for benefits of mitigation, refuge, or park amenity.

An approach for California sites would likely include identification of regional water quality control board discharge requirements within the authority of a given site. This will also lead towards determination of local and regional stakeholders and community groups who may have adopted the local inland salt marsh site.

The process of permitting might follow the approach used for traditional land treatment discharges for industrial or municipal wastewaters. In California, in addition to a number of other western states, it is likely to be at least 1 order of magnitude and probably several orders more costly to successfully permit a discharge impact and meet necessary mitigation requirements on an existing inland salt marsh than if one were constructed for the purpose of the discharge. This is due to the fact that the existing site, if established as a known salt marsh entity, is likely protected, adopted, or managed by any number of sponsoring groups or agencies.

In contrast, a constructed site can often be presented and permitted as an alternative solution to impacts on groundwater, an amenity opportunity, a beneficial reuse of an otherwise unused property or undesirable site condition, etc.

Should an existing site be identified as a preferred site for discharge, one could expect to carry out and justify a nonimpact through extensive environmental investigations, impact statements, and potentially extensive mitigation efforts. The approach anticipated for use might include the alignment of the practice with land applications of municipal or industrial wastewaters (USEPA, 1981).

Cost Issues

It is not yet possible to develop a detailed cost model due to the untested nature of this approach; nevertheless, some general capital and O&M cost considerations can be described.

Capital Cost

One of the primary benefits of inland salt marsh disposal in the southwestern region is the relative cost of land compared to ocean outfall rights and coastal zone development. Most coastal zone development sits on real estate valued at over $2 to $3 million/acre. Inland desert (arid) regions are valued significantly lower than coastal zone properties. Land values will vary widely, depending on where the disposal sites are located near development, but they will be on an order of magnitude of at least 20:1 less than for coastal zones. Based on the assumption of arid high desert values in relatively undeveloped areas of Arizona and New Mexico, land values can reach well below $10,000/acre. Further site-specific investigations of land cost for alternatives will be required depending on proposed locations with respect to regional development.

Depending on the quality of the concentrate being proposed and the location of the discharge pipeline termination, additional capital cost considerations might include pretreatment facilities, conveyance, pumping, and possibly some type of outfall structure. Furthermore, if the site’s hydrologic and biological needs dictate a sensitivity to flow variations, storage fore bay or other disposal alternatives will be required. Similar cost considerations are discussed below under “Constructed Wetlands Treatment.”

O&M Cost

O&M cost considerations will likely include salt marsh water management and level control, vector (pest) control, and potential plant management. Maintenance costs associated with the facility will need to cover all associated mechanical treatment, pumping, or storage facility systems as well as any piping or distribution control valves. The local agency or owner of the site will be required to adequately fund the site’s O&M cost and ensure performance over a period of years while in use.

Monitoring costs will be associated mostly with plant growth monitoring and that of soil and groundwater level monitoring in order to ensure the site remains within the expected impact criteria identified. Similar requirements are discussed below under “Constructed Wetlands Treatment.”

Cost of Lost Water

Concentrate discharged to a salt marsh could potentially have several fates, including runoff, evaporation, or percolation to groundwater. Runoff to surface water resources and percolation to groundwater would likely be prohibited, and therefore the ultimate sink for water in the concentrate would be evaporation. As such, the water in the concentrate is not lost to the hydrologic cycle as would be the case for deep well injection but nevertheless represents a 100% loss of potential potable water to the local area.

Economic Risk Factors

Economic risk factors would include potential long-term loss of the salt marsh as a point of discharge as a result of buildup of saline toxicity, unfavorable monitoring results, or regulatory changes.

Human Health and Ecological Risk Factors

The major risk issues of salt marsh discharge would likely be ecological rather than human health. As described previously for surface water discharges in Chapter 2, ecological effects could be from either direct toxicity or through bioaccumulation of constituents, such as arsenic, mercury, and selenium. Concentrations of these constituents in the source water, and also, if needed, the ability to reduce concentrations through pretreatment, would be a major determinant in the overall success of the salt marsh, whether it is constructed or naturally occurring. The potential impacts to wildlife of the open water marsh systems can be largely mitigated by pretreatment wetlands, such as those described in the next section.

Applicability to Other Salt Streams and Overall Basin Salt Management

Other salt streams could potentially be discharged to salt marshes, but regulatory constraints would likely be considerable, and ecological issues would have to be carefully evaluated for each salt stream.

Conclusion

Concentrate byproducts from reverse osmosis and other forms of membrane filtration processes could potentially be discharged to naturally occurring or artificially created inland salt marsh areas. When compared to constructed sites, most existing sites are not likely candidates as primary discharge sites due to the low and intermittent flows required to sustain these ecosystems. Additionally, the regulatory permitting processes required to address the impacts of the concentrate discharge on the native conditions would likely be difficult, especially for naturally occurring salt marsh areas.

Constructed salt marsh areas are somewhat more likely to be successful in the permitting process. However, since these sites receive the discharged concentrate as their only source of water, they will be subject to a more rapid buildup of constituents. Constructed salt marsh areas should be designed to address these issues through infrastructure to allow an operator to maintain a proactive water balance management approach between constructed marsh areas.

CONSTRUCTED WETLANDS TREATMENT

Using membrane concentrate as a water source to wetlands dominated by brackish or salt marsh wetland plant species would provide an environmentally compatible alternative for brine disposal for inland as well as coastal applications. Existing research on wetland halophyte irrigation with brackish water supports this concept. Toxic levels of certain constituents in some concentrates may preclude direct discharge of concentrates without some pretreatment. Wetlands treat specific constituents through natural biological, chemical, and physical processes and provide volume reduction through evapotranspiration. The potential volume reduction associated with the use of treatment wetlands is beneficial because there is less fluid to handle and, presumably, to store, discharge, or truck away.

As described in the previous section, restoration of both coastal and inland salt marshes can provide a number of ecological services, in addition to providing a potential cost-effective beneficial use for membrane concentrate. This alternative will have potential applications for both coastal facilities as well as landlocked areas of the arid Southwest. Linking this option to a pretreatment wetland system is being tested in Oxnard, CA (Appendix A) and has the potential for low-maintenance reuse for beneficial purposes. Contaminant removal from a brine stream would create salt water suitable for use to restore wetlands, and preliminary results are encouraging.

The concept of using wetlands for saline water management is being explored to varying degrees on an experimental scale. For example, the USBR has studied the use of wetlands for volume reduction, salt management, and contaminant removal at small-scale test cells in southern California (Boegli and Thullen, 1996). Detailed studies of wetland treatment of other saline wastewaters have been conducted, including agricultural drainwater prior to desalination to reduce pretreatment costs (Beuhler and Kinshella, 2005), as well as produced water from oil fields (Negri et al., 2003) and coal bed methane (e.g., Kirkpatrick, 2004; Phelps et al., 2005).

Recently, saltwater wetlands were one of the recommendations for consideration by an AWWA committee (AWWA, 2004), and are a technology that should be investigated (Sandia, 2003). However, it should be noted that in their review of the Sandia-USBR road map, the NRC (2004) concluded that "constructed wetlands do not fit into a desalination- or membrane technology-based purification strategy to ensure a sustainable water supply, [and] this item should be deleted because it appears to be beyond the scope of the roadmapping effort."

Wetlands for Volume Reduction: Produced Water Studies

Considerations for produced water disposal parallel those for concentrate disposal. Oil and gas production typically results in bringing a brine solution that may exceed seawater TDS levels to the surface that must then be discharged. Usually the only option is deep well reinjection of the brine solution at considerable cost. Reductions in volume directly translate into reduced costs for disposal.

Volume reduction of produced water is typically achieved through the use of evaporation ponds, but these require considerable time and space (Negri et al., 2003). The Argonne National Laboratory led recent studies on the use of salt marsh plants for the purpose of reducing the volume of produced water (Negri et al., 2003). This study developed a two-stage bioreactor, with great bulrush (*Scirpus validus*) in the lower-salinity initial compartment and saltwater cordgrass (*Spartina alterniflora*) and Vermilion cordgrass (*Spartina alterniflora* var. *vermilion*) in the higher-salinity second compartment. The two field studies in Oklahoma found the following:

- With an influent of 30,000 mg/L of chloride (estimated >50,000 mg/L of TDS), a constant 75% reduction in volume was achieved in less than 5 days.
- With an influent of 60,000 mg/L of chloride (estimated >100,000 mg/L of TDS), the volume reduction was 30% more than the open water control.

They concluded that the ideal plants for this kind of volume reduction technology were large grass or grass-like plants, native to salt marsh or coastal environments (Negri et al., 2003). They also warned that winter dormancy or seasonal variations in system capacity would be an issue that would have to be addressed in the design of any such system.

It is important to note that the study did not address scale-up issues associated with going from small pilot-scale tests to full-scale wetlands. The flowthrough troughs used in the study were 0.7 m^3 in size. It is likely that water loss per unit area would be much less than that found in the pilot test. Kadlec and Knight (1996) noted that wetland ET and lake evaporation tend to be approximately the same, that is, the net effect of the vegetation is zero. However, in very small wetlands (such as those used in the pilot tests above), advection becomes increasingly important, and wetland ET may exceed that of an open water surface. Kadlec and Knight (1996) explained that little information is available in this area for wetlands, but they cited studies that suggest wetland ET is similar to open water at a size of somewhat less than 1 hectare. However, they went on to cite work by Bavor et al. (1998), who found that water loss from a 4- by 100-m vegetated wetland was double that of an open water surface. Therefore, the order of magnitude of the difference between open water and vegetated wetland systems was roughly similar in the Bavor et al. and Negri et al. studies.

Ongoing studies led by James Bauder of the Department of Land Resources and Environmental Sciences, Montana State University (http://waterquality.montana.edu), have found water from CBM production facilities support good species survival and colonization for seven of nine species selected (Kirkpatrick, 2004). The study indicated that constructed wetlands planted with native, salt-tolerant species have potential to utilize substantial volumes of CBM product water while remaining robust and viable. Although results suggest evaporation from an open water surface to be greater than evapotranspiration from a constructed wetland, the researchers note that constructed wetlands include added benefits of providing wildlife habitat, recreation, and aesthetic enhancement.

Treatment Wetlands: Oxnard Pilot Treatment Wetland Study

Currently, the best available data on the use of treatment wetlands with membrane concentrate is the work at Oxnard, CA. Complete preliminary results are provided in Appendix A and are briefly summarized here.

Objectives and Rationale

The Membrane Concentrate Pilot Wetlands Project is designed to test the following hypotheses concerning the reuse of membrane concentrate:

- *Concentrate can sustain viable native plant communities:* By planting the pilot system with native wetland plants and monitoring their growth characteristics, species water quality tolerance and improvement potential can be determined under hydraulic regimens similar to those that might be implemented on a larger scale.

- *Removal of nonconservative elements will occur through natural biological and chemical transformation processes and will vary among wetland types:* The types of pilot systems selected have been based upon known configurations that have been reported to treat common pollutants. This study is designed to allow comparison of wetland influent and effluent water quality within each cell to determine cell pollutant removal performance and compare it to published water quality improvement models.

- *Some removal of conservative elements can occur through physical and chemical processes, and removal will vary among wetland types:* Few studies are available in the literature that have reported on treatment of brackish waters and their compounds. Again, by comparing wetland influent and effluent water qualities, this study will support analyses to determine if removal is occurring through biological assimilation or other processes.

- *Discharge is ecologically safe to wetland biota:* By comparing samples taken of the brackish concentrate at the influent and effluent from each of the cells, changes in toxicity of the effluent to brackish and saltwater organisms can be assessed. This information can be used to determine if water quality components exceed state water quality criteria or pose a measurable concern to native aquatic organisms.

The rationale for conducting this study includes the following:

- If shown to be environmentally safe, membrane concentrate may be useful as a water source for the creation of new wetlands or the restoration of existing salt marsh wetlands.
- The potential supply of membrane concentrate may be useful to the restoration of the Ormond Beach wetlands.
- An environmentally safe reuse of membrane concentrate could minimize the need and cost of other disposal options.
- Very little information is available in the published literature on the effects, treatment, or reuse of membrane concentrate. Results obtained from this study could prove to be beneficial to water supply managers worldwide, particularly in the arid West and Sunbelt states.

Results and Discussion

The Oxnard Membrane Concentrate Pilot Wetland Project is a pilot system approach to address the feasibility of using membrane concentrates—including those from the planned advanced wastewater treatment facility, regional desalter, and tertiary treatment facility—as a water source to a wetlands-based system. Preliminary data available from the initial pilot phase reported here indicate the following responses to the hypotheses posed at the outset of the study:

- *Concentrate can sustain viable native plant communities:* Native wetland plants adapted to salt and brackish water conditions exhibited normal, even vigorous growth. Wetlands with little or no outlet flow showed normal plant cover and growth, even with an increase in salt content through evaporation of 30%.

- *Removal of nonconservative elements will occur through natural biological and chemical transformation processes and will vary among wetland types:* Parameters of greatest concern, such as selenium and nitrate-nitrogen, were significantly decreased within the wetland, indicating that environmentally safe levels are achievable. This removal was most detectable in vertical upflow wetlands, as described below.

- *Some removal of conservative elements can occur through physical and chemical processes, and removal will vary among wetland types:* Concentrations of many inorganic water quality parameters did not appreciably decline during the study, but some, such as calcium, alkalinity, and total hardness, declined in submerged aquatic vegetation wetlands. However, because water volumes were reduced by as much as 30%, the mass of inorganic constituents in the wetland discharge was significantly reduced.

- *Discharge is ecologically safe to wetland biota:* Treatment by the marshes in general yielded brackish water with significantly reduced contaminant levels that, with further testing and regulatory approval, may be used for regional benefit, including assisting with restoration of the Ormond Beach wetlands system. Future analysis will compare results with known ecotoxicological thresholds. Specific toxicity testing of the wetland effluents is planned.

Implementation Issues

Wetland Types

Several different types of wetlands can be used, depending on site constraints and treatment goals. These types include surface flow, horizontal subsurface flow, vertical flow, floating aquatic systems, submerged aquatic vegetation, and natural wetlands. Plant species can be selected from existing flora found from inland and coastal marshes, thereby incorporating brackish water tolerance into the planting design. Maintaining the appropriate design depth during wetland operation will enhance vegetation growth and survival. A cross-section of several major types of treatment wetlands is shown in Figure 3-20.

Surface Flow Wetlands: Typically, these are shallow impoundments with thickly vegetated areas of emergent wetland species, such as cattail (*Typha* spp.) and bulrush (*Scirpus* spp.), that alternate with deeper, largely unvegetated zones (Kadlec and Knight, 1996). The depth of water is usually less than 16 in. Conditions are typically aerobic above a sediment water interface and anaerobic below it (CH2M HILL, 2004). Major potential benefits of this type of wetland are the ancillary benefits of wildlife habitat, public recreational uses such as bird watching, and surface runoff retention (CH2M HILL, 2004).

Subsurface Flow Wetlands: The substrate for plant growth in subsurface flow wetlands is typically gravel, but there is no free water at the surface of the substrate. Microorganisms grow on plant root surfaces and the gravel medium. These designs are most commonly used in colder climates and areas where available land is limited (CH2M HILL, 2004).

Floating Aquatic Systems: These are typically deeper impoundments (1.5 to 6 ft deep) than surface flow wetlands, and vegetation consists of floating species, such as duckweed (*Lemna* spp.) and water hyacinth (*Eicchornia crassipes*) (CH2M HILL, 2004). Aerobic processes are limited to near the water surface (CH2M HILL, 2004). The plant species used are generally sensitive to salts and, therefore, this design is generally not applicable to concentrate (CH2M HILL, 2004).

Vertical Flow Wetlands: Similar to subsurface flow wetlands in design, vertical flow wetlands receive water distributed over the top or from the bottom of a bed of soil, gravel, or peat medium planted with wetland vegetation. The surface application supports aerobic decomposition processes through the entrainment of air as fluid moves down into the soil medium, and the bottom application of water into a wetland supports anaerobic decomposition of organic matter, denitrification of nitrogen, and reduction of oxidized forms of selenium (CH2M HILL, 2004). These types of systems may also be planted with vegetation that does not require continuous inundation and may include plants typical of saturated to unsaturated soils.

Submerged Aquatic Vegetation: Submerged aquatic vegetation includes open shallow impoundments 3 to 5 ft in depth, which is too deep to support emergent vegetation but can instead support dense growth of native aquatic plants, such as pondweed (*Potamogeton* spp.) and wigeongrass (*Ruppia* spp.). These types of plant communities are commonly found in the deepest portions of inland wetlands and are tolerant of high salinities (Kantrud et al., 1989). Their concentrate treatment benefit is found in their potential to take up free carbon dioxide in the water column for photosynthesis, thereby shifting the pH to alkaline conditions that favor precipitation of calcium carbonate, fluoride, and phosphorus.

Natural Wetlands: Naturally occurring emergent marshes can be incorporated into a concentrate treatment wetland conceptually as the final system in a series that would receive flow pretreated by the previous constructed treatment wetlands. While the inflow to the natural wetland would retain a high salt content, the concentrate contaminants and associated toxicity would be significantly reduced, if not removed altogether.

Efficacy of Treatment

Wetlands are especially effective in treating nutrient contaminants with significant transformations and atmospheric losses, such as nitrogen, or with significant biological uptake and storage, such as phosphorus (Kadlec and Knight, 1996). Constituents such as sodium, chorine, TDS, and hardness are usually not significantly affected, other than through dilution from precipitation or concentration resulting from evaporation (CH2M HILL, 2004).

Other Issues

While the long-term viability of a concentrate treatment wetland remains untested, general experience indicates that the working life of a treatment wetland is on the order of decades or longer. Provisions can be made during design that can allow long-term accretion of biomass without adversely affecting hydraulic operation. Similarly, design provisions can be made that would allow for periodic leaching and draining of accumulated salts from wetland soils, just as they would be for a land application system. Also, the design can factor in “extra cells” that would allow flow to be routed away from cells during routine refurbishment or replacement, as necessary.

The microbial communities responsible for denitrification and other contaminant removal and transformation processes occur in naturally occurring salt marshes and would likely be viable under the salinity ranges anticipated for long-term operation of a concentrate wetland. Monitoring would indicate changes in performance likely attributable to the effects of elevated salinity. Given the general experience of treatment wetland design, a broad range of design measures (e.g., underdrains, extra cells, access for substrate replacement) are available that anticipate maintenance requirements, and with monitoring, concentrate wetlands could be sustained over a longer period. A full-scale demonstration project is necessary to fully assess this concern.

Given that there are so few examples of concentrate wetlands available, it is not possible to fully evaluate this technology. This report summarizes the example provided by Oxnard and, it is hoped, leads to an awareness of the need for continued research to describe and assess the potential of the performance and long-term sustainability of treatment wetlands receiving concentrate.

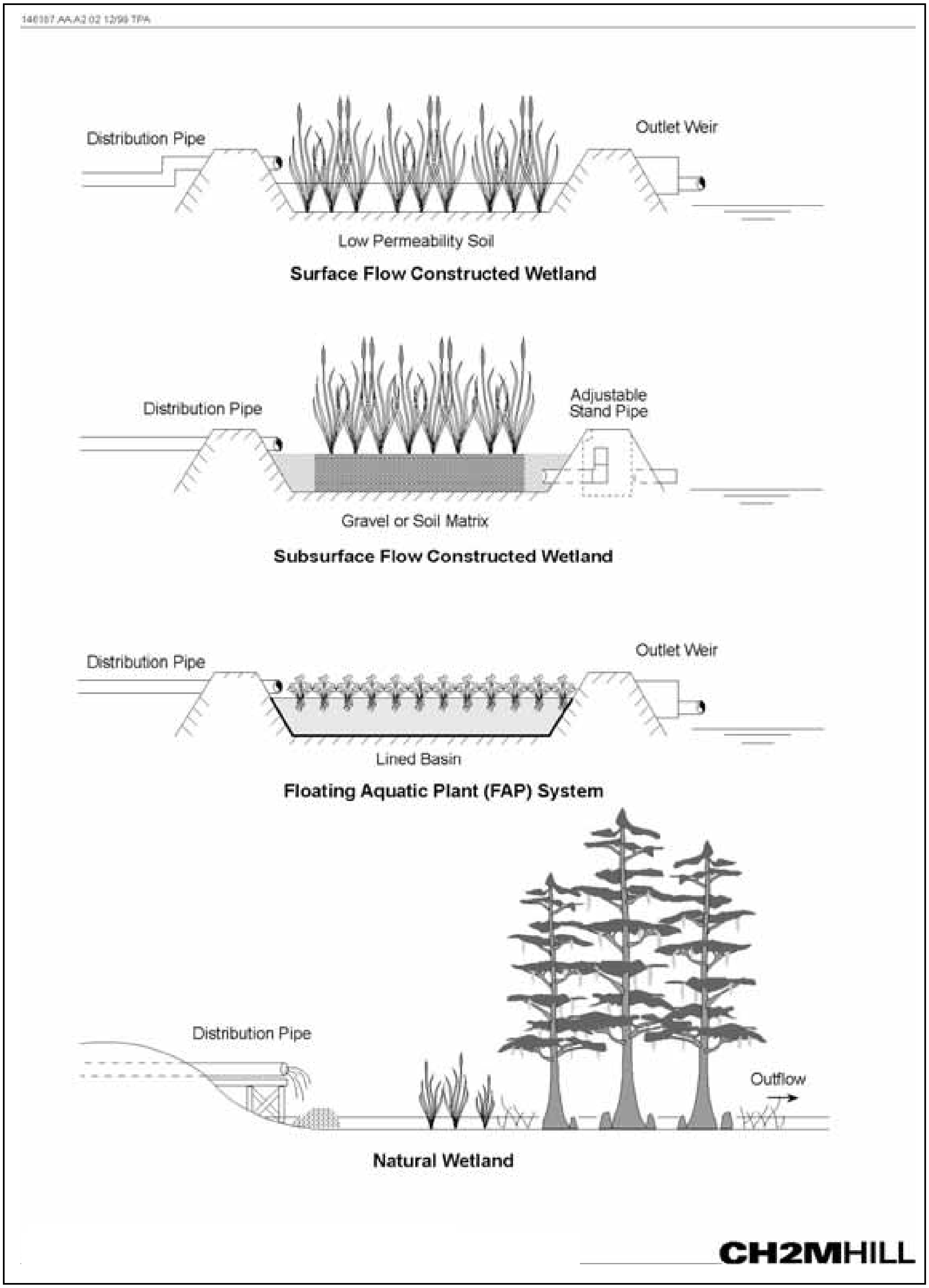


FIGURE 3-20
Types of Constructed Treatment Wetlands.

Other significant implementation issues for treatment wetlands are summarized in Table 3-21.

TABLE 3-21
Summary of Other Implementation Issues for Treatment Wetlands of Membrane Concentrate

Parameter	Discussion
Geographical and Climatic Relevance	Treatment wetlands have been used in a broad range of climates, arid to humid, tropical to far northern regions; more temperate climates are likely to have better year-round performance; more arid climates are likely to have higher evapotranspiration rates
Level of Water Utility Control	Level of control is moderate; water flow rate, depth, medium, and type and plant selection are the operable components of a treatment wetland
Membrane Cleaning Solutions	The wide-ranging capacity of treatment wetlands to address a range of constituents suggests that many cleaning solutions can be addressed in a properly designed wetland system
Proven Technology	Treatment wetlands are well-proven under a wide range of conditions for a number of organic and inorganic constituents, but the only available data specifically on concentrate are from the Oxnard study

Regulatory Issues

Regulatory issues for treatment wetlands are essentially the same as other surface water discharges in that they are primarily driven by water quality objectives established in NPDES permits at the state and federal levels. This includes protection of groundwater as well as surface water. A regulatory issue specific to the potential discharge of concentrate to an open marsh, whether constructed or natural, is the potential for protected species to reside within the wetland. While this could be considered objective proof of the functionality of the wetland, the potential exposure to inorganic contaminants, such as selenium, with known ecotoxicological properties would warrant specific consideration, and consultation with state or federal wildlife agencies would likely become necessary. Their input and approval to wetland operations and maintenance plans would provide assurance that the wetland could be operated as intended with no unexpected disruption.

Cost Issues

Capital Cost

The costs of a wetland can include engineering, preconstruction site preparation, and construction (e.g., labor, equipment, materials, supervision, indirect and overhead charges, and cost of land) (Mitsch and Gosselink, 2000). An overview of capital costs for treatment wetlands provided by Kadlec and Knight (1996) identified land costs, pumps, liner, planting, and complex structures as items that contribute to wetland costs. Median surface flow wetland costs were on the order of $20,000/acre, while median costs for a subsurface flow wetland were $145,000/acre (1993 dollars). Significant cost items were found to include earthwork, elaborate control structures, and detailed planting efforts.

Mitsch and Gosselink (2000) reviewed the construction costs of 16 treatment wetlands and noted a strong economy of scale, with small 1-hectare wetlands costing almost \$200,000/hectare, a 10-hectare wetland costing \$60,000/hectare, and a 100-hectare wetland costing about \$19,000/hectare. The following predictive relationship was suggested: $C_A = \$196{,}336\ A^{-0.511}$, where C_A is the capital cost of wetland construction per unit area (\$/ha) and A is the wetland area (ha).

These relationships provide useful initial approximations for wetland planning purposes, but diligence needs to be brought to costing a wetland project and detailed construction cost estimates need to be prepared using conservative unit costs derived locally.

O&M Cost

O&M of treatment wetland projects typically includes hydraulic system maintenance to ensure free flow into, through, and from the wetland, water quality monitoring of constituent loading and performance indicators, site vegetation maintenance and monitoring, and prevention of nuisance conditions, including vector management, such as mosquito control. Since no full-scale concentrate wetland system has yet been created, O&M costs can only be estimated from experience drawn from other treatment wetlands.

Kadlec and Knight (1996) provided general guidance on maintenance costs, ranging from \$1000 to \$2000/acre/year for subsurface flow wetlands to a median cost of \$285/m^3/day for surface flow wetlands.

For wetlands receiving membrane concentrate, given their proven potential to accumulate salts, the likelihood is high that the soils may need to be replaced at some point. This accumulation rate is not currently quantified but may be on the order of once every 20 years or more, if experience with conventional treatment wetlands applies (Sees and White, 2005). Prudent forecasts of long-term O&M costs may require inclusion of periodic soil replacement.

Cost of Lost Water

Concentrate discharged to a brackish treatment wetland could potentially have several fates, including runoff, evaporation, or percolation to groundwater. Uncontrolled runoff to surface water resources and percolation to groundwater would likely be prohibited. Controlled and regulated surface water discharge of treated water as described in this section would be available for other uses. The water evaporated from the concentrate is not lost to the hydrologic cycle, as would be the case for deep well injection, but nevertheless represents a 100% loss of potential potable water to the local area. Alternatively, water discharging from a treatment wetland may be treated with an additional membrane treatment process and the water recovered for beneficial use.

Economic Risk Factors

Economic risk factors for a concentrate treatment wetland are likely to be found in the currently experimental nature of this wetland technology application. Since no full-scale system has been constructed and operated for any length of time, special maintenance or refurbishment considerations have yet to be determined, if there are any. Given this, the largest economic risk factor is likely to be the need to remove wetland soils and replant because of the long-term accumulation of salts. Given the track record of conventional treatment wetlands, this interval may be on the order of 20 years or more. In this sense, the risk is low, given that treatment wetlands have been known to operate for at least 30 years and reportedly longer in some cases (Kadlec and Knight, 1996). The economic risk can be minimized by factoring in the costs of periodic wetland soil refurbishment. These economic risks can also be balanced against the economic benefits of providing wetland habitats, possibly as a recreational park, and the proven positive economic benefits of bird watching and natural history park destinations.

Human Health and Ecological Risk Factors

Human health risks associated with treatment wetlands are virtually nil, provided the site is well-maintained and nuisance conditions are avoided. Recent concerns about the potential for vector-borne diseases, particularly given the spread of West Nile virus, have focused on the need to include management activities in wetland O&M that minimize the population of mosquito larvae through larvicide application, vegetation management programs, and water level maintenance.

Ecological risk issues associated with treatment wetlands are similar to those for surface water or salt marsh discharge and for evaporation ponds. A corollary concern for treatment wetlands is that constituents should not jeopardize the effectiveness of wetland processes so that they reduce the functioning of the treatment wetland system below acceptable levels. Although treatment wetlands are useful when concentrations of bioaccumulative chemicals (such as selenium) are low, they are not appropriate when they may cause unacceptable levels of exposure to wildlife through the food chain (Lemly and Ohlendorf, 2002).

Effective mitigation measures could include the following:

- Preliminary treatment cell design to maximize water control and provide flexibility in water control structures
- Periodic long-term harvesting of cattail and excavation of sediments in initial cells to remove contaminants from the project site
- Removal and reestablishment of marsh plants by draining and drying vegetation and then removal by mechanical cutting or burning
- Maintaining open water channels within and adjacent to emergent vegetation stands to ensure predatory fish access to mosquito larvae. Spreader and collection canals designed to allow water movement within treatment cells can serve a dual purpose by providing this habitat.
- Raising water elevation periodically to reduce nesting areas to meet ecological risk goals; any water management actions require evaluation and balance with selenium removal requirements, because alteration of water levels may remobilize selenium
- Management of water, including flow patterns within and between checks, to avoid “dead spots” in which salinity and contaminants such as Se could become so highly concentrated as to compromise vegetative growth and Se treatment, while potentially increasing ecological risk
- Management of exotic species may be achieved through cutting, herbicide spraying, or burning and must be aggressively implemented to be successful.

Applicability to Other Salt Streams and Overall Basin Salt Management

Treatment wetlands may be broadly applicable to a wide range of concentrate streams, given the potential to select from a species list that includes a broad spectrum of salt tolerance. While there may be little reduction noted in TDS, measurable reductions in contaminants and conventional pollutants can be expected. Also, the potential for enhanced wastewater volume reduction through evapotranspiration and soil sequestration is significant and may be useful in managing basin-wide salt loads in surface discharges. Full-scale systems would need to be built and evaluated to determine their potential value in overall basin salt management.

Conclusions

Treatment wetlands represent a technology application that has been tested for several decades for treatment of conventional wastewater pollutants, but they have only been tested on an experimental scale for concentrate treatment. Preliminary results from published studies (e.g., Negri et al., 2003) and the preliminary results from the Oxnard study indicate that contaminant concentrations and total water volume can be reduced. Treatment wetlands clearly may have a role in reducing the concentrations of a number of constituents, such as selenium and nitrate, and are capable of reducing salt loads but are not capable of reducing TDS. The potential exists for treatment wetlands to function as a pretreatment technology before discharge to surface waters for these reasons. The creation of wetlands using treated concentrate could be a significant environmental enhancement where saline wetlands occur naturally.

OTHER BENEFICIAL AND NONTRADITIONAL USES

Other potential beneficial and nontraditional uses are discussed in this section, including stormwater and wastewater blending, recreational uses, mineral transport, subsurface storage, sodium hypochlorite generation, cooling water, and other direct uses of concentrate.

Stormwater or Wastewater Blending

Blending of concentrate with stormwater, or effluent from wastewater treatment facilities, could in some circumstances help reduce salinity-related effects of discharge of freshwaters to some estuarine or marine environments, particularly for small receiving water bodies where the discharges represent a significant portion of the ambient water flow. This novel approach to concentrate use would require careful analysis of variability in discharge and receiving water quality to determine beneficial blending ratios, receiving water benefits, and ultimate compliance with surface water standards. Blending with continuously discharged WWTP effluent could reduce the necessity of potentially cost-prohibitive storage for blending with stormwater runoff.

Recreation

Potential recreational uses of concentrate are likely in most cases to be a subset of irrigation and wetland reuse alternatives. As described previously, this could include irrigation of highly salt-tolerant turf grass species on golf courses, soccer fields, or other recreational areas. Salt marshes and wetland areas could also provide recreational benefits such as bird-watching. Issues associated with these options were discussed in this chapter under land application and irrigation, wetland creation and restoration, and constructed wetlands treatment.

Transport of Mineral Resources

Concentrate could potentially be beneficially used as a carrier for mineral resources. In Arizona, Mojave Power (Southern California Edison) uses water to transport coal as slurry through a pipeline from the Black Mesa Mine operations. The plant separates the water from the coal and uses both in their operations. For this particular operation, it would not be economically feasible to use concentrate for the slurry, as the mine location is remote (approximately 120 mi from Flagstaff, AZ). The operation uses water found near the mine as a carrier (Guy Leary, Salt River Project, personal communication).

Transport of mineral resources could be a beneficial use, but logistics are not likely to be favorable, due to the remote nature of most mining operations. In addition, this would not constitute final disposal, as after separation of the mineral resource, the concentrate would still require disposal.

Subsurface Storage

Subsurface storage to allow later recovery and reuse, especially for concentrates with 10,000 mg/L of TDS or less (NRC, 2004) may be a potential option where local geological conditions are favorable. Even a concentrate with 10,000 mg/L of TDS is still 99% pure water, a resource worthy of preserving and accessing as freshwater supplies become increasingly scarce (NRC, 2004). A major constraint is the fact that typical RO concentrates have constituents at or near saturation, and direct recovery of additional water would require expensive treatment to recover additional potable water. A better understanding of geochemical and hydrological issues is needed to implement this type of approach (NRC, 2004).

Salt dome deposits in some areas may be suitable for concentrate disposal and/or storage (CASS, 2005). High-quality sodium chloride is extracted by Morton Salt from the Luke Salt Deposit in Arizona by solution mining (CASS, 2005). Limitations to concentrate storage at the Luke Salt Deposit include the following (CASS, 2005): (1) the capacity created by mining operations each day only amounts to 66,000 gal; (2) although they work well for gas storage, salt domes may not work well for concentrate; (3) Morton Salt has concerns over possible hazardous constituents in the brine. Therefore, concentrate disposal to the Luke Salt Deposit does not appear feasible.

Feedstock for Sodium Hypochlorite Generation

Concentrate typically contains abundant chloride, which could potentially be used as part of an electrolyte solution to produce sodium hypochlorite (NaOCl), although there are a number of significant technical and economic limitations. The use of concentrate as a feedstock for generation of hypochlorite for disinfection is an area of current research.

The City of Phoenix is cooperating in a USBR–Carollo study (cooperative agreement no. 02-FC-81-0757) titled *Making RO More Cost Effective: Innovative Scale Inhibitors for Recovery Maximization and Beneficial Use of RO Concentrate*. The project includes an evaluation of a new hypochlorite generation technology that may provide a way to convert concentrate into other valuable chemicals for application at existing or future water or wastewater treatment plants. Investigators acknowledge that the hypochlorite generation component of the study has the least likelihood of success (<50%). A marine-class hypochlorite generator (U.S. Filter) and a Klorigen chlorine generator will be evaluated in the study.

Hypochlorite generators are commonly used at desalination and power plant intakes to control biofouling without requiring the handling of chlorine or other hazardous chemicals. On-site generation of hypochlorite from seawater is typically the most cost-effective means of controlling biofilm, pathogen, algae, and mussel growth for both power and desalination facilities (Electrochlor, 2001). Seawater is often used for hypochlorite generators at coastal desalination plants. A relatively low-concentration product (~0.8%) is typically produced, which is usually only used on site. It is unlikely that it would be economically feasible to export hypochlorite from this type of facility. Inland industries employing on-site generation use a brine mixer, preparing a brine solution from dry salts and softened water (Electrochlor, 2001).

It is noteworthy that established industries that produce hypochlorite as a surplus by-product typically find it difficult to sell or otherwise dispose of their surplus by-product because it falls outside the established commercial distribution channels. Existing commercial producers have dedicated production facilities and usually produce hypochlorite in response to consumer demand. By-product producers would probably not have guaranteed outlets for their hypochlorite, but were these guaranteed outlets developed, it is likely that a situation would arise in which hypochlorite production would be required to meet contractual obligations, even though insufficient RO concentrate was being produced. This would put the by-product producer in the position of having to decide whether to be a commodity manufacturer or a water utility. Small-scale production of sodium hypochlorite is uneconomical because of its status as a commodity.

Major limitations to the production of hypochlorite from concentrate include the following:

- The composition of the concentrate would be critical for proper hypochlorite generation and to avoid scaling. Concentrates are typically supersaturated with sparingly soluble salts, and use of concentrate for hypochlorite would require that the solution be stabilized (i.e., softening, silica removal).
- The relatively low concentrate chloride concentrations would limit yield.
- In most (probably all) NF/RO systems with high scaling potential, the idea of using concentrate for hypochlorite generation would not be economically feasible, as the pure dry salts typically used for on-site generation are relatively inexpensive.
- Conversion of bromide to bromate would be a concern for potable water.

In general, the use of concentrate as a feedstock for sodium hypochlorite generation is not likely to be economically viable for anything other than on-site use by seawater desalination facilities.

Cooling Water

Colocation of desalination plants with coastal power plants is common in some parts of the world. Concentrate is blended with cooling water discharge through a common outfall, providing dilution of concentrate constituents. Benefits include obtaining power at wholesale prices, increased water temperatures for desalination if power plant discharge is used for the water plant intake, reduction of the thermal plume from the power plant, security, compatible land use, and utilization of common intake and discharge infrastructure (WDTF, 2003b; 2003c). For example, a 50-MGD seawater RO plant has been proposed near Carlsbad, CA, that would be colocated with a power plant that withdraws 600 MGD. The resulting blended flow would have 36,200 mg/L of TDS, approximately 8% above ambient seawater (WDTF, 2003a). The Tampa Bay desalination facility in Florida also is blended with the discharge of cooling water from a power plant, reducing salt concentrations considerably.

Constraints may include mismatches between the operational schedule of the power plant and the desalination facility, mixing within the outfall, and the relicensing or elimination of once-through cooling for power plants (WDTF, 2003a). There are major ongoing efforts to reduce the extent of once-through cooling (WDTF, 2003b), although colocating may provide a rationale for continuation of once-through cooling (WDTF, 2003c).

Membrane concentrate could be an additional source of cooling water for many processes, but because cooling tower discharges also face a number of restrictions, this application would likely be very limited. Moreover, as concentrations increase through evaporation, cooling towers must regularly replace (blowdown) a portion of the volume to prevent scaling. Many concentrates are at or near saturation of some salts and would therefore have limited value as cooling water.

Power plants near the Colorado River are required to be ZLD and, therefore, these plants may be more capable of making use of concentrate for cooling water than plants in other areas without ZLD technology in place (M. Mickley, personal communication).

The Palo Verde nuclear power generation station at Wintersberg, AZ (about 34 mi west of Phoenix) takes water from the 91st Avenue Wastewater Treatment Plant and uses it as a cooling water source (Guy Leary, Salt River Project, personal communication). The blowdown from the cooling towers is discharged to evaporation ponds. It is the largest nuclear energy-generating facility in the United States, and it is the only nuclear energy facility in the world that uses treated sewage effluent for cooling water. This project is relevant to concentrate disposal because a number of facilities using desalting membrane technologies discharge their concentrate to sewers that flow to the 91st Avenue facility, and their concentrate passes through the towers and ultimately to the evaporation ponds (CASS, 2005). Several additional communities in the area are considering brackish groundwater treatment and concentrate disposal via the same conveyance for Palo Verde (CASS, 2005). Therefore, the beneficial use of cooling is accomplished through first blending concentrate with wastewater. As a result of the high TDS in the wastewater, only a limited number of cycles are possible (CASS, 2005).

Dust Control and Deicing

Dust control on unpaved roads is a potential use where concentrate could substitute for much of the water and at least a portion of the salts (Morales and Smith, 2004). Salts and salt solutions are also commonly used for deicing of roadways and runways. Dust control agents include $CaCl_2$ and $MgCl_2$ (Morales and Smith, 2004), major components of many concentrates. The main reason magnesium chloride and calcium chloride are used for dust control is that they are hygroscopic (adsorb moisture from the atmosphere), thereby keeping dust moist during dry periods. Brines high in sodium chloride do not have this same attribute and likely would be of limited value for dust control. Consequences of accumulating nonhygroscopic salts such as sodium carbonate in surface soil are evident in the salt-dust problem on the salt flats of Owens Lake, where salt dust becomes airborne during certain seasons of the year (see Appendix B). Colorado prohibits the use of concentrates for dust suppression and deicing, and in California, each new deicing product (i.e., every individual concentrate) must undergo expensive health and environmental testing (M. Mickley, personal communication). Moreover, a very high number of road miles would be required to dispose of even 1 MGD of concentrate (M. Mickley, personal communication).

In summary, the mixed salt nature of most concentrates, environmental restrictions, and large volumes make it highly unlikely that concentrate could successfully be used for dust suppression or deicing. If pure salts can be recovered, such as $CaCl_2$ or $MgCl_2$ (Chapter 4), dust control and deicing could be beneficial uses.

Other Direct Uses of Concentrate

There are no general uses for mixed salt solutions, although there may be rare cases where concentrates consist predominantly of one or two salts (M. Mickley, personal communication). Magnesium carbonate, sodium carbonate, and sodium hydroxide could potentially be recovered from brine solutions such as concentrate, and if this were accomplished without complete dewatering, the economic advantages would be considerable (Ahuja and Howe, 2005). This is an area for future research, but it does not represent a viable, proven technology for disposal of concentrate. Magnesium carbonate trihydrate (nesquehonite) is produced from magnesium hydroxide and carbon dioxide as part of the lime-magnesium carbonate process for softening seawater. This chemical could be used to precipitate calcium from seawater as effectively as sodium carbonate. The market value of magnesium carbonate trihydrate is not established because it is not currently available through commercial channels.

Although sodium carbonate production from RO reject has been suggested, the complexity of the production process would be a deterrent to serious consideration. Production of sodium hydroxide also might be technically possible; however, the most current technology, which is based on membranes, requires use of very pure sodium chloride solutions. Although theoretically and technically possible, it is highly unlikely that production of these byproducts would result in viable outlets for RO reject.

The only potential exception to the lack of direct uses of mixed salt solution (i.e., concentrate) that has been identified are the products of one company, Virotec. This firm has an interest in potentially colocating industrial facilities along the Texas Gulf coast that would use concentrate from seawater desalination projects (Bill Asher, Virotec International, personal communication). They require 2–4× seawater concentrations for their products.

CHAPTER 4

SALT SEPARATION OF MEMBRANE SYSTEM CONCENTRATE*

INTRODUCTION

The concept of recovering individual salts from concentrate was examined to evaluate its potential as a concentrate disposal option. Previous studies and presentations (Mickley, 2004b; 2005) have introduced and discussed the concept in general terms. The present study was undertaken to provide a more focused consideration of issues involved.

Geo-Processors (now Geo-Processors USA, Inc.) claims to have successfully and commercially recovered and sold a wide variety of salts from many different waters in Australia and other countries, and they are intent on demonstrating their technology in the United States. Documentation independent of Geo-Processor materials is generally lacking. The technology appears to exist to accomplish the salt separations and recovery, but the commercial viability for site-specific applications is uncertain.

The present analysis shows that there are many applications for the major salts obtainable from concentrates and that many of the salts have sufficient value to make their sale economically attractive. The feasibility of a site-specific operation to recover and market salts, however, depends on several factors, including the following:

- Volume of concentrate
- Water quality (salts obtainable from the concentrate)
- Quality (form and purity) of salts obtained
- Reliability and consistency of salt quality
- Types of applications for the obtainable salts (types of markets)
- Existence of a local market
- Size of the local market
- Reliability of the local market
- Combined income from sale of the different salts

Each site-specific consideration of the concept will require a feasibility analysis to address these and other issues prior to commitment to the concept. It is also important to note that market value is not directly related to economic feasibility. A sufficient mass of salts must be available to make processing and recovery feasible. There is likely a fundamental conflict that must be resolved between the economic structures of the function of producing water as a utility and producing salt or other by-products as price-variable commodities.

There is a need for development of value-added products that utilize salts removed from concentrate to uncouple feasibility from dependence on existing markets, and this likely remains a significant challenge.

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*This Chapter was authored by Dr. M. Mickley, Mickley & Associates.

In general, salt separation and marketing of salts hold considerable promise to provide concentrate disposal solutions for many locations, including locations in the arid Southwest United States, where desalination plants are not being built due to the lack of a cost-effective concentrate disposal solution.

Of importance beyond providing cost-effective concentrate disposal solutions, the separation of salts and their marketing is a strong step toward achieving a sustainable, environment-supporting solution where water recovery is maximized and salts are recycled.

BACKGROUND

The Reason for Consideration of Salt Separation

There are locations, particularly in the arid Southwest United States, where desalination plants are not being built due to the lack of cost-effective concentrate disposal. The consideration of selective and sequential salt removal from concentrate and marketing of the salts has resulted from the logical consideration of and elimination of other concentrate disposal options for these locations. It is also an approach with the benefit of maximizing water recovery and ultimately represents a sustainable solution, an important goal.

An analysis of disposal options (M. Mickley, personal communication) for the Phoenix area suggested the following:

- Conventional disposal options are not available or cost-effective. This includes surface water disposal, disposal to the sewer, deep well injection, land application, and evaporation ponds.
- Concentrate, in general, does not have any use that also serves as a means of disposal. Beneficial use of concentrate (as concentrate) does not necessarily solve the concentrate disposal challenge.
- If concentrate is processed in a conventional ZLD scheme to obtain solids, the mixed salts obtained from concentrate, in general, do not have any use and thus must be landfilled at considerable cost.
- Commercial ZLD technology (thermal brine concentrators, not presently used for treating municipal concentrate) are very energy-intensive and have high operating costs, and they are thus also not cost-effective.
- The use of commercial volume reduction technologies (such as high-recovery RO systems) prior to brine concentrators can lower capital costs significantly but still results in high operating costs due to high chemical usage and high solids disposal costs.

In the long term, reducing ZLD processing costs will lower the water production costs associated with further processing concentrate and disposing of the solids, that is, achieving a disposal solution. Improvements in desalination technologies that can be incorporated into ZLD processing schemes are the subject of research and will in time have this impact. In the short term, recovery and sale of individual salts may be the only option to significantly reduce operating costs and thus impact the total cost associated with disposal. The practicality of this possibility has been given considerable support by the identification of an Australian (now a U.S.) company—Geo-Processors USA—that reports to have successfully done this in several commercial ventures on a wide range of waters outside the United States. It is recognized that water production is in the realm of a critical utility, whereas salt production and sale rates as a commodity. It is inevitable that at some point water production will need to continue with no significant market for the salt that could be produced. Consequently, there will always be a need for brine or salt disposal capabilities, if only as a backup to commercial distribution of recovered products.

There is also a larger need being served by consideration of individual salt recovery. Landfills, even if they were a cost-effective means of disposing of salts, may at some point become point sources of pollution. The counterargument in terms of sustainability is that if lined cells are used, landfilling is a sustainable practice for at least the near future. The mass per volume of salt disposed in landfills is considerably less than that of typical solid waste, for which we have no alternative. The only truly sustainable solution to concentrate disposal over the long term is recovery of most of the water and recovery and use of the salts. The recovery of most of the water is highly desirable in regions of limited water resources.

The key questions then become: (1) Can separation of salts lead to high water recovery at a reasonable cost? (2) Can the recovery of individual salts lead to cost-effective concentrate disposal solutions? This report addresses various aspects of this question.

Salts Recoverable from Concentrate

As water is evaporated from a mixed salt solution, salts will precipitate (or be removed from solution) in a sequence, according to their solubilities and propensities for coprecipitation and adsorption. This precipitation aspect is dependent on the particular salt solution, temperature, pH, residence time, agitation, presence of other species such as antiscalants, and other variables. Control of salt form in terms of crystal size, morphology, and purity, for example, is a complex function of such variables and an important consideration in defining a technical approach to produce the salts.

A general sequence of common salt precipitations is obvious from experience with RO, thermal brine concentrators, and crystallizers. RO is limited by the precipitation of sparingly soluble salts that include calcium carbonate, silica, and calcium sulfate. Use of antiscalants (and historically acid) have allowed operation past the saturation level of such sparingly soluble salts. With higher-quality waters, when extensive pretreatment has removed the limitation due to sparingly soluble salts, osmotic force becomes the limiting factor for second-stage RO recovery. With brackish sources, a limitation due to sparingly soluble salts may still exist even with extensive pretreatment. Practical limits on pressure to overcome osmotic forces result in second-stage (or seawater) RO concentrates in the range of 65,000 to 75,000 mg/L. Thermal brine concentrators that frequently process concentrates and other wastewaters are limited by the formation of sodium sulfate and sodium carbonate precipitates. They typically produce brine in the range of 180,000 to 230,000 mg/L. Crystallizers operating on the brine from thermal brine concentrators will precipitate Na_2CO_3, Na_2SO_4, and NaCl but require a blowdown stream for the highly soluble $CaCl_2$ and $MgCl_2$ salts.

From this general consideration, one can see the promise of sequential and, thus, selective removal of salts from solution, with a likely sequence being as follows:

General Solubility Level	*Salt Example(s)*
Sparingly soluble salts	Calcium carbonate, calcium sulfate
Moderately soluble salts	Sodium carbonate, sodium sulfate
Soluble salts	Sodium chloride
Highly soluble salts	Calcium chloride, magnesium chloride

Prediction of the salt precipitation sequence in terms of amounts corresponding to physical and chemical conditions is difficult. Most software programs are limited in one or more ways, in part due to the fact that they were not designed to perform these calculations and that many double salts are poorly characterized and seldom encountered. Software used for estimating possible membrane system recovery with antiscalant use is limited in terms of the different salts included, the salinity range, accuracy (due to the inclusion of safety factors), and difficulty of incorporation into an iterative calculation necessary for defining the precipitation path.

Better suited for precipitation path calculations are various geochemical speciation programs that are used to determine how a given water will separate into liquid and solid phases. These programs are also limited, however, in that they (with few exceptions) do not predict the pH change that takes place upon precipitation involving carbonate species, are limited in terms of salinity range, are generally difficult to use, and are also not suited for sequential application to predict the precipitation path of a solution as it becomes more concentrated. There have been few published studies of the predictive capability of the software programs (Bourcier et al., 1996; Huff, 2004) to predict precipitation pathways, including amounts precipitated and effects of pH and other factors.

While there may be minor salts of high value (Dirach et al., 2005) that would shift the economics of concentrate disposal through their recovery, the present review is focused on the removal of bulk salts that offer the opportunity for improving the cost-effectiveness and lessening the environmental impact. Table 4-1 presents a list of major salts, abstracted in large part from the website of Geo-Processors USA (www.geo-Processors.com). The individual salts are listed along with several application areas for each salt. Some of these application areas will be discussed in a later section.

TABLE 4-1
Major Salts and Application Areas

Chemical Formula	Name	Some Application Areas
$CaCO_3$	Calcium carbonate	Paper coating pigment; filler for plastics and rubbers, special inks, paints, and sealants
$CaSO_4 \bullet 2H_2O$	Gypsum	Remediation of sodic soils; manufacture of building products
$CaSO_4 \bullet 2H_2O + Mg(OH)_2$ Slurry	Gypsum magnesium hydroxide	Wastewater treatment; pH buffering; soil conditioner for sodic soil
$CaCl_2$ (liquor)	Calcium chloride	Dust suppression; road base stabilization; sodic soil remediation; cement and concrete stabilizer; construction industry
$KNaSO_4$	Glacerite	Potassium fertilizer
$Mg(OH)_2$ Slurry	Magnesium hydroxide	Water and wastewater treatment; environmental; animal stock feed; feedstock for magnesium metal production; fire retardants and refractories; acid neutralization
$xMgCO_3 \bullet yMg(OH)_2 \bullet zH_2O$	Magnesium carbonate light	Fire retardant; feedstock for magnesium metal production; filler for paper manufacturing, rubber, and paint
NaOH	Caustic soda	Many applications industrially; basic feedstock for chemical processes, pH adjustment, etc.
NaCl	Halite	Food and industrial processes; chloralkali production; many industries require bulk salt supply
Na_2CO_3	Soda ash	Water treatment; chemical industry;
Na_2SO_4	Thenardite	Surfactant manufacture; detergent manufacture; glass manufacture; remediation of calcareous soil
NaOCl	Sodium hypochlorite	Disinfection; chemical industries; pool chlorine
$NaClO_4$	Sodium chlorate	Paper bleaching; chemical industries

The particular salts potentially recoverable from a given concentrate depend on the water quality of the concentrate and the processing scheme. Typically not more than five salts are recovered in a given scheme. Examples include the following:

San Joaquin Valley Drainage Water (current pilot project)

- Chemistry is dominated by sodium sulfate.
- Sequential recovery of gypsum ($CaSO_4$), glacerite ($KNaSO_4$), and NaCl
- Highly concentrated “bitterns” (at a concentration of 400,000 mg/L) might be used as a source of nitrate and boron (applied at low rates per acre); however, high selenium levels in the source water are problematic.

San Joaquin Valley Drainage Water (proposed scheme of Geo-Processors) (Geo-Processors, 2005)

- Chemistry is dominated by sodium sulfate.
- Sequential recovery of gypsum, magnesium hydroxide [$CaSO_4 \bullet 2H_2O + Mg(OH)_2$], precipitated $CaCO_3$, and Na_2SO_4
- Highly concentrated bitterns may be reused or recycled as described above

Wagga-Wagga, Australia: Treatment of Well Water (application by Geo-Processors) (Geo-Processors, 2005)

- Chemistry dominated by bicarbonate; low sulfate
- Sequential recovery of $Mg(OH)_2$, NaCl, and $CaCl_2$

Wyoming: Treatment of CBM Produced Water (proposed scheme of Geo-Processors) (Geo-Processors, 2005)

- Chemistry is dominated by high bicarbonate; relatively high sodium (low sulfate)
- Sequential recovery of precipitated $CaCO_3$ and Na_2CO_3

EXISTING SALT SEPARATION EFFORTS AND TECHNOLOGIES

A review of the literature reveals that the terms most frequently used to describe individual salt recovery from solutions are “fractional crystallization” and “fractional precipitation.” Fractional crystallization is discussed in geology texts as the process by which magma produces crystals that then separate from the original magma, so that the chemical composition of the magma changes with each generation of crystals, producing igneous rock of different compositions. Fraction crystallization and fractional precipitation are both laboratory and industrial techniques. Sometimes distinctions appear where fractional crystallization is referred to as the situation in which one or more ions in a mixture are precipitated by changing salt concentrations in solution through evaporation or temperature control. In contrast, fraction precipitation is described as adding a precipitating agent to selectively remove an ion from solution. Other references associate fractional precipitation with all these actions as utilizing temperature, pH, added salts, and salinity as tools.

The literature contains many references to the production of individual salts, such as NaCl, potash (KCl), the refining of sugar, the separation of radionuclides from salts, etc. Very few of the references involve recovery of multiple salts from process concentrates or brines.

Some more pertinent and representative literature offerings include the following:

- The 1999 final report entitled *Salt Utilization* from the San Joaquin Valley Drainage Implementation Program and the University of California Salinity/Drainage Program: This major study looked at the removal of the major component of salt in the San Joaquin Valley, sodium sulfate, and the recovery of selenium from agricultural drainage waters. Processing technologies, salt markets, and research needs were defined. The conclusion was that the opportunity exists to utilize salt and selenium as commercially viable resources; however, this was not one of the approaches taken forward in the full-scale implementation of the program.
- A 2005 article in *Desalination* entitled “Salt Production from Coal-Mine Brine in ED-Evaporation-Crystallization System” by Turek et al.: This study considered removal of $CaSO_4$ and $Mg(OH)_2$ from brine by utilizing ED/EDR technology as pretreatment to a conventional ZLD system of a brine concentrator followed by a crystallizer. The study

focused on the role of the ED/EDR pretreatment and preconcentration system on reducing energy requirements and increasing the purity of separated salts.
- A 2005 article in *Desalination* entitled “Extraction of Strategic Materials from the Concentrate Brine Rejected by Integrated Nuclear Desalination Systems” by Le Dirach et al.: This paper focused on the recovery of valuable elements from seawater desalination concentrate. Elements of interest were identified, processing approaches were evaluated, and future experiments were planned.

Common elements to most literature studies include a specific site focus and a research and developmental aspect.

In contrast, there are two groups that have been taking a broader, more comprehensive approach in consideration of salt recovery from various waters: Superior Salt Company (Gerald Grott) and Geo-Processors USA (Aharon Arakel).

Gerald Grott and Superior Salt

Gerald Grott is a pioneer and visionary in the area of utilization of salts obtained from concentrate, drainage water, produced waters, and other wastewaters for use in a variety of applications. Some of his publications date back more than 50 years. His extensive background in producing and working with salts has made him a strong advocate for solving problems characterized by salinity and soil issues. This includes the following:

- Tailoring the irrigation and remediation water to meet the needs of the local soil
- Using salts to remediate sodic (high-SAR) soils
- Increasing the rate of infiltration of soils to limit loss of rainfall through evaporation
- Using higher-salinity water where possible for soils with good SAR and hydraulic conductivity
- Using salts derived from concentrate and other wastewaters for dust suppression, soil sealing, and soil stabilization

He carries a broad vision of needs and potential solutions and is actively involved in making these more visible through written and personnel communications, patents, and projects. One of the more recent and continuing efforts involves the development of an ion exchange “hardener” (as opposed to a softener) that replaces sodium with calcium. Such technology could be used to remediate sodic soils (G. Grott, personal communication). Review of material available from Mr. Grott is imperative for those concerned with salt applications and salt recovery.

Aharon Arakel and Geo-Processors USA

It appears that Geo-Processors is the only group that has systematically developed an approach and the necessary technology to treat virtually any water or wastewater for the purpose of obtaining salts for markets (Geo-Processors, 2005). As part of this, Geo-Processors has developed nonsolar technologies that could be applied without regard to climate and location. Such nonsolar technology is also necessary for fine control of salt product form and purity. They have developed a water classification system and typically examine several alternative processing schemes to tailor processing and salt production to local salt market needs. Geo-Processors claims to have commercially successful projects in Australia and other countries, but rigorous documentation is lacking, and criteria for commercial success have not been defined. Recently, Geo-Processors moved its operation to the United States, and they are preparing to demonstrate and apply their technologies to the treatment of concentrate, produced waters, drainage, and other waters.

Dr. Arakel carries a broad, big-picture understanding and vision of salt and salinity issues, and he has been active in making his understanding visible through presentations, patents, publications, and projects. His vision includes development of sustainable long-term solutions to solve environmental problems beyond providing cost-effective technical solutions.

MARKET NEEDS

A general review of salt prices is provided in this section.

Table 4-2 includes prices from the June 6, 2005, Chemical Market Reporter (www.chemicalmarketreporter.com). It shows prices for different grades of several salts along with the per weight price range.

A qualifier was provided by the Chemical Market Reporter with these costs:

> *These chemical prices are list, unless otherwise specified. These listings are based on pricing information obtained from suppliers. Posted prices do not necessarily represent levels at which transactions may have actually occurred, nor do they represent bid or asked prices. Price ranges, as indicated by the two columns, may represent quotations from different suppliers, as well as differences in quantity, quality and location. Although prices are reported as accurately as possible, they do not carry any guarantees. The prices are intended as a benchmark for Chemical Market Report readers and are not to be used as a basis for negotiations between producers and customers.*

Sodium chloride and calcium sulfate (gypsum) (not listed in Table 4-2) are among the lower-valued salts and typically cost under $20/ton. In terms of evaluating the overall economic potential of marketing separated salts, it is important to note that NaCl is the dominant salt in seawater concentrate, and gypsum is typically the first or second most predominant salt in brackish groundwater concentrate. The treatment of calcium sulfate-dominated brackish groundwater concentrate, however, does not imply that calcium sulfate will be a produced product. Other calcium salts can be recovered through the addition of inexpensive salts to produce desired salts.

Typical costs of landfilling solids range from $30 to $60/ton. To illustrate the swing in operating costs possible due to recovery and sale of salts, consider the case where (1) the total income from sale of salts averages $60/ton based on all the salts produced, (2) the local landfill cost is $60/ton, and (3) the concentrate is 1 MGD in volume with a salinity of 4000 mg/L.

TABLE 4-2

Salts and Market Prices

Name	Description[a]	Price Range, $
Calcium Carbonate	(Ground) dry, coarse (9–17 μm), bags, bulk, t.l.	60–66/ton
	(Ground) medium (4–9 μm), bags, t.l.	95–100/ton
	(Ground) fine (0.5 μm), 50-lb. bags, t.l., f.o.b., works	230–280/ton
	Precipitated, tech. (0.5 μm), 50-lb. bags, t.l., f.o.b., Adams, MA	264–350/ton
	Ultrafine (0.05–0.5 μm), 50-lb. bags, f.o.b., works	0.43–6.2/lb
	Surface treated, tech., 50-lb. bags, f.o.b., Adams, MA	0.205/lb
Calcium Chloride	Conc. reg. 77–80%, flake, bulk, c.l., works	200/ton
	Conc. reg. 77–80%, flake, 50-lb. bags, paper, plastic, works	250–280/ton
	Anhyd. 94–97%, flake or pellet, bulk, c.l., works	275/ton
	Anhyd, 94–97%, flake or pellet, 50-lb. bags, c.l., works	346–354/ton
	Anhyd. 94–97%, flake or pellet, 50-lb. bags, works	0.35/lb
	Liq. 35% basis, t.c., t.t.	132–153/ton
	Liq. 45% basis, t.c., t.t.	160–175/ton
Magnesium Hydroxide	Slurry, technical, dms, t.l., l.t.l., f.o.b.	238–250/dry ton
	Powder, technical, dms, bags, t.l., f.o.b.	0.45/lb
Sodium Carbonate	Dense, 58% Na_2O, 100-lb. paper bags, c.l., works, f.o.b.	152–159/ton
	Dense, 58% Na_2O, bulk works, f.o.b.	127–135/ton
	Light, 58% Na_2O, 100-lb. paper bags, c.l., works, f.o.b.	188–215/ton
	Light, 58% Na_2O, bulk, works, f.o.b.	176/ton
Sodium Sulfate	East bulk, c.l., works, frt., equald.	115–130/metric ton
	Gulf bulk, c.l., works, frt., equald.	110–135/metric ton

[a] Abbreviations: anhyd., anhydrous; c.l., carload; conc., concentrate; f.o.b., free on board; frt., freight; liq., liquid; tech., technical; t.c., tank car; t.l., truckload; t.t., tank truck; l.t.l., less than truckload.

The total amount of salts obtainable from the concentrate in 1 year is 12.2 million lb. To landfill this amount of solids (neglecting additional solids produced due to chemical treatment of the concentrate to produce the solids) at $60/ton would cost more than $365,000/year.

If instead the solids could be sold at an average price of $60/ton, they would bring an income stream of $365,000/year. If the average salt price were $180/ton, the income stream would be over $1.3 million/year. Assuming these salts were derived from concentrate produced from a brackish RO plant operating at 5 MGD product flow, this income ($365,000/year) would be equivalent to $0.20/kgal, which represents a substantial offset of typical O&M costs. Better documentation is needed, but is not yet available, of the additional capital and O&M costs needed to concentrate, precipitate, and produce a salable salt, for comparison with this income stream.

NEED FOR ADDITIONAL TECHNOLOGIES

General Processing Schemes

The processing steps of selective salt recovery serve to concentrate and treat the solution in a series of steps to obtain the individual salts in their desired form (this being dependent on the marketable use in question). Concentration steps bring the solution near the point of precipitation for the salt. The treatment steps involve causing the salt in question to precipitate and to be recovered in a desired form and purity.

Where multiple salts are recovered and where they have a wide range of solubilities, the processing may involve a series of alternating concentration and treatment steps. The initial steps recover the salts of lowest solubility; the final steps recover the salts of highest solubility. The concentration (desalination) steps have included RO, NF, ED/EDR, thermal evaporation, crystallization, evaporation ponds (including enhanced evaporation ponds), and solar ponds. The treatment steps have included such operations as pH adjustment, chemical addition, temperature control, thickening, washing, etc.

Some salts whose market values are low (some forms of NaCl, $CaSO_4$, etc.) cannot be cost-effectively processed by equipment-intensive processing schemes. These salts are more typically recovered by solar pond treatment of specialized water and wastewater high in the salt of interest. This becomes a climate-dependent and land-intensive process not suitable for most locations.

While there are some applications of crude salts of lower quality, many applications require salts to meet quality specifications that may include form, size, and purity. Salts obtained from the initial precipitation may need to be washed to remove surface impurities and even redissolved and then recrystallized or reformed to remove “bubbles” of impurities of highly soluble salts. This processing also allows control over crystal size. Reformed NaCl is produced from crushing, grinding, and dissolving NaCl crystals and then crystallizing under very controlled conditions that usually mean indoors, away from the influence of climate. This “refinement” of salt quality adds value to the salt at the expense of additional production cost.

In general, there is a need for equipment and processing not dependent on climatic changes (temperature, rainfall) to allow accurate control of salt characteristics to meet product specifications. This is typically not possible with solar ponds.

Geo-Processors has such a technology and has applied it to a variety of situations. Some details and insights into Geo-Processors’s technology are available in their patents. While the exact processing conditions and treatment sequence for a given salt recovery operation are not evident from the patents, it is apparent the key to their success is a detailed and in-depth understanding of the many possible chemical reactions that can take place, including how the reactions are affected by temperature, pressure, pH, and other salts and chemicals present. This understanding allows for precise control and tailoring of processing conditions for a wide range of water qualities and salts. Surface waters often have varying surface water chemistry, and it is uncertain whether or to what extent these variations have in controlling the process.

For any new technology to be suitable for broad application to salt production, it must allow for considerable control over processing conditions. As with all processes, improvements can be achieved via reduction in processing throughput (decreased residence time) of each processing step. This reduces the equipment size and likely the footprint of the technology.

MARKET AND ECONOMIC ANALYSIS

Different Markets and Challenges

In this section, various marketing challenges are identified and discussed. It is helpful to distinguish different types of salt markets.

Existing Markets for Individual Salts (Type 1 Market)

In a type 1 market, salts are produced for an existing use with the salts representing an alternative source for the established market. Examples include NaCl for various uses and $MgCl_2$ and $CaCl_2$ for dust suppression and deicing. The marketing challenges include the following:

- Meeting product specifications (purity, form and size, etc.)
- Cost competitiveness
- Competing in the local market
- Saturating the local salt market

Potential Markets for Individual Salts (Type 2 Market)

In a type 2 market, salts are produced for an existing use, but one for which the market has not been realized. An example might be where the application is good, but other less expensive and perhaps less beneficial products are entrenched. A soil remediation example is the use of more-beneficial $CaCl_2$ for sodic (high-SAR) soils where gypsum is cheaper and well-accepted. In addition to the marketing challenges just mentioned, there are additional challenges when the application of salts has promising benefits and improvements over existing salts used for the application. These challenges include the following:

- Overcoming market reluctance to change products (regardless of cost)
- Getting buyers to see a larger picture than cost (when costs are greater for the better salt product)

Potential Markets for Salts Incorporated into Value-Added Products (Creation of New Markets)

The creation of new markets differs from the previous market types in that the salts produced need to be further processed to become a usable product. An example is the incorporation of magnesium salt into building products. Challenges include the following:

- Identifying and developing the value-added product
- Penetrating the market (which includes most of the previously mentioned challenges)

In addition to the previously mentioned challenges, it is necessary that the individual salt-producing operation have sufficient volume to achieve cost-effectiveness, have sufficient reliability to consistently meet product specifications, and have a local market to minimize transportation costs.

Example: Consideration of the Soil Sealing, Dust Suppression, Soil Stabilization Applications (Type 1 Market)

Dust suppression is an existing market for calcium chloride, along with magnesium chloride. Moisture is the key to keeping fine particles in unpaved roads together, as it coats all particles and binds them. Calcium chloride absorbs large amounts of water, holds the water tightly, and has a high surface tension that reduces evaporation and coats soil particles with a strong, thin film of moisture that reduces friction between particles so that they compact readily. Once compacted, the surface tension creates a cohesive force that holds the consolidated base together and performs a soil-sealing, soil stabilization function.

In this example, the market for calcium chloride exists and the product will, in most cases, need to meet established project specifications.

Example: Consideration of Soil Remediation Markets (Type 2 Market)

Salt-affected soils are particularly abundant in the arid Southwest United States. As described in Chapter 3, the properties of soils are frequently characterized by the SAR and hydraulic conductivity (rate of flow through the soil) (Warrence et al., 2005).

Three main problems caused by high sodium levels (high SAR) are the following:

- Reduced infiltration
- Reduced hydraulic conductivity
- Surface crusting

Rainfall on such soils does not soak into the soil and is lost by evaporation. The soil does not support agriculture, and the water is lost to the local area as the water does not enter local groundwater pathways. Through the addition of calcium salts, it is possible to change the hydraulic conductivity of soils to obtain increased rates of infiltration and reduce the amount of “lost” rainfall and significantly increase the supply of usable water (G. Grott, personal communication).

Current practices for soil remediation include the application of gypsum to sodic soils. Research has shown that more effective soil remediation techniques include the use of calcium and magnesium chloride for sodic soils (A. Arakel, personal communication). These products, however, are more costly than gypsum, and farmers are reluctant to pay more money for remediation, even though the more expensive chemicals may be more efficient.

In this example, a large-scale need (soil remediation) could reap large long-term benefits that would include increased agricultural yields and reduced water loss due to evaporation of rainfall. The more beneficial salts available from concentrate processing, however, are often more costly than the salts that are widely used. A formidable challenge to developing this market is to bring about a shift from the short-term focus on chemical cost to a comprehension and appreciation of longer-term benefits and resulting lower “total cost” associated with the other salts. Salts made for this use may need to meet existing product specifications for the application or undergo environmental testing for the application.

Comment on Economics

The added processing (additional concentration and treatment processing steps) necessary for selective salt removal increases the capital cost of the processing scheme relative to that of a single RO stage. Operating costs are also increased (relative to that of a single RO stage system), but the operating costs may be somewhat offset, completely covered, or changed into an operating income stream by salt sales. Geo-Processors USA claims to have demonstrated the commercial and economic feasibility of such processing (Dirach et al., 2005), but independent documentation is limited. Economics are site specific, depending on the water quality and volume in question and the local salt markets.

As the above discussion illustrates, the economic success depends not only on the availability of technology to bring about selective salt recovery but also on the local salt market and the challenges associated with marketing each salt.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions based on the above discussion include the following:

- There are applications for each of the salts composed of major ions in concentrates.
- Technology appears to exist (as evidenced by Geo-Processors's claims of success) to obtain such salts, although the level of documentation is limited. Some details of their technologies are proprietary, and various aspects of these and other likely appropriate technologies are patented.
- The feasibility of a given site-specific operation to recover and market salts from a concentrate is dependent on many factors. These factors include the following:
  - Volume of concentrate
  - Water quality (salts obtainable from the concentrate)
  - Quality (form and purity) of salts obtained
  - Reliability, consistency of salt quality
  - Types of applications for the obtainable salts (types of markets)
  - Existence of a local market
  - Size of the local market
  - Reliability of the local market
  - Combined income from sale of the different salts

- There is a need for market development, the development of value-added products to remove feasibility dependence on existing markets.
- The recovery of individual salts from concentrate and the marketing of such salts have potential to offer cost-effective concentrate disposal solutions to many locations, including those for which no such solutions currently exist.
- Associated benefits of salt recovery and sale include increased overall water recovery and decreased environmental impact

Recommended areas for research include the following:

- Conduct detailed identification of and documentation of regional salt markets and applications, including identification of salt quality (form and purity) required for different applications

- Salt disposal options and economics when previously available markets are disrupted (e.g., reverting to landfill disposal)
- Develop value-added products from obtainable salts for
  - Calcium carbonate-based products
  - Gypsum-based products
  - Magnesium-based products
- Develop equipment-based cost-effective technologies for producing salt products to meet product specifications at any location

CHAPTER 5

SUMMARY AND ANALYSIS OF DISPOSAL OPTIONS

The purpose of this chapter is to compare and contrast concentrate disposal alternatives, with an emphasis on beneficial and nontraditional options. Key issues, advantages and disadvantages, economics, risks, research issues, and overall conclusions are described.

EVALUATION OF OPTIONS

Beneficial and nontraditional disposal options relative to a number of evaluation criteria are shown in Table 5-1. Key issues and advantages and disadvantages are listed in Tables 5-2 and 5-3, respectively. Table 5-4 provides a draft summary of disposal options for the U.S. desert southwest developed in the CASS project, and Figure 5-1 provides a flow chart for disposal options.

TABLE 5-1
Summary of Beneficial and Nontraditional Disposal Options Relative to Evaluation Criteria

Parameter	Oil Well Field Injection	Solar Ponds	Land Application and Irrigation	ZLD	Aquaculture	Wetland Creation and Restoration	Constructed Wetlands Treatment	Separated Salts Recovery	Stormwater Blending	Wastewater Blending
Geographical and Climatic Relevance	TX, CA, AZ, WY, KS, OK, MT, NM, LA	Southwest U.S.	Broadly applicable but rates, seasonality, and groundwater impacts vary	Universal	Temperate regions	Broadly applicable coastal, but rare inland	Broadly applicable, seasonally limited in northern regions and at higher elevations	Universal	Coastal regions	Universal
Regulatory										
Complexity	H	M	H	L	H	H	M	L	M	L–M
Risk (change)	H	M	H	L	H	H	M	L	H	M
Level of Utility Control	M	H	L	H	L	L	M	H	M	M
Economic Considerations										
Economies of Scale	H	M	L	?	L	M	L	?	M	?
Capital cost	$$$$$	$$$	$$$	$$$$$	?	Site specific	$$	?	Site specific	$
O&M Cost	?	?	$	$$$$$	?	?	$	?	$	$
Economic Risk	?	L	M	M (energy costs)	H	H	?	M (sustainable markets?)	?	L
Human Health Risk	L	L	M	L	M	M	L	L	M	?
Ecological Risk	L	M	M	L	M	H	M	L	M	?
Capability to deal with membrane cleaning solutions	Site specific	M	H	?	?	?	H	?	Site specific	M
Applicability to other salt streams and overall basin salt management	H	H	M	H	M	M	H	H	H	H
Proven Technology	L	M	H (nonhalophytes) L–M (halophytes)	H (with high energy use)	L (for concentrate)	VL	L	L	H	H

TABLE 5-1
Summary of Beneficial and Nontraditional Disposal Options Relative to Evaluation Criteria

Parameter	Oil Well Field Injection	Solar Ponds	Land Application and Irrigation	ZLD	Aquaculture	Wetland Creation and Restoration	Constructed Wetlands Treatment	Separated Salts Recovery	Stormwater Blending	Wastewater Blending
Overall Sustainability	M	M	M	H (with salt recovery for beneficial use) L (energy use)	M	L	M	?	H	M
Terminal Disposal[a,c]	Y	N	N	Y (salt recovery or landfilling)	N	N	N	Y (some salts, some markets)	Y	N
Beneficial Use[a]	Y[b]	Y	Y	Y (recovery of high-quality water)	Y	Y	Y	Y	Y	Site specific
Free Up Resources[a,d]	Y	Y	Y	Y (recovery of high-quality water)	N	N	N	Y	N	Site specific

[a] These criteria are being developed as an approach to evaluate disposal alternatives for a current USBR project “Treatment of Concentrate” (M. Mickley, personal communication).

[b] Oil well field injection would constitute a beneficial use if used for secondary oil recovery and not simply for disposal into abandoned oil or gas well fields.

[c] “Terminal disposal” means that an additional treatment or disposal step for concentrate after the beneficial or nontraditional use is required.

[d] “Free up resources” is defined as having the capability to provide energy recovery or water recovery for other uses.

Key Issues to Be Addressed

TABLE 5-2
Summary of Key Issues Associated with Disposal Alternatives

Method	Issue
Traditional Disposal Methods	
Surface Water Discharge	Environmental and habitat issues Regulatory requirements and permits
Sewer Discharge	Increasing size of desalination facilities Overall basin salt management and reuse issues
Evaporation Pond	Land availability Climate applicability Salt drift (mechanical misting systems) Potential groundwater contamination Disposal of solids Aesthetic issues (odors) Habitat and ecological risk issues
Deep Well Injection	Geologic and geohydrologic conditions Seismic activity Concentrate compatibility with formation Public perception and acceptance Regulatory requirements and permits Potential to use abandoned or active oil wells
Rapid Infiltration	Concentrate must be higher quality than aquifer Difficult to permit
Beneficial and Nontraditional Uses	
Oil Well Field Injection	Secondary oil recovery is unproven for concentrates Regulatory uncertainty Compatibility with formation Concentrate flow vs. injectivity of formation Expected duration of secondary recovery vs. membrane facility
Solar Ponds	Unproven with concentrate or full-scale membrane plant operations Maintaining pond clarity (algae control) Increasing TDS of concentrate to ~250,000 mg/L for establishment Start-up time Ultimate salt disposal Maintaining the gradient
Land Application and Irrigation	Fate of salts (vadose zone storage; volume reduction, capture, and further treatment; deep percolation) Land availability and space requirements Selection of plant species Potential groundwater contamination Concentrate quality (TDS, B, Se, Na) Hydraulic loading rate Growing season limitations

TABLE 5-2

Summary of Key Issues Associated with Disposal Alternatives

Method	**Issue**
ZLD	Costs (capital and O&M) Complexity of equipment Solids disposal Height of system Energy and power requirements
Aquaculture	Disposal of effluent Unproven with concentrates Low salinity range of typical U.S. marine aquaculture relative to many concentrates Concentrate chemistry differences from seawater
Wetlands Creation and Restoration	Need for intermittent flows Ultimate fate of constituents Regulatory and NGO scrutiny
Constructed Wetlands Treatment	Land availability and space requirements Potential groundwater contamination Concentrate quality Additional downstream treatment may be required Plant selection and wetland type(s) Habitat issues Climate
Stormwater Blending (Coastal Regions)	Storage and permitting requirements
Wastewater Blending	Permit requirements Decrease in reuse water quality
Recreation	Same issues as land application and irrigation, salt marsh, or treatment wetland
Transport of Mineral Resources	Rare, but might be possible Disposal of water after transport still required
Subsurface Storage	High cost of extraction and water recovery, especially for high-salinity concentrates at or near saturation of one or more salts
Feedstock for NaOCl Generation	Unlikely to be technically or economically feasible
Cooling Water (Concentrate as Feed)	Likely only available if blended with lower-salinity water, such as wastewater
Cooling Water (Concentrate Blended at Point of Discharge)	Blending concentrate with cooling water generally more practical and beneficial than using concentrate for cooling water
Dust Control and Deicing	Mixed salts undesirable, difficult to permit
Other Direct Uses of Concentrate	Unlikely to be found
Separated Salts Recovery	
	Uncertain markets Need for alternate disposal Yet to be proven in U.S.

Source: adapted from CH2M HILL (2004).

Advantages and Disadvantages

TABLE 5-3
Advantages and Disadvantages of Disposal Alternatives

Disposal Alternative	Advantage(s)	Disadvantage(s)
Traditional Disposal Methods		
Surface Water Discharge (Ocean and Inland Water Body)	• Treatment of brine or concentrate not required prior to disposal for nontoxics • No additional permits required if continue to meet existing NPDES permit • May enhance diffusion of low-TDS buoyant discharge, such as wastewater • Environmentally acceptable alternative • Proven technology for brine and concentrate disposal	• Costs associated with transporting brine and concentrate are variable • Ocean outfall of brine and concentrate may become unacceptable to regulators and/or public in the future • Brine and concentrate must meet discharge requirements set by downstream treatment operator • Disposal pipeline may be necessary
Sewer Discharge	• Dilution of concentrate TDS • Reliable • Low operating cost • Simple permitting	• Pretreatment requirements • Negative impacts on wastewater reuse
Evaporation Ponds	• Inherently simple technology • Low capital costs (assuming land is available) • Low O&M costs • Wide range of acceptable concentrations	• Large land area requirement • Ecological risks; attractiveness to waterfowl • Lining requirements
Deep Well Injection	• Treatment of brine and concentrate not required prior to disposal • Low environmental risk • Mature technology: there are a number of successful installations for RO brine and concentrate disposal worldwide • Small footprint requirement	• Expensive well construction due to industrial waste classification of RO brine and concentrate (tube and packer with annular fluid integrity monitoring system, corrosion-resistant materials) • Rigorous and expensive feasibility and permitting process • Periodic testing of well casing integrity; requires backup disposal method when testing • Geohydrology must be appropriate to accept the brine and concentrate flows

TABLE 5-3
Advantages and Disadvantages of Disposal Alternatives

Disposal Alternative	Advantage(s)	Disadvantage(s)
	• Minimal aesthetic impact (noise, odor, or insect or waterfowl attraction) • Simple to design and operate • Potential to use abandoned or active oil wells, which would eliminate drilling costs	• Monitoring well(s) must be drilled in addition to disposal well • Potential for well plugging by organics and nutrients • Must comply with regulations protecting USDW
Rapid Infiltration	• Inherently simple technology • Low capital costs (assuming land is available) • Low O&M costs	• Ecological risks; attractiveness to waterfowl • Need for high infiltration rates • Limited to areas with low-quality upper aquifers
Beneficial and Nontraditional Uses		
Oil Well Field Injection	• Potential to aid secondary oil recovery	• Unproven for secondary oil recovery • Regulatory uncertainty • Compatibility with formation may be an issue • Expected duration of secondary recovery vs. membrane facility
Land Application and Irrigation	• Treatment of brine and concentrate may not be required prior to disposal • May yield agricultural revenue • Minimal staffing and O&M costs	• Limited plant types available for irrigation with high-TDS water • Precipitation and scaling issues • Permitting and regulatory requirements • Continuous or near-continuous production of RO brine and concentrate requires storage or additional, seasonal disposal alternative when irrigation requirements are low • Long distance between irrigation site and treatment facilities
ZLD	• Simple permitting • High-quality product water (distillate) for industrial applications	• High capital and O&M costs (especially energy) • Solids disposal still needed
Aquaculture	• Potential source of income	• Disposal of effluent

TABLE 5-3
Advantages and Disadvantages of Disposal Alternatives

Disposal Alternative	Advantage(s)	Disadvantage(s)
		• Unproven with concentrates • Low salinity range of typical U.S. marine aquaculture relative to many concentrates • Concentrate chemistry differences from seawater
Wetlands Creation and Restoration	• Habitat restoration	• Ecological risk • Groundwater protection • Need for intermittent flows
Constructed Wetlands Treatment	• Proven technology for treatment of wastewater with high organic loading • Low maintenance and power usage • Creation of wildlife habitat • Potential for environmental mitigation and positive community impacts	• Large footprint requirement • May attract nuisance birds and insects • Alternative form of water required during the months when recharge system is not operating • Vegetation not very effective in removing sodium, chloride, and sulfates • Limited experience in using NTS to treat brine and concentrate • Additional disposal mechanism required
Stormwater Blending (Coastal Regions)	• Potential reduced impact of low-salinity stormwater	• Storage requirement for stormwater
Recreation	• Public benefits	• Same issues as land application and irrigation, salt marsh, or treatment wetlands
Transport of Mineral Resources	• Economic benefits	• Mining sites are typically remote relative to desalination facilities
Subsurface Storage	• Potential future recovery	• High cost of extraction and water recovery, especially for high-salinity concentrates at or near saturation of one or more salts
Feedstock for NaOCl Generation	• Possible on-site use for disinfection	• Unlikely to be technically or economically feasible

TABLE 5-3
Advantages and Disadvantages of Disposal Alternatives

Disposal Alternative	Advantage(s)	Disadvantage(s)
Cooling Water (Concentrate as Feed)	• Beneficial use	• Likely only possible to use concentrate as cooling water source if blended with lower-salinity water, such as wastewater • Limited number of cycles possible if concentrate used as cooling water
Cooling Water (Concentrate Blended at Point of Discharge)	• Mutual dilution (blended flow may be cooler than cooling water and less saline than concentrate)	• None
Dust Control and Deicing	• (Not feasible unless salt separation achieved)	• Mixed salts undesirable; difficult to permit
Other Direct Uses of Concentrate	• (Unlikely to be feasible)	• Unlikely to be feasible
Separated Salts Recovery		
	• Potential sale of salts to offset operations costs	• Recoverable salts may not match market needs, especially locally
	• Avoid or minimize landfill costs	• Market needs can change, and a backup disposal method (e.g., landfill) would still be needed
	• Salts can be removed from the local basin and do not negatively affect water reuse	• Concentrate chemistry (and salts produced) may not match the local market

Source: adapted from CH2M HILL (2004).

Central Arizona Salinity Study Draft Results

Draft results from the CASS study, summarizing disposal options deemed feasible for the U.S. desert southwest, are shown in Table 5-4 (CASS, 2005). The results suggest evaporation ponds and sewer disposal will likely continue to generally meet the needs of smaller concentrate generators. In contrast, more sophisticated solutions will likely be required for utilities with larger concentrate flows (CASS, 2005). A ranking of "H" indicates a high ranking as a feasible option, and "L" indicates a low ranking.

TABLE 5-4

Summary of Draft CASS Evaluation of Disposal Alternatives for Central Arizona

	Feasibility with Indicated Capacity			
Concentrate Management Alternative	**0.25 MGD**	**1 MGD**	**3 MGD**	**5 MGD**
Evaporation Ponds (Conventional)	H	M–H	L	L
Evaporation Ponds (WAIV[a])	--	--	--	--
Sewer Disposal	H	M–H	L	L
Deep Well Injection	L	L	L	L
ZLD and Near ZLD Technologies				
Brine Concentrator	L	L	L	L
DewVaporation[b]	H	M–H	L	L
Sal-Proc[c]	L	M	H	H
HERO[d]	L	L	M–H	M–H

[a] Wind-aided intensified evaporation (Gilron et al., 2003). There are insufficient data to evaluate the alternative fully.

[b] Ranking based on all criteria except technical and operational feasibility.

[c] Alternative is heavily dependent on water quality. Ranking based on all criteria except technical and operational feasibility.

[d] Alternative heavily dependent on water quality.

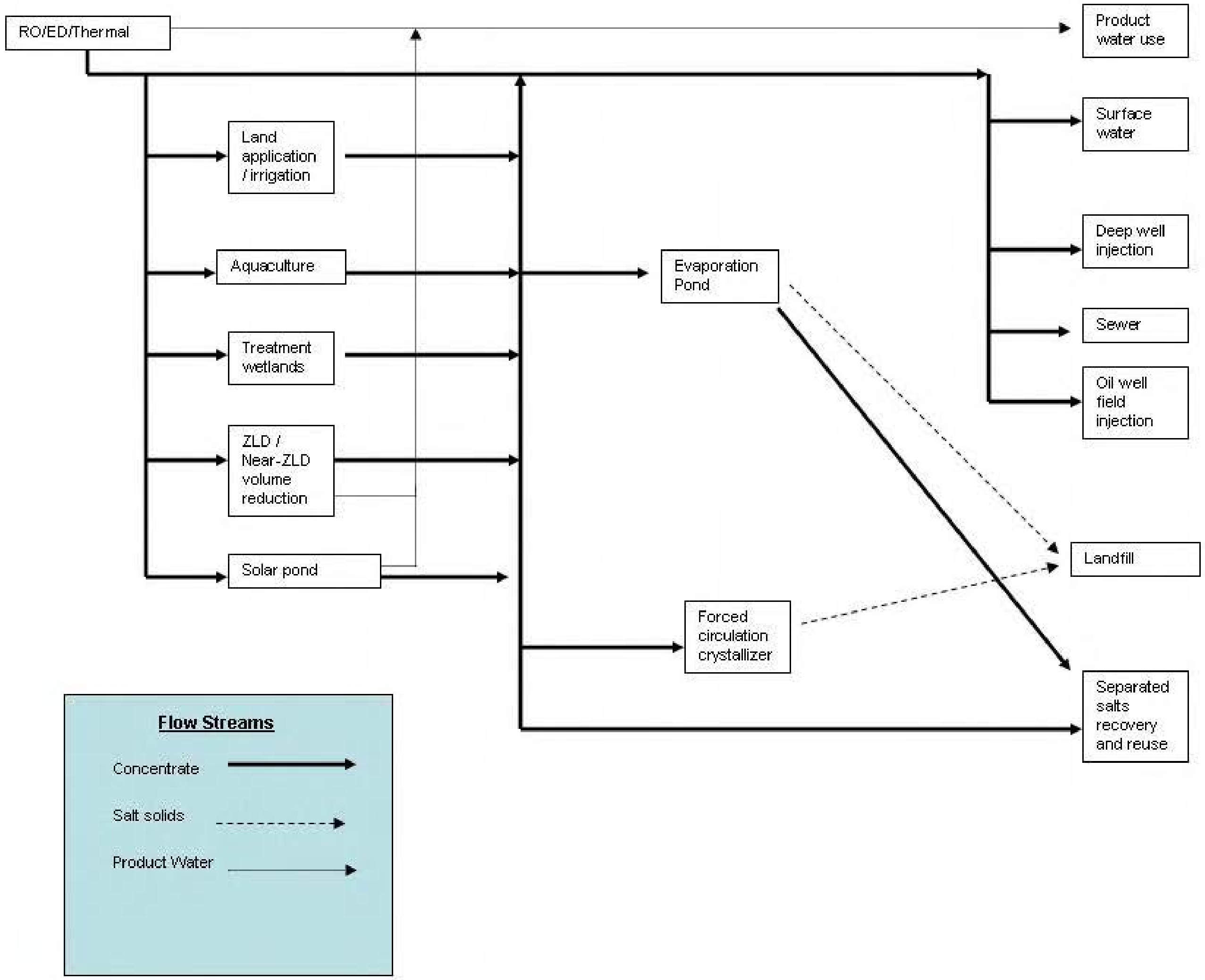

FIGURE 5-1
Flow Chart for Disposal Options

ECOLOGICAL AND HUMAN HEALTH RISK ASPECTS

The recommended overall process to evaluate ecological and human health related issues associated with disposal options is as follows:

1. Begin with regulatory compliance issues: address the risks and exposure pathways.
2. Identify potential receptors: How would they be exposed? How frequently?
3. Characterize concentrate: major ions, trace constituents, and pathogens.
4. Screen with regulatory standards as appropriate; for others, screen against ecotoxicology benchmarks and/or human health risk-based concentrations.
5. If necessary, calculate a risk-based concentration for other receptors (field workers, recreational users).

Ecological and human health issues associated with traditional, beneficial, and nontraditional uses are summarized in Table 5-5.

TABLE 5-5
Summary of Ecological and Human Health Risk Aspects of Disposal Alternatives

Method	Issue
Traditional Disposal Methods	
Surface Water Discharge	Potential impacts on aquatic organisms are primary considerations. Human health impacts may occur if the discharge degrades water quality for potable water use downstream, limits recreational use of the surface water body, or restricts fish ingestion because of accumulation of toxic constituents. For inland facilities, ecological receptors are sensitive to significant salinity changes. Surface water discharges should generally be avoided for inland facilities to avoid degradation of surface waters and groundwater. Other issues include cumulative increases in salinity downstream resulting from multiple dischargers, consideration of designated uses, and emerging constituents of interest. For oceanic discharge, ecological risk factors are likely a major constraint. Concentrates may contain elements at toxic concentrations or that may cause food chain impacts. Significance of constituents can be evaluated on a site-specific basis by comparing waterborne concentrations to ambient water quality criteria or other ecological benchmark values. An ecological risk assessment or environmental impact analysis is the recommended approach for evaluating the potential ecological significance of constituents to the receiving water body.
Sewer Discharge	Relatively low risks, assuming that (1) constituents are not present at concentrations that represent a health risk for workers in the WWTP, (2) constituents would not adversely affect WWTP operation, and (3) final discharge meets permit conditions.

TABLE 5-5

Summary of Ecological and Human Health Risk Aspects of Disposal Alternatives

Method	Issue
Evaporation Pond	Public health impacts can be minimized by limited potential exposures at the ponds. Measures implemented to prevent seepage into groundwater reduce potential impacts to potable water supplies. Misters may result in potential exposure of nearby residents to constituents (chemicals or pathogens) that may be present in the aerosol. Design and implementation should consider minimizing this pathway. Waterfowl, shorebirds, and other aquatic birds are attracted to surface water, including evaporation ponds.. Certain kinds of aquatic organisms (such as brine shrimp or brine flies) may thrive and create viable feeding habitats for birds. Some concentrates may contain constituents that pose some hazard to avian receptors.
Deep Well Injection	The primary human health exposure pathway for deep well injection relates to potential migration to public or private potable water supplies. This is rare but has occurred. Ecological risks are low, unless failures result in discharge to surface waters (or surface ponding) or shallow subsurface discharge within the rooting depth of plants that affects surrounding vegetation.
Rapid Infiltration	Controlled access should prevent public exposures, and health and safety plans should provide protection for workers. Design and operation would need to limit adverse impacts to groundwater that may impact downgradient water supplies and/or surface waters. Ecological risk very similar to evaporation ponds, except that risks to aquatic birds are expected to be lower because of lower average concentrations (less evapoconcentration). The duration of exposure is also less than for evaporation ponds because of the required rest periods.
Beneficial and Nontraditional Uses	
Oil Well Field Injection	Exposure pathways occur only if concentrate migrates to drinking water or surface water. Very little risk if appropriate assessments are done and no failures occur as described in Chapter 2 for deep well injection.
Solar Ponds	(Essentially the same issues as described above for evaporation ponds)
Land Application and Irrigation	Major issues for project feasibility are potential groundwater and surface water impacts. Human exposure for potential receptors like farm workers or persons playing in parks may occur primarily during spray application. Concentrate characteristics, mode of application, and frequency of exposure are key factors. Fate of constituents may also be a factor. Plant uptake of metals or organics is not likely to be a significant route of exposure. Perceived risks may be important, and risk analysis may need to be coupled with risk communication.

TABLE 5-5
Summary of Ecological and Human Health Risk Aspects of Disposal Alternatives

Method	Issue
ZLD	Evaporation pond and solid waste disposal considerations may apply. Energy use and associated emissions may be an emerging consideration.
Aquaculture	First consideration is toxicity to aquaculture organism. Second consideration is the food chain; human health or other ecological receptors may be more sensitive to selected constituents.
Wetland Creation and Restoration	Ecological issues may be direct toxicity or bioaccumulation (e.g., arsenic, mercury, selenium).
Constructed Wetlands Treatment	Risk issues are similar to those for evaporation ponds, salt marsh, and surface water discharges. May result in unacceptable levels of wildlife exposure to bioaccumulative constituents (e.g., selenium)
Stormwater or Wastewater Blending (Coastal Regions)	(See surface water discharge)
Recreation	(See surface water discharge and land application and irrigation)
Transport of Mineral Resources	(Depends largely on subsequent disposal method and pretreatment)
Subsurface Storage	Groundwater protection
Feedstock for NaOCl Generation	(Depends largely on subsequent disposal method of residuals)
Cooling Water	(Depends largely on subsequent disposal method)
Dust Control and Deicing	Ecological risk
Other Direct Uses of Concentrate	(Insufficient information)
Separated Salts Recovery	
	Human health and ecological risk issues primarily driven by purity of recovered salts and intended uses

MARKET AND ECONOMIC ANALYSIS

For the vast majority of utilities, concentrate is a significant liability and not a valuable resource. The costs for concentrate disposal are generally driven by the following factors (Malmrose, 2005):

- Geological and hydrological suitability for subsurface injection
- Dissolved solids and ion concentrations
- Low flow of surface waters
- Capacity of sewers and WWTP
- Limitation of sewer ordinances
- Land availability and cost
- Availability of dilution water
- Climate

- Local value of water
- Demand for irrigation water

Comparison of Costs

Only limited cost information was available on beneficial and nontraditional disposal options, and what information was available varied widely in the level of documentation of assumptions. Moreover, site-specific considerations typically have major impacts on costs of these options. Direct comparisons of costs are therefore not feasible.

Several organizations have developed cost comparisons of a limited number of disposal options. Cost comparisons compiled by the AWWA, CASS, and UTEP are summarized in this section.

AWWA Committee Summary

A summary of estimated costs for several conventional disposal options is provided in Table 5-6.

UTEP Cost Comparisons

UTEP developed a cost comparison of product water costs for an RO plant based on their results for a ZLD system that incorporated a solar pond and cost models developed in Mickley (2004a) for deep well injection, evaporation ponds, and conventional ZLD. Results of this comparison are shown in Table 5-7.

TABLE 5-6

AWWA Committee Cost Comparison of Several Disposal Options[a]

	Cost (2004 $ in 1000s)[b]											
	Spray Irrigation[c]				**Evaporation Pond[d]**				**Subsurface Injection[e]**		**Brine Concentrator[f]**	
Flow Rate, MGD	**Acres at 2 ft/year**	**$ at 2 ft/year**	**Acres at 20 ft/year**	**$ at 20 ft/year**	**Acres at 0.5 gpm/acre**	**$ at 0.5 gpm/acre**	**Acres at 2.0 gpm/acre**	**$ at 2.0 gpm/acre**	**$ at 2500 ft**	**$ at 10,000 ft**	**$, capital**	**$/year, energy**
0.01	6	200	0.6	40	14	1,600	4	400	1,750	5,700	1,300	55
0.1	60	1,000	6	200	140	16,000	35	4,000	1,750	5,700	2,000	1,230
1	600	6,000	60	1,200	1,400	160,000	350	40,000	2,500	8,100	8,750	3,500
2			120	2,400					2,800	8,500	14,900	6,850
5			300	6,000					3,600	10,000	38,500	17,200

[a] Only relative costs are given; site-specific costs may vary significantly.

[b] Costs are based on 2004 US$ and exclude the cost of conveying concentrate to a site (Mickley, 2004a).

[c] Costs exclude means of blending and dilution, pretreatment to meet water quality requirements, and monitoring wells.

[d] Costs exclude solids disposal and seepage monitoring.

[e] Costs exclude pretreatment and standby disposal system.

[f] Based on power cost of $0.10/kW•h; costs exclude solids disposal and disposal of possible small brine stream.

Source: AWWA (2004).

TABLE 5-7

Comparison of Product Water Costs Based on Concentrate Disposal Alternative[a]

	Cost ($/1000 gal) for Capacity (MGD) of:					
Method	**1**	**5**	**10**	**15**	**20**	**25**
ZLD with Solar Pond and BCRS	$4.01	$3.72	$3.61	$3.54	$3.50	$3.46
Deep Well Injection	$3.35	$2.66	$2.55	$2.52	$2.50	$2.49
Evaporation Ponds	$3.45	$3.39	$3.37	$3.36	$3.36	$3.36
Conventional ZLD (Crystallizer)	$7.73	$6.38	$6.36	$6.36	$6.36	$6.36

[a] Assumptions: Energy was assumed to cost $0.10/kWh. Solid salt disposal was assumed to cost $30/ton. A 6% interest rate was used. Salt disposal costs were included for all options except deep well injection. Annual O&M costs were included. Costs for flows greater than 2 MGD with conventional ZLD were assumed to be directly proportional to the capital cost of a 2.0-MGD plant (i.e., costs are not directly derived from the model of Mickley, 2004a).

Source: Swift et al. (2002).

Given their assumptions, for all levels of flow deep well injection was the least costly, and conventional ZLD was the most costly. Product water costs for the solar pond and evaporation pond systems were intermediate, with product water costs that were slightly higher than for evaporation ponds. The UTEP analysis suggests economies of scale are significant with the solar pond ZLD system and deep well injection, minimal with evaporation ponds, and significant for ZLD going from 1 to 5 MGD.

CASS Cost Comparisons of Disposal Alternatives

Cost comparisons for several conventional disposal options, conventional ZLD, and near-ZLD were developed in the draft CASS study and are shown in Table 5-8. Beneficial and nontraditional disposal options other than separated salts recovery were not considered feasible.

Summary

Costs models are available for traditional disposal methods with a variable level of documentation of assumptions. In general, reliable cost models are not available for beneficial and nontraditional uses of concentrate as a result of limited information, limited or nonexistent full-scale applications, or site-specific considerations.

CREATING MARKETS

It should be recognized that starting with a product (such as concentrate or salts derived from concentrate) and trying to develop a market for it is a difficult strategy. The most successful methodology occurs when a product is developed in response to a known or recognized need.

Concentrate

There is little existing “market” for concentrate, and little prospect for creating one. That being said, there may be local, site-specific beneficial uses for concentrate that can be developed.

TABLE 5-8

Summary of CASS Evaluation of Capital and O&M Costs of Disposal Alternatives (Arizona Conditions)

	Cost ($ Million)							
Method	**.25 MGD**		**1 MGD**		**3 MGD**		**5 MGD**	
	Capital	**Annual Operating**	**Capital**	**Annual Operating**	**Capital**	**Annual Operating**	**Capital**	**Annual Operating**
Evaporation Ponds (Conventional)	$4.5	$0.02	$18.0	$0.09	$54.0	$0.3	$91.0	$0.5
Evaporation Ponds (WAIV)	Not available		Not available		Not available		Not available	
Sewer Disposal	$5.3	$0.02	$5.7	$0.7	$7.8	$2.2	$11.1	$3.6
Deep Well Injection	$3.9		$6.3		$8.2		$10.6	
ZLD and Near-ZLD								
DewVaporation	Not available		Not available		Not available		Not available	
Brine Concentrators	$3.2	$0.14	$9.6	$0.5	$18.5	$1.5	$25.0	$2.5
SAL-PROC	$0.10	$0.07	Not available		Not available		Not available	
HERO	$3.2				$14.2		$19.2	
V-SEP	$0.6	$0.07	$2.4	$0.3	$7.3	$0.9	$12.1	$1.5

Assumptions: Costs shown are not inclusive. The concentration of the influent to each alternative was defined as 5000 ppm TDS. The operating costs for each alternative are based on 8680 operating h/year. Eighty hours is subtracted to accommodate shutdown of equipment for maintenance. Deep well injection is not based on flow. The costs for 0.25 MGD are associated with a 2500-ft depth, 1 MGD is associated with a 5000-ft depth, 3 MGD is associated with 7500-ft depth, and 5 MGD is associated with a 10,000-ft depth. The hauling and disposal costs are based on 22 tons of waste/year for each alternative. Deep well injection does not include the pump in the capital cost estimation or the operating cost. Maintenance and operation labor costs are based on an hourly wage of $30/h. The operating cost for the Sal-Proc technology is offset by the sales of the valuable product produced. The annual operating cost for 0.25 MGD is approximately $100,000 and, assuming 100% of the product is sold, the value of the product is approximately $175,000. Models do not include engineering design costs. Costs are not at all inclusive and do not include significant site-specific cost components; refer to the summary description of each technology, above. Actual costs to implement and operate each technology will likely be higher than shown on this table

Separated Salts

As described in Chapter 4, there may be existing markets for individual salts, potential markets for individual salts, and the potential for incorporation of salts into value-added products. Salts produced from concentrate may need to compete with existing sources of salt or alternate materials. Even if salts produced from concentrate were competitively priced, there may be various reasons why buyers may be reluctant to change sources. In general, major salts that could potentially be extracted from a concentrate need to be compared to existing and potential local markets.

RESEARCH NEEDS

Research needs for beneficial and nontraditional disposal options are summarized in this section.

Oil and Gas Well Field Injection

- Compatibility of concentrates with oil-bearing formations
- Map by region the relationships between injectivity, need for concentrate disposal, and recoverable oil and gas resources
- Studies of economics and sustainability of oil recovery operations together with water treatment plant operations

Solar Ponds

- Lower-cost liners and chemical sealing options (NRC, 2004)
- A greater understanding of life cycle economics (NRC, 2004) and ultimate salt disposal
- Technologies to allow maintenance of pond clarity

Land Application and Irrigation

- Crop uptake from shallow groundwater in controlled drainage systems for reduced drainage volumes with irrigation
- Agronomic practices for halophyte production
- Sustainable upper limits of soil salinity and leaching fractions for irrigation, especially for halophytic crops
- Understanding the impacts of concentrate on various soil and plant systems
- Sustainable drainage management

Aquaculture

- Evaluation of typical RO concentrates in an aquaculture system
- Evaluation of marine aquacultural systems in the United States under higher levels of salinity than currently practiced
- Evaluation of effluent disposal issues

Wetland Creation and Restoration

- Understanding and optimizing site hydrology and site salinity relative to concentrate flows and ecological needs
- Minimum flows and levels to sustain wetlands created using concentrate
- Tools to identify appropriate locations
- Constituent fate, ecological impacts, and mitigation of ecological impacts of concentrate discharge
- Demonstration projects for inland and tidal salt marsh creation and enhancement

- Soil salinity and salt accumulation effects on wetland plant communities
- Regulatory feasibility assessment
- Understand limits and opportunities related to restoration as mitigation

Constructed Wetlands Treatment

- Long-term studies of treatment wetland performance with concentrate
- Optimization of treatment wetland designs for specific concentrate treatment and/or volume reduction objectives
- Contaminant removal and toxicity reduction using constructed treatment wetlands
- Contaminant accumulation in plants, sediments, and wildlife using constructed treatment wetlands.
- Regulatory feasibility assessment

Subsurface Storage

- Aquifer storage and recovery applications, especially for <10,000-mg/L concentrates as a future water resource (NRC, 2004).

Separated Salts Recovery

- Develop selective precipitation and purification methods
- Economic studies of existing markets and potential markets for separated salts and value-added products
- Integration of salt separation facilities with existing treatment plants

Miscellaneous Research Needs

- Better understanding of the biology of concentrates in the environment and the potential for biological treatment systems (Sandia, 2003)
- Engineering disposal to avoid harm to ecosystems at a minimum and where possible provide improvements to ecosystems (Sandia, 2003)
- Innovative methods for management or removal of silica, arsenic, and selenium; need to better understand fate and environmental thresholds for toxic constituents and to develop viable removal technologies where necessary prior to disposal (NRC, 2004)
- Volume reduction, deep well injection technology, lower-cost liners, and chemical soil sealing options for evaporation ponds (and solar ponds), extraction of mineral resources from concentrates, and better overall data for feasibility analyses of commercial use options (NRC, 2004)

CONCLUSIONS AND RECOMMENDATIONS

A number of emerging potential beneficial and nontraditional uses have been identified and examined in this report, but these generally are either not well-proven or do not provide a final discharge for salts contained in concentrate. Clearly, there is no panacea for concentrate discharge, but it may be possible to develop creative local options for beneficial use, and beneficial and nontraditional uses should nevertheless be carefully considered in an evaluation of alternatives. A combination of methods, such as linking more conventional options with beneficial or nontraditional uses, may be most cost-effective and could provide redundancy and reliability.

Beneficial and nontraditional options, including separated salts recovery, tend to have numerous and critically important site-specific issues that must be considered prior to implementation, including climate, markets, regulatory issues, and ecological risk concerns. Additional investigation appears to be especially warranted for volume reduction technologies, oil well field injection, halophyte irrigation, treatment wetlands to address reductions in the mass of specific constituents, and recovery of separated salts.

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LIST OF ACRONYMS

ADEQ	Arizona Department of Environmental Quality
ASU	Arizona State University
AwwaRF	American Water Works Association Research Foundation
BCRS	brine concentration and recovery system
BOD	biological oxygen demand
CASS	Central Arizona Salinity Study
CBM	coal bed methane
CWA	Clean Water Act
DO	dissolved oxygen
EC	electrical conductivity
ED	electrodialysis
EDR	electrodialysis reversal
ET	evapotranspiration
FDEP	Florida Department of Environmental Protection
gpm	gallons per minute
HERO	high-efficiency reverse osmosis
IDA	International Desalination Association
MEMS	multi-effect, multistage
MF	microfiltration
MGD	million gallons per day
NDEP	Nevada Division of Environmental Protection
NF	nanofiltration
NGO	non-governmental organization
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
O&M	operation and maintenance
PDFB	percent difference from balance
psi	pounds per square inch
RCRA	Resource Conservation and Recovery Act
RO	reverse osmosis
SAR	sodium adsorption ratio
SAWS	San Antonio Water System
SDWA	Safe Drinking Water Act
TCEQ	Texas Council on Environmental Quality
TDS	total dissolved solids

TSS	total suspended solids
UIC	underground injection control
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USDW	underground source of drinking water
USEPA	United States Environmental Protection Agency
UTEP	University of Texas-El Paso
V-SEP	vibratory sheer enhanced process
WET	whole effluent toxicity
WTP	water treatment plant
WWTP	wastewater treatment plant
ZLD	zero liquid discharge

APPENDICES

APPENDIX A

CASE STUDY – TREATMENT WETLANDS FOR CONCENTRATE, CITY OF OXNARD, CA

Oxnard Membrane Concentrate Pilot Wetland Study: Overview of First-Year Results

Presented at American Membrane Technology Association, San Antonio, TX, Aug. 5, 2004

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Introduction

The Membrane Concentrate Pilot Wetland Project is being conducted by the City of Oxnard Water Division to assist with the City's water resources master planning process and implementation of the Groundwater Recovery Enhancement and Treatment (GREAT) Program. The GREAT Program is being implemented by the City to develop additional alternative water supply sources to continue meeting the City's goal of providing current and future residents and businesses with a reliable and affordable source of high-quality water. This program, described in the GREAT Program Advanced Planning Study (May 2002), will include construction and operation of an advanced water treatment facility (AWTF), a regional desalter, and a tertiary treatment facility (TTF).

These water production technologies will generate brine concentrate that will require disposal. One conceptual alternative, compatible with the local environment, could be to use the membrane concentrate as a water source to brackish or salt marsh wetlands. This Research Plan outlines a pilot system approach to address the feasibility of using concentrates, including those from the planned AWTF, regional desalter, and TTF, as a water source to a wetlands-based system. If feasible, these concentrates could be used for regional benefit, including assisting with restoration of the Ormond Beach wetlands system.

Pilot Study Design

The Membrane Concentrate Pilot Wetlands Project consists of 12 wetland bench-scale tanks comprised of six wetland types (treatments) and two replicates, randomly arranged. The pilot wetlands take up approximately 1000 square ft (20 by 50 ft) and, besides the 12 wetland tanks, include a water storage tank, constant head tank, and all associated piping. The wetland types include five flowthrough mesocosms (surface flow [SF] high marsh, SF low marsh, horizontal subsurface flow [SSF], peat-based vertical upflow [VF], and submerged aquatic vegetation [SAV]), and a saltgrass evaporation system. The evaporation cells receive concentrate inflow but are operated to achieve a zero discharge. Figure A1 provides a layout of the Membrane Concentrate Pilot Wetland Study.

Of the wetland types selected, the SF high marsh, SF low marsh, and the SAV cells represent the major brackish water plant communities known to exist within the existing Ormond Beach wetlands. Testing this broad spectrum of plant types is intended to establish if any are inherently more sensitive than other types to this water source and quality. Plant materials were obtained from native plant nurseries, and plant palettes were adjusted based on species availability.

The primary water source for the wetland mesocosms is reverse osmosis (RO) membrane concentrate from the Port Hueneme Water Authority's Brackish Water Research Desalination Facility (BWRDF). On a weekly basis, the storage tank is refilled with concentrate from the BWRDF. Treated effluent from the wetland mesocosms is collected in a 2-in. polyvinyl chloride drain pipe and discharged directly to an infiltration sump located on-site. The total average inflow for the 12 wetland mesocosms ranged from 25 to 75 gal/day.

The Membrane Concentrate Pilot Wetlands Project is designed to test the following hypotheses concerning the reuse of membrane concentrate:

- **Concentrate can sustain viable native plant communities.** By planting the pilot system with native wetland plants and monitoring their growth characteristics, species water quality tolerance and improvement potential can be determined under hydraulic regimens similar to those that might be implemented on a larger scale.
- **Removal of nonconservative elements will occur through natural biological and chemical transformation processes and will vary among wetland types.** The types of pilot systems selected have been based upon known configurations that have been reported to treat common pollutants. This study is designed to allow comparison of wetland influent and effluent water quality within each cell to determine cell pollutant removal performance and compare it to published water quality improvement models.
- **Some removal of conservative elements can occur through physical and chemical processes, and removal will vary among wetland types.** Few studies are available that have reported on treatment of brackish waters and their compounds. Again, by comparing wetland influent and effluent water qualities, this study will support analyses to determine if removal is occurring through biological assimilation or other processes.
- **Discharge is ecologically safe to wetland biota.** By comparing samples taken of the brackish concentrate at the influent and effluent from each of the cells, changes in toxicity of the effluent to brackish and saltwater organisms can be assessed. This information can be used to determine if water quality components exceed state water quality criteria or pose a measurable concern to native aquatic organisms.

The rationale for conducting this study includes the following:

- If shown to be environmentally safe, membrane concentrate may be useful as a water source for the creation of new wetlands or the restoration of existing salt marsh wetlands.
- The potential supply of membrane concentrate may be useful to the restoration of the Ormond Beach wetlands.
- An environmentally safe reuse of membrane concentrate could minimize the need and cost of other disposal options.
- Very little information is available in the published literature on the effects, treatment, or reuse of membrane concentrate. Results obtained from this study could prove to be beneficial to water supply managers worldwide, particularly in the arid West and Sunbelt states.

Figure A2 provides multiple views of the wetland pilot facility. More detail is available at www.oxnardwater.org/wetlands.asp.

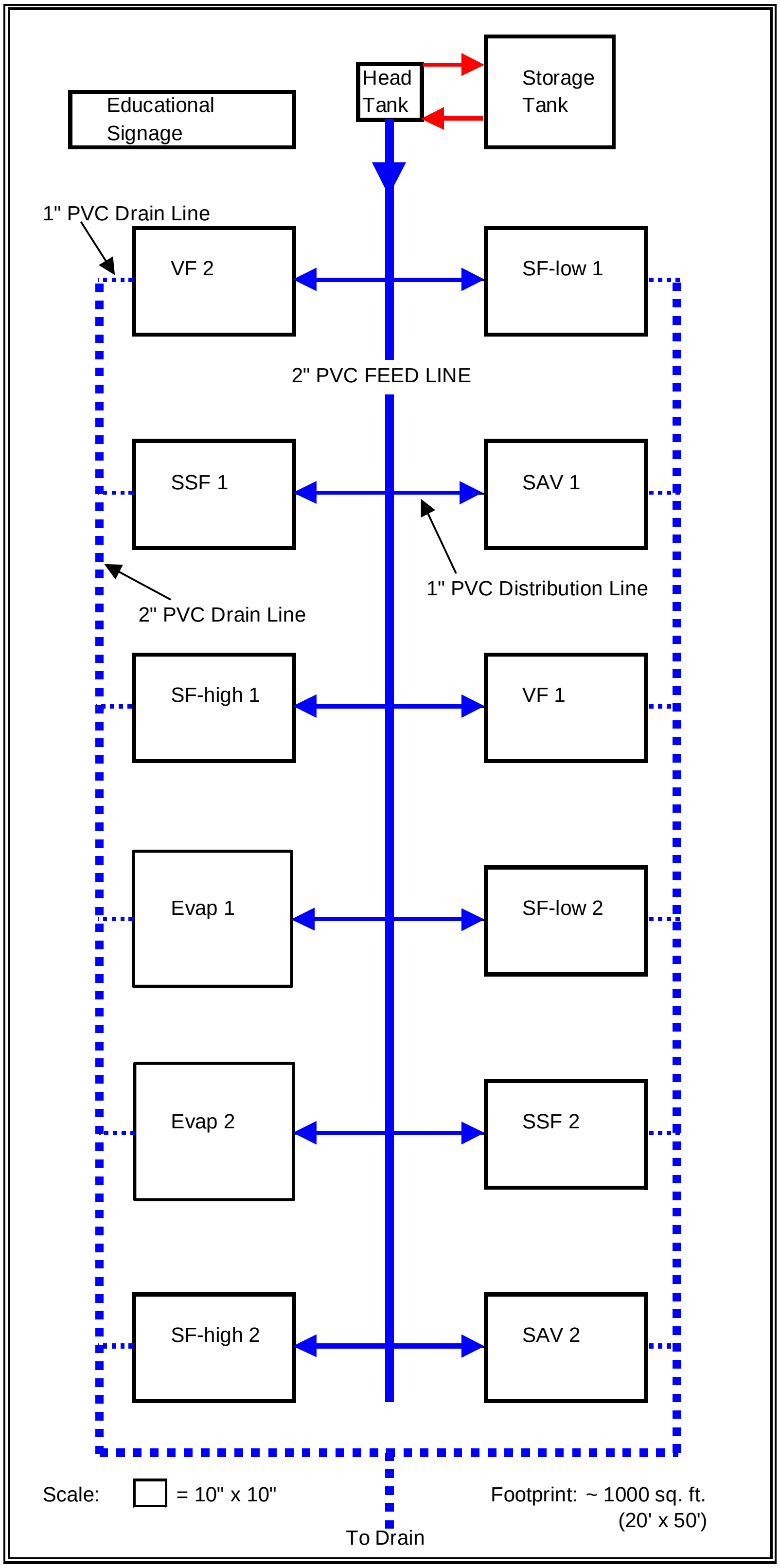

FIGURE A1

Site Layout for the Membrane Concentrate Pilot Wetland Research


Surface Flow Low Marsh


Vertical Flow


Saltgrass Evaporation


Submerged Aquatic Vegetation


Surface Flow High Marsh


Subsurface Flow

FIGURE A2
Representative Views of the Oxnard Membrane Concentrate Pilot Wetlands.

Results

Preliminary results available from the first season of testing are summarized into three broad categories: hydrology, water quality, and vegetation.

Hydrology

Table A1 summarizes the median inflow and outflow (Q in, Q out), hydraulic loading rate (HLR), and hydraulic residence time (HRT) for each wetland type for the 2003 experiment.

TABLE A1
Median Inflow and Outflow Data Summary
October– November 2003

Parameter	Units	SAV	SFHM	SFLM	SSF	VF
Q in	gpd	3.87	3.38	6.18	4.35	4.23
Q out	gpd	0.81	0.63	0.22	2.44	1.81
HLR in	cm/day	1.19	0.79	1.58	1.35	1.30
HLR out	cm/day	0.04	0.19	0.00	0.83	0.55
HLR median	cm/day	0.61	0.49	0.79	1.09	0.93
HRT	days	88	30	62	19	32

Bin area = 1.18 m^2 (12.8 ft^2).

Since the pilot mesocosms are sealed and lose no water through infiltration, the only water losses possible are through evapotranspiration (ET) and the outflow. The effect of ET on the water balance, measured here as the difference between inflow and outflow rates, was greatest in the SF low marsh and SAV systems, with little or no outflow found frequently. In contrast, the SSF and VF systems, which exposed little or no surface water, minimized the losses through evaporation.

Hydraulic loading rates varied from 0.8 to 1.6 cm/day. Hydraulic retention times were relatively long, compared to the average HRTs of 15 to 30 days reported by Kadlec and Knight (1996).

Water Quality

Water quality samples of the BWRDF concentrate and the wetland mesocosm effluents were collected three times during the experiment at 3-week intervals. Figure A3 summarizes average concentrations of selected water quality constituents in the influent and effluent from each wetland system during the experiment.

Comparison of these average values with average influent values indicates that constituents generally either increased or decreased. Increases in ion concentrations through the wetland can be attributed to evaporative concentration. Other increases, such as in total kjeldahl nitrogen, chemical oxygen demand, and aluminum, can be attributed to leaching of materials from the soil. Concentrations of other constituents decreased through physical, chemical, and biological processes. These included metals such as copper, iron, nickel, and selenium and plant nutrients, such as nitrate-nitrogen and phosphorus.

FIGURE A3
Average Constituent Concentration by Wetland System.
PQL, practical quantitation limit.

Analyte	PQL	Units	Influent	SAV	SFHM	SFLM	SSF	VF
General Minerals								
Total Hardness	2.5	mg/L	2293	1987	2367	2905	2453	2633
Calcium	1	mg/L	514	341	487	608	545	586
Magnesium	1	mg/L	246	277	280	338	265	285
Potassium	1	mg/L	20.7	22.3	17.8	8.3	17.2	17.5
Sodium	5	mg/L	424	513	495	579	459	483
Boron	0.1	mg/L	1.0	1.2	1.3	1.4	1.1	0.9
Copper	10	ug/L	26.7	5.0	5.0	5.0	5.0	5.0
Iron	50	ug/L	300	43	103	139	25	53
Manganese	10	ug/L	6.7	5.0	7.9	9.2	5.0	43.3
Zinc	20	ug/L	10.0	10.0	10.0	10.0	10.0	10.0
Total Alkalinity (as CaCO3)	10	mg/L	660	95	553	681	654	712
Sulfate	20	mg/L	2350	2635	2632	2983	2548	2697
Chloride	5	mg/L	274	330	327	333	289	300
Nitrate	0.4	mg/L	54.4	58.6	24.7	8.4	37.2	9.5
Fluoride	0.1	mg/L	2.1	1.3	1.9	2.1	1.9	1.9
pH		units	7.9	8.9	8.2	8.0	8.0	7.8
Specific Conductance	1	umhos/cm	4997	4990	5343	6112	5276	5507
Total Dissolved Solids	50	mg/L	4560	4478	4971	5823	4933	5162
Metals, Total								
Aluminum	10	ug/L	10.0	46.7	23.3	28.8	22.5	30.8
Antimony	1	ug/L	1.0	0.9	0.8	0.8	0.7	0.5
Arsenic	2	ug/L	5.3	5.0	5.3	4.7	4.5	5.5
Barium	0.2	ug/L	90.5	18.9	46.0	62.6	134	133
Beryllium	0.2	ug/L	0.1	0.1	0.1	0.1	0.1	0.1
Cadmium	0.2	ug/L	0.1	0.1	0.1	0.1	0.1	0.1
Chromium	1	ug/L	0.5	0.5	1.2	0.7	2.1	2.3
Lead	0.2	ug/L	0.1	0.2	0.1	0.1	0.1	0.2
Mercury	0.01	ug/L	0.0	0.0	0.0	0.0	0.0	0.0
Nickel	5	ug/L	5.0	3.1	3.2	2.5	3.8	2.5
Selenium	2	ug/L	22.3	24.7	15.7	22.2	20.7	7.3
Silver	1	ug/L	0.5	0.5	0.5	0.5	0.5	0.5
Thallium	0.2	ug/L	0.1	0.1	0.1	0.1	0.1	0.1
Vanadium	2	ug/L	7.7	9.3	5.8	6.0	10.6	1.3
Wet Chemistry								
Ammonia-N	0.2	mg/L	0.1	0.1	0.1	0.2	0.1	0.1
Chemical Oxygen Demand	20	mg/L	17	100	20.8	71.7	15.0	113
Nitrogen, TKN	0.5	mg/L	0.4	0.7	0.6	1.1	0.6	0.7
Phosphorus, Total	0.1	mg/L	0.2	0.1	0.1	0.2	0.1	0.1

Figure A4 compares the average inflow and outflow concentrations of total selenium. Presence of this parameter in the membrane concentrate poses the greatest concern to the beneficial use of concentrate for wetland restoration, given the well-known potential for bioaccumulation and reproductive effects on sensitive wildlife (Ohlendorf, 1989). These data show that the VF and SF low marsh systems reduced selenium significantly to levels near the chronic toxicity threshold for freshwater ecosystems of 5 µg/L (NOAA, 1999). Removal rate constants determined from these data can provide a basis for wetland sizing to achieve discharges below this threshold.

Figure A5 compares the average inflow and outflow concentrations of nitrate-nitrogen. Long-term agricultural practices in the Oxnard region have contributed to elevated groundwater concentrations of this common plant nutrient. With the exception of the SAV system, all of the wetlands decreased nitrate-nitrogen significantly through denitrification and plant uptake. The SF low marsh and VF systems reduced nitrate concentrations below the World Health Organization standard of 10 mg/L.

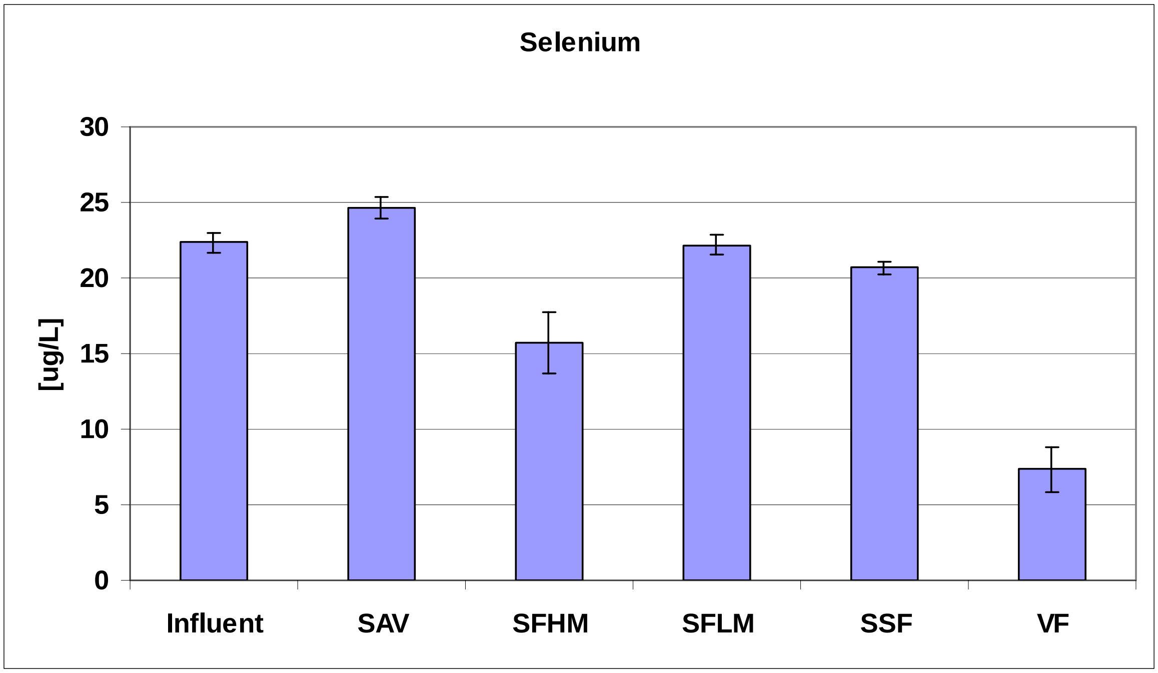

FIGURE A4
Average Selenium Concentration by Wetland System.
Error bars show ± one standard error.

Vegetation

Plant species occurrence, cover, and shoot height were measured in each mesocosm in May 2004, approximately 10 months after initial planting. Table A2 summarizes the relative cover of all plant species observed in the mesocosms, indicating that most of the plant species installed survived and exhibited normal growth. Surface flow high marsh and vertical flow marshes were dominated by saltgrass (*Distichlis spicata*) and yerba mansa (*Anemopsis californica*). Surface flow low marsh was dominated by two native species of bulrush (*Scirpus americanus* and *S. californicus*). The subsurface flow marsh was dominated by yerba mansa, pickerelweed (*Salicornia virginica*), and jaumea (*Jaumea carnosa*), all native plants. Saltgrass dominated the saltgrass evaporation tanks. Only frankenia (*Frankenia salina*), a plant of the infrequently flooded high salt marsh, exhibited little or no growth. This trend is attributed to flood stress by the sustained hydroperiod within the tanks.

Measurements of plant growth indicated that the installed plants grew to normal expected heights, ranging from 1 ft or less for jaumea, a groundcover plant with a sprawling growth habit, to over 9 ft for giant bulrush, a stout, vigorous emergent marsh plant.

Discussion

The Oxnard Membrane Concentrate Pilot Wetland Project is a pilot system approach to address the feasibility of using membrane concentrates, including those from the planned AWTF, regional desalter, and TTF, as a water source to a wetlands-based system. Preliminary data available from the initial pilot phase reported here indicate the following response to the hypotheses posed at the outset of the study:

- **Concentrate can sustain viable native plant communities.** Native wetland plants adapted to salt and brackish water conditions exhibited normal, even vigorous growth. Wetlands with little or no outlet flow showed normal plant cover and growth, even with an increase in salt content through evaporation of 30%.
- **Removal of nonconservative elements will occur through natural biological and chemical transformation processes and will vary among wetland types.** Parameters of greatest concern, such as selenium and nitrate-nitrogen, significantly decreased to environmentally safe levels within the wetland. This removal was most detectable in the VF and SF low marsh wetlands.

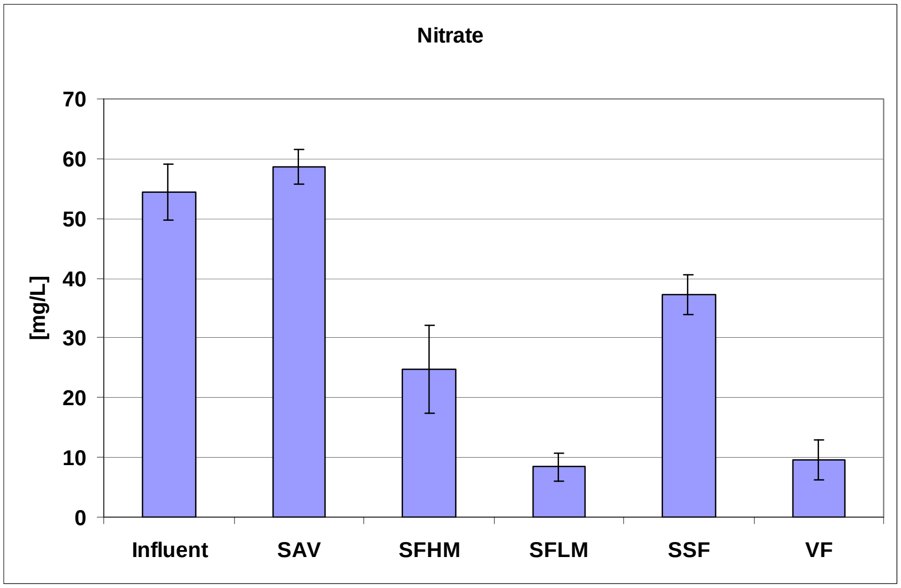

FIGURE A5
Average Nitrate-Nitrogen Concentration by Wetland System.
Error bars show ± one standard error.

- **Some removal of conservative elements can occur through physical and chemical processes, and removal will vary among wetland types.** Concentrations of many inorganic water quality parameters did not appreciably decline during the study, but some, such as calcium, alkalinity, and total hardness, declined in the SAV wetlands.
- **Discharge is ecologically safe to wetland biota.** Treatment by the marshes in general yielded brackish water with significantly reduced contaminant levels that, with further testing and regulatory approval, may be used for regional benefit, including assisting with restoration of the Ormond Beach wetlands system. Future analysis will compare results with known ecotoxicological thresholds. Specific toxicity testing of the wetland effluents is planned.

The Oxnard Membrane Concentrate Pilot Wetlands have become a common focal point for environmental educational activities within the City. Science class field trips for grades K–12 have been regularly conducted, and public outreach activities have resulted in a positive profile of the City's environmental and water supply planning activities.

TABLE A2
Average Plant Species Relative Cover by Wetland Type

	SFHM	SFLM	SAV	VF	SSF	SE
Anemopsis californica	32	--	--	23	26	6
Carex obnupta	0	--	--	--	--	--
Distichlis spicata	49	--	--	28	8	84
Frankenia salina	1	--	--	0	1	--
Juncus balticus	--	--	--	12.5	3	--
Jaumea carnosa	8	--	--	16	42	6
Muhlenbergia asperifolia	--	--	--	--	--	1
Monanthochloe littoralis	--	--	--	12.5	9	--
Potamogeton natans	--	--	100	--	--	--
Potamogeton pectinatus	--	--	--	--	--	--
Scirpus acutus	--	3	--	--	--	--
Sporobolus airoides	--	--	--	0.5	1	0
Scirpus americanus	--	68	--	--	--	--
Scirpus californicus	--	22	--	--	--	--
Scirpus maritimus	--	3.5	--	--	--	--
Salicornia virginica	4	--	--	2.5	10	3
Typha latifolia	6	3.5	--	5	--	--
Relative Cover	**100**	**100**	**100**	**100**	**100**	**100**

This study will be extended through 2004 and modified to a series of connected, flowthrough wetland systems to maximize contaminant removal. Detailed toxicity studies conducted on the pilot system will be summarized and reported in future studies, and results will be communicated to the water utility industry.

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APPENDIX B

CASE STUDY – HALOPHYTE IRRIGATION AND SALT MARSH RESTORATION AT OWENS LAKE, CA; LOS ANGELES DEPARTMENT OF WATER AND POWER

Large-Scale Halophyte Irrigation: Managed Vegetation at Owens Dry Lake, California

TO:	WateReuse Foundation
FROM:	John Dickey/CH2M HILL Ben Jacob/CH2M HILL Maurice Hall/CH2M HILL Rod Jackson/CH2M HILL
REVIEWED BY:	Mica Heilmann/CH2M HILL Jason Smesrud/CH2M HILL Jim Jordahl/CH2M HILL Matt Gordon/CH2M HILL
DATE:	October 24, 2005

Background and Introduction

The purpose of this memorandum is to describe aspects of an extremely large saltwater management project that might have application in management of membrane concentrate, particularly when concentrate is used to irrigate plants. The Los Angeles Department of Water and Power funded preparation of this appendix as an in-kind contribution to the WateReuse Foundation's report on *Beneficial and Nontraditional Uses of Concentrate.* All of the basic information was developed in the course of implementing the Owens Lake Dust Mitigation Program, for which CH2M HILL has served as Program Manager and provided numerous services. Figure B1 shows the location of Owens Lake.

A great deal of this work involved saltwater management in some manner, since the project environment is a saline playa. More specifically, of the 30 square miles irrigated, about 3.3 square miles is planted with a halophyte (called "managed vegetation"). Figure B2 shows the location of these facilities on the playa. Throughout the project area, saltwater is collected, stored, distributed, applied to land, and monitored. In the vegetated area, the goal of these activities is to create a favorable growing environment for the plants, so that they can in turn protect and stabilize the playa surface. Nonvegetated areas are maintained in a wet-surface condition (called "shallow flooding") throughout the 9-month season when dust tends to blow. Scarcity of water and other factors encourage recycling of water wherever possible throughout the facility.

The goal of the Owens Lake Dust Mitigation Program (Program) is to comply with requirements of the *Owens Valley* PM_{10} (particulate matter with an aerodynamic diameter less than 10 microns in diameter) *Planning Area Demonstration of Attainment State Implementation Plan* (SIP), *2003 Revision* (Great Basin Air Pollution Control District). This document specifies dust suppression treatments for about 30 square miles of exposed, saline, desert surface of what was once the bottom of Owens Lake (referred to as the Owens Lake playa, or simply "Playa" in this document). The requirements were determined pursuant to various laws, ordinances, regulations, and standards, such as the federal Clean Air Act, and Section 42316 of the California Health and Safety Code. Implementation of the SIP is intended to bring an end to man-caused violations of federal PM_{10} standards beyond the Playa margin in the planning area. See Figure B3 for an oblique view of a large dust storm on the Playa. The federal standards, in turn, have been established primarily for the protection of human respiratory health.

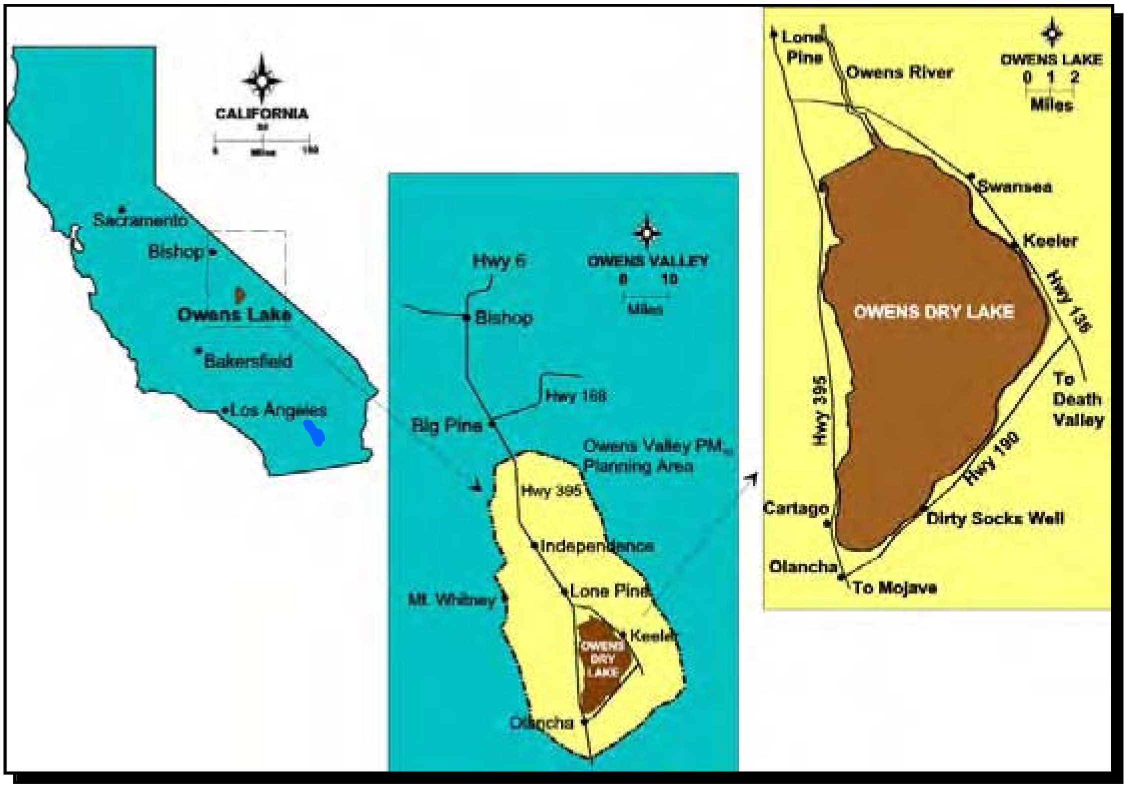

FIGURE B1
Vicinity Map of Owens Lake

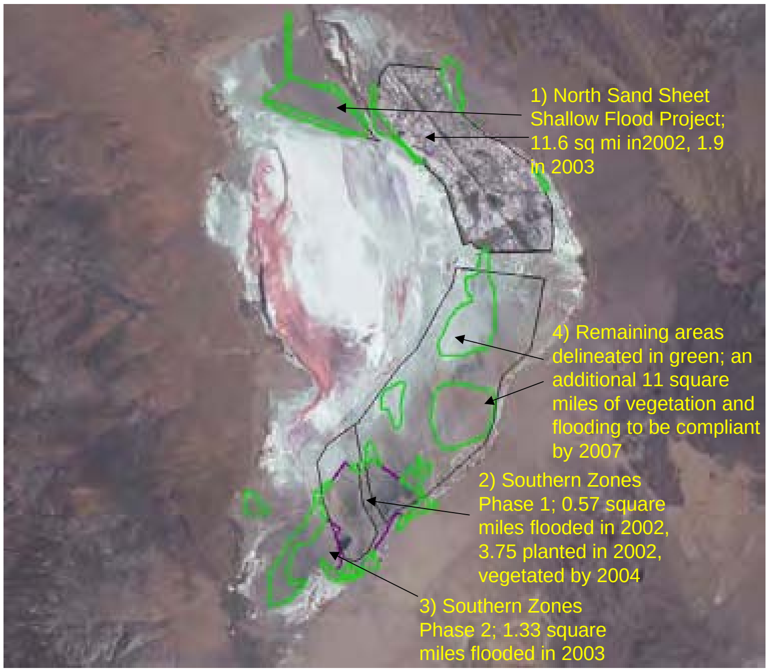

FIGURE B2
Dust mitigation program layout and timing, shown on a 2002 satellite photo of the lake. Shown are (1) two areas shallow-flooded in the northern end of the lake, (2) and (3) Southern Zones projects operated in 2002 and 2003, and (4) planned dust mitigation area through 2006.

FIGURE B3
Dust storm spanning the eastern margin of the Owens Playa, as seen looking east-southeast from Horseshoe Meadows Road (photo: Bill Cox, GBUAPCD).

Several pertinent challenges to the achievement of the SIP requirements include the following:

- **Schedule**: Having begun construction in 2001, the entire specified area is required to be compliant with the SIP by 2007.
- **Scope:** Fulfillment of the requirements in the SIP required a wide range of activities, including research and development (on specifics of dust control measures), site

characterization, planning, permitting, environmental documentation, coordination with regulatory agencies (responsible for air, water, wildlife, and state and federal lands), and communities (regional, municipal, and tribal), design, construction, construction management, operations, and environmental monitoring and reporting. Construction cost of the facilities is about $330 million, with implementation spread across six phases. The 30 square miles contain irrigation facilities (water conveyance, distribution, and application), drainage (subsurface and surface collection networks, sumps, pumps, and saltwater conveyance and storage), instrumentation and control, roads, equipment maintenance and storage, offices, and monitoring equipment (for aerometric, meteorological, shallow groundwater, and system hydraulic and chemical conditions).

- **Complexity**: Dust control is specified as either (1) coverage of the Playa with gravel, (2) protection of the Playa surface with vegetation (requiring irrigation, drainage, and planting of halophytes), or (3) protection of the Playa surface with water (requiring irrigation). Details of related water supply, engineering, agronomy, operations, environmental performance, and permissions from other agencies remained to be worked out.
- **Site conditions**: Since the Playa was exposed by evaporation of a large, very saline lake, soils and shallow groundwater contained exceptionally high concentrations of water-soluble (mainly sodium) salts so that all construction, facilities, and operations are affected by salinity. Even freshwater applied to the Playa becomes mixed with indigenous salts, so that a large part of the project involves storing, circulating, and applying saltwater. Construction took place in a dry, salty, and dusty environment, and on a playa saturated with brine just a few feet below the playa surface. Figure B4 shows the range of salinity concentration encountered in shallow groundwater at the site, and Figure B5 shows the makeup of this salinity.

Salt Management Approach and Irrigation Water Blending to Meet Plant and Soil Requirements

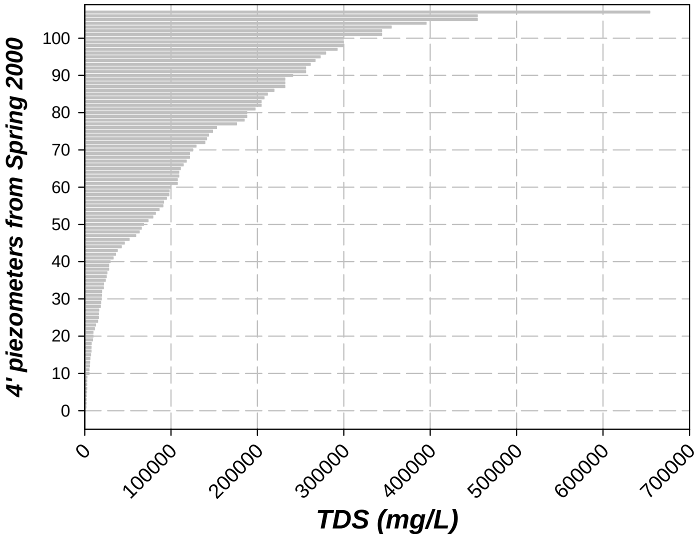

FIGURE B4
Frequency distribution of shallow groundwater salinity. Data from Great Basin Air Pollution Control District.

Where water was applied simply to wet the soil surface, irrigation water quality was not a significant short-term concern. However, where water was applied to planted areas, the nature of the soil and plant, along with the quality of the water (salinity and specific ion content) were considered and balanced.

Plants vary widely in their tolerance of salinity and specific elements. They also range in tolerance of drought and water logging. The nature of the climate, soil, irrigation water, and expected management practices in the planted areas dictated the range of conditions to which plants would be subjected.

At Owens Lake, soils and shallow groundwater are extremely saline and sodic (having elevated concentration of sodium). Average soil salinity in the surface 3 feet of soil ranges in electrical conductivity (EC) from about 10 dS/m to 225 dS/m while shallow groundwater averages around 130,000 milligrams per liter (mg/L) total dissolved solids (TDS) or approximately 115 dS/m. To avoid dispersion of soil by excessive sodium, water applied to vegetation must have an EC_w of approximately 9 dS/m (~6,000 mg/L TDS) or greater. This threshold was determined by leaching fine-textured Playa soil with Owens Lake shallow groundwater at a wide range of dilution factors and corresponding salinity levels. A concentration at which permeability was reliably maintained was selected as the target for irrigation water salinity.

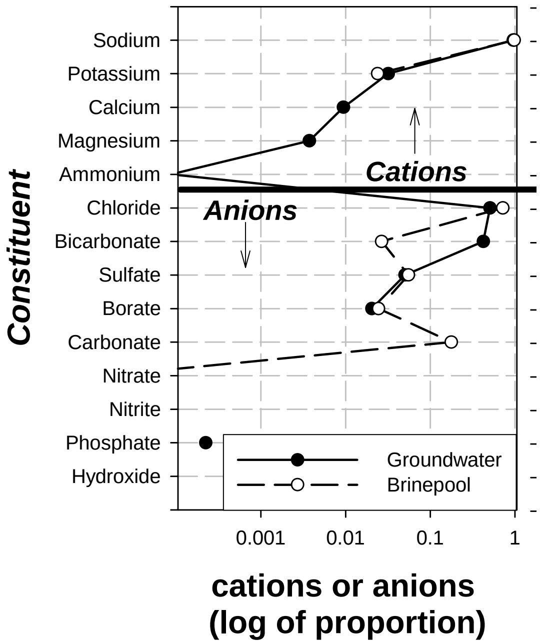

FIGURE B5
Relative proportions of major cations and anions in shallow groundwater and brine pool. Data from Great Basin Air Pollution Control District's 1993 sampling.

Saltgrass (*Distichlis spicata*) was planted to stabilize the soil surface. For it to survive, soil salinity had to be maintained below a soil saturated paste extract EC_e of approximately 30 dS/m. This determines the upper boundary for the range of soil salinity.

Water from the Los Angeles Aqueduct (the freshwater source) is far less saline than the lower limits for avoiding soil dispersion (9 dS/m), while shallow groundwater at the site is far more saline than plants could tolerate. To create an acceptable irrigation water quality, shallow groundwater recovered as subsurface drainage (ranging from 20,000 to more than 200,000 mg/L TDS) is blended with freshwater to create the desired irrigation water quality. Figure B6 shows a turnout facility where this takes place.

In addition to sodium and bulk salinity, boron, chloride, and other elements are also present in the blended irrigation water at relatively high concentrations. So, plants in this system need to be quite salt, sodium, boron, and chloride tolerant.

For reference, many undiluted membrane concentrates have concentrations comparable to the blended irrigation water, and of course much lower than most shallow groundwater at the site. Also for reference, many agricultural crops are sensitive to salinity levels on the order of one tenth the concentration of the blended water.

Owens Lake is a desert, with average rainfall about 6 inches and average potential evapotranspiration of about 66 inches. Project freshwater is costly, so irrigation is to be reasonably minimized; therefore, drought tolerance is desirable.

FIGURE B6
Blending and filtration facilities at turnout from main pipeline.

Owens Lake soils are highly stratified and frequently have low-permeability layers in the surface profile. Shallow groundwater is naturally present a few feet below the soil surface. Therefore, water applied for irrigation has a tendency to remain in the root zone (or the first few feet of soil that contains live plant roots when plants are mature and actively growing). This makes needed leaching of salts from the root zone difficult and can lead to water logging. Artificial subsurface drainage was installed to facilitate leaching. The SIP specified saltgrass for vegetative dust control on Owens Lake, as this species tolerates moderate drought and water logging, as well as extremely high levels of salinity and specific elements relative to most plants. Several other species have similar levels of tolerance.

Freshwater in the blend contains small but significant concentrations of calcium and magnesium. Recycled subsurface drainage has a very high carbonate concentration. The blended water therefore has very significant scaling (calcium-magnesium carbonate precipitate formation) potential. Scale can clog valves, filters, and irrigation application equipment. To counter the possible impacts due to scaling, a polyphosphonate scale inhibitor is continuously injected. In addition, secondary filtration, well downstream of the water blending point, was included in the system to capture precipitate particles and prohibit clogging in the irrigation system. Periodic pulses of acidic water are also run through the system, and the system is regularly flushed to remove precipitate and other unwanted debris.

Site-Specific Characterization of Saline Waters

All natural water has dissolved non-water constituents. Some of these are inorganic ions derived from the weathering of rocks and soil in the watershed through which the water has flowed. Others may have been added through some human activity (in municipal or industrial discharges, in runoff from roads or agricultural lands, etc.) In any case, the mixture of inorganic ions constituting what we normally call salinity (or bulk salinity) and measure as TDS, is variable, and characteristic of each water supply. As the concentration of bulk salinity increases, the properties of the water solution diverge from those of pure water. Physical and chemical properties of saline water also depend strongly upon the proportions of the major dissolved ions (sodium, calcium, magnesium, potassium, chloride, carbonate, bicarbonate, and sulfate) making up bulk salinity. This can affect engineering, geochemical, and biological considerations for the management of that water. A site-specific characterization of a project's saltwater is useful and perhaps necessary, especially where bulk salinity concentration is high.

The proportions of major dissolved constituents in saline water in the Owens Lake Project site are quite different from typical saltwater from the ocean. The information in this section arose from research and empirical testing performed during the initial phases of the Owens Lake Project. The characterization approach and some of the other observations may be applicable at other saltwater management project sites.

Freezing point, for example, is one physical property that varies significantly among saline water. It is well known that seawater has a lower freezing point than pure water; however, the freezing point is also affected by the ratio of chloride to carbonate. The freezing point of water from Owens Lake, which contains an appreciable concentration of the carbonate ion, is about 2 degrees Fahrenheit lower than that of seawater (at a concentration of approximately 35 grams per liter [g/L] TDS).

Important physical properties considered during the design, construction, and operations phases of the Owens Lake Project included electrical conductivity, density (specific gravity), viscosity, freezing point, evaporation rate, and temperature compensation coefficients for both electrical conductivity and specific gravity. Some of these properties varied dramatically from seawater, since the salt in seawater is predominantly sodium chloride. Important engineering properties are affected by changes in physical properties, such as the gravitational head of pressure generated by a given depth of water, and the energy required to boost water pressure.

Assessment of salinity concentrations is frequently required when managing systems containing high salt concentrations. Electrical conductivity or specific gravity can be (and are) often used to rapidly (but indirectly) measure salinity levels. Correlations between TDS concentration and both electrical conductivity and specific gravity were therefore the two most important physical properties considered.

Laboratory and field-based experimental protocols were developed to quantify the physical properties of saline waters found at Owens Lake. These relationships have been in constant use since to allow for consideration of salinity during planning, design, and operations.

Reclamation and Irrigation for Vegetative Establishment on Hypersaline Soils

Owens Lake has naturally extremely salty soil. Figure B7 illustrates this point, showing the Playa surface during a spring "salt bloom."

Maintenance of acceptable ranges of salinity in an irrigated soil is critical, even when tolerant plants are being grown. The principal means of achieving this goal is to ensure that excess salts are removed from the soil through application of water and subsurface drainage of some of that water (leaching). In the case of Owens Lake, a massive initial load of soil salinity needed to be removed by leaching. Even after the target soil salinity level is attained, some maintenance leaching is necessary to prevent long-term buildup of salinity due to evapoconcentration of saline irrigation water over time.

Leaching for reclamation at Owens Lake is restricted by low permeability of soil, by sensitive sodic soil, by obstructing strata (low-permeability sediment or cemented hardpan), and by perched groundwater at shallow depth. Natural subsurface conditions are illustrated in Figure B8. Similar to the water used for irrigation, reclamation water had to be blended to a salinity level that would not result in soil dispersion. Blended water is less effective for leaching (removing salts with saline water), but necessary to ensure water permeation into the soil. Therefore, artificial subsurface drainage (a perforated, gravity pipe network) was required for fields to drain adequately. The subsurface drainage system consists of networks of field drains converging to collector drains and then to sumps. The sumps are pumped into pressurized saltwater lines, which supply saline water for irrigation water blending or for surface wetting in other dust control areas. Excess drainage water may also be discharged to saltwater storage ponds.

The salinity levels of drainage water and shallow groundwater are similar. Their salinity and inorganic constituent concentrations are several times that of applied irrigation water.

The irrigation and drainage system for the 3.3-square-mile vegetated area was designed and constructed on a fast track. Design criteria were based on small (2- to 10-acre) pilot tests of drip irrigated saltgrass. Limited soil and subsoil data were available for the effort, and the design schedule did not allow time for intensive site characterization. Because soil and shallow groundwater conditions were known to be quite heterogeneous across the Playa, some system components had to be adapted during operations. However, with adaptive management, soils were reclaimed and saltgrass was successfully established over this large area under very challenging site conditions.

The following approach was used to provide adequate drainage and to establish plant cover:

1. Drainage design was based on the best available data, recognizing that in some areas drainage would be restricted even after drain installation and operation. The drainage design used reasonable drain spacings, anticipating that additional drains could be added at a later date to correct localized drainage problems where closer drain spacings were necessary.
2. An irrigation system was installed after the drainage system. High rates of irrigation were used to initially reclaim hypersaline soils, pushing salts out of the future root zone. This initial reclamation required about 40 days and is illustrated in Figure B9.
3. Fields were planted, and irrigation was scheduled (amount and frequency of irrigation) to ensure survival and rapid growth of plants in the largest portion of the area. This plan necessarily resulted in over watering and poor establishment of plants in the most poorly drained areas. About 20 percent of the plants in these areas of the site did not survive.
4. Once initial reclamation and plant establishment was complete, about 80 percent of the site had established vegetation. This vegetation had developed roots reaching the wetted zones of subsurface drip emitters and was able to tolerate reduced irrigation rates and still obtain irrigation water. Therefore, irrigation rates could be reduced significantly while still maintaining established vegetation.

5. Wet areas where plants had not established successfully were assessed to identify actions that would lead to successful plant establishment. Three general conditions were observed, including (a) reduced irrigation rates alone would result in drainage of water logged areas, (b) improvements to local irrigation or (surface or subsurface) drainage facilities were needed, and with restricted irrigation, would likely eliminate water logging, or (c) local conditions (such as restrictive soil layers or off-site shallow groundwater sources) prevented reliable establishment of vegetation. As a result of this assessment, about 120 acres with condition "c" that were heavily impacted by off-site shallow groundwater were removed from continued operation of managed vegetation and designated for construction of surface flooding facilities.
6. A site drainage improvement plan was developed and executed to provide drainage improvements in areas where these improvements could reasonably change site conditions and enable plant establishment.
7. Barren areas previously too wet for plant survival (about 20 percent of the site) were replanted.
8. Reduced irrigation was implemented. Specifically, irrigation scheduling was based on monitoring (1) soil wetness and plant conditions in the wettest replanted areas and (2) plant viability in the driest areas. This strategy allowed establishment of plants in the replanted areas and survival of plants in the already established areas, but with moderately compromised growth rates in the already established areas.
9. Vegetation was established on about 99.5 percent of the site, exclusive of the 120 acres where managed vegetation was discontinued and replaced by surface flooding.

In this manner, the overall drainage cost was maintained at a minimum level since drainage improvements were focused on areas with proven need, the leaching volume and drainage loads were minimized, and the site was successfully vegetated.

A long-term soil monitoring program has been initiated. Soil conditions monitored include soil salinity, structure, and fertility levels, as well as distribution around the drip irrigation source and throughout the root zone. Results will be employed to fine tune irrigation scheduling and water quality management.

Integrated Salt and Water Balance

In terms of the project wide water and salt balance, the major components are listed as follows:

Freshwater Supply

- Los Angeles Aqueduct (LAA) – The primary supply of water for the project (see Figure B10).
- Precipitation – Minor component with only 5.4 inches of precipitation per year on average.
- Stormwater inflows – Minor in terms of the overall annual water balance but significant during storm events.

FIGURE B7
The salt-crusted Playa showing cracking of clay-dominated soil.

FIGURE B8
Playa subsoil showing network of oxidized cracks among otherwise black, reduced soil. Reduction causes formation of minerals with black color and is an indication of perennial waterlogging and the depletion of oxygen.

FIGURE B9
After drainage, tillage, and initial irrigation, salts formed a hard crust at the surface, but the region below this crust, surrounding the drip tubing, had low enough salinity to allow for plants to grow.

FIGURE B10
One of two diversions in the Los Angeles Aqueduct supplying freshwater to the Playa. Downstream of these points, water is conveyed and distributed in pipes ranging from less than 1 inch to 60 inches in diameter.

Saline Water (Brine) Supply

- Subsurface drain water – Water collected in subsurface drain piping installed within the managed vegetation dust control areas is very saline and makes up the primary supply of brine used for blending with LAA water. Circulation of fresh and saltwater is illustrated in a schematic in Figure B11.
- Shallow flooding tailwater – Freshwater from LAA and brine from the subsurface drain water are mixed together for control of dust within shallow flooding areas. Tailwater collected along the downgradient edges of shallow flooding basins is recirculated back into the central brine conveyance system and can be directed back to shallow flooding or to brine storage or managed vegetation blending.

- Ultimate fate of excess salt -- Excess salt produced from reclamation of soil within the vegetated area is applied to shallow flood areas and is expected to accumulate in the basins along the lower elevation perimeter of the project. Periodic storm flows through these areas transport salt to the brine pool (the historic, natural repository for these flows).

As suggested in the two previous sections, salinity management in the soil of the Owens Lake managed vegetation area is critical to project success and requires careful management of the fresh and saline water sources. Several water management constraints and complicating factors make this project particularly challenging, including the following factors:

- **Regulatory constraints on discharges** – The complex regulatory climate of the Owens Lake Project has developed over many years, and includes multiple state and federal agencies with jurisdiction over portions of the local resources. The residual brine pool of the historic Owens Lake lies downhill from the dust control site and is a significant mineral resource, supporting an active trona mining facility adjacent to the managed vegetation site. Due to general contamination concerns and concern for possible effects on the quality of the trona deposits, direct discharges of brine water from the site were prohibited. Therefore, the water and brine system had to be largely self-contained.
- **Stormwater flows onto site** – Several stream channels draining large areas of the surrounding desert mountains flow onto the site of the dust control facilities. These channels are normally dry, but are subject to intermittent high flows as a result of intense rainstorms or snowmelt events in their headwater areas. These occasional, short-duration flows can quickly overwhelm the storage capacity of shallow flooding basins with very little advance notice. Salt flows out of shallow flooded areas, over downgradient spillways, along with these high stormwater flows. The volumes, frequency, and concentration of these storm flows can not be predicted with any precision, and therefore can only be incorporated approximately into the overall salt and water balance for the site.
- **Evapoconcentration of stored brine** – The recycling and open storage of high-salinity brine water in a desert environment necessarily results in considerable increases in salinity concentrations through evaporation. In the Owens Lake environment, it was recognized that brine could easily approach levels where increased brine density and salt precipitation lead to significant conveyance challenges.
- **Imbalances in the timing and locations of brine supply and demand** – It was recognized that the drain system would have to be operated year round to avoid intrusion of highly saline groundwater into the plant root zone. Driven by the resident hydrogeologic conditions and erratic climatic conditions, as well as by irrigation practices, the drainwater production does not necessarily occur at the same rate and/or at the same time as the saline water is consumed by blended irrigation water. In fact, the demand for irrigation water has a very steep peak in hot parts of the summer to meet the evapotranspiration (ET) demands of the vegetation. At the same time, irrigation in excess of ET demands is curtailed in the peak ET periods since these periods already demand the maximum flows in order to meet the high ET demands. Drainwater production, therefore, peaks in the times of the year when irrigation demand for saline water is less, such as early in the season, when excess irrigation is called for to leach accumulated salts from the root zone or during the winter, in the event of sustained precipitation events.

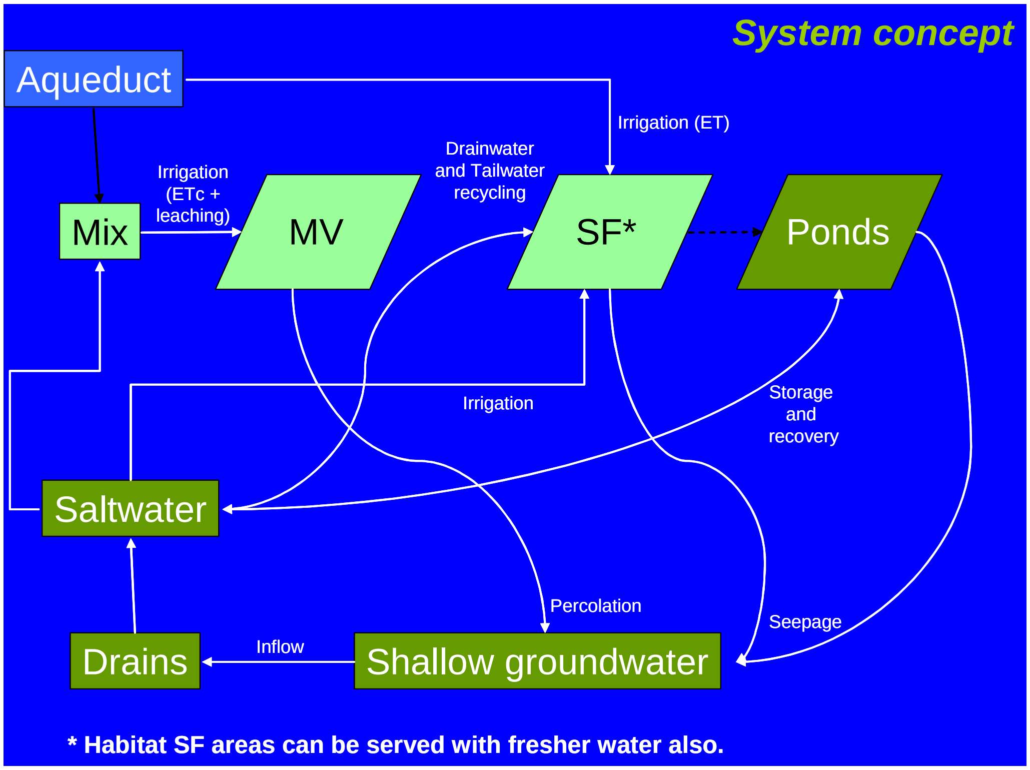

FIGURE B11
Components of the salt and water flow at Owens Lake.

The design of the water and salt balancing system included considerable upfront planning for operational flexibility along with monitoring and adaptive management responses. Following is a brief description of some of the key tools used to build an understanding of system wide water and salt management requirements:

- **General groundwater model** – In the early stages of system design, a general groundwater model was developed for the lakebed area targeted for the managed vegetation implementation. The model was first built using information from previously published, general-level reports and groundwater monitoring information for a handful of discreet locations around the lakebed that had been collected by the Air District as part of the research efforts conducted to develop the SIP. Supplemental, more site-specific information on hydraulic properties and groundwater quality was then collected during the design process to refine the model for the managed vegetation site. This model provided key information, albeit with wide confidence intervals, for sizing and spacing the subsurface drainage system and for estimating drain production under different irrigation scenarios.
- **Sitewide water and salt balance model** – Once the general concepts were developed for site-wide management and movement of the water and salt, a sitewide water and salt balance model was developed. This model incorporated a crop evapotranspiration module, best-estimate leaching fraction assumptions, drainwater yield estimates developed from the groundwater modeling effort and from operational monitoring data collected after startup, and pond evaporation estimates as a function of pond salinity. The model was developed on a monthly time step in order to represent the within-year imbalances in salt production and demand described above. This modeling process was

highly iterative to respond to rapid concept adaptations made as new information was gathered and new issues arose. However, the water balance model allowed estimation of drainwater volumes required for startup, storage capacity requirements for managing intra-year and inter-year imbalances between supply and demand, and intra-site conveyance capacities for meeting production and demand conveyance needs. The model was updated several times after the system was started to refine assumptions and to help reflect the impacts and needs of future facilities as new dust control areas were constructed.

Operational scenarios developed within the sitewide water and salt balance model highlighted several critical issues that would have to be addressed during project startup and operations. Some of these critical issues are outlined as follows:

- **Need for a dedicated brine-water conveyance system** – Blending freshwater and saltwater sources within a single irrigation water conveyance system was evaluated at the beginning of the project. However, due to the variations in brinewater quality and production both spatially across the project and temporally through each year, the irrigation water quality was projected to vary widely outside the irrigation water quality limits for various project components. Consequently, a dedicated brine-water conveyance system was developed that parallels the freshwater conveyance system across much of the project.
- **Incorporation of brine-water storage ponds** – The modeling effort quickly highlighted the need for flexible storage of brine water as a key component of the system. With informed estimates from the modeling effort, the size of this storage capacity was estimated, and the operational rationale for the pond connections was developed. The storage pond operational rationale allowed brine water to spill into the ponds from the pressurized brine water system whenever brine supply exceeds demand. Conversely, when demand for brine water exceeds immediate supply, additional brine can be pumped into the supply system from the pond storage.
- **Early construction of startup water storage -** One strategy that developed from the insight provided by the modeling effort was the concept of building a storage facility for advance storage of brine water for startup. To respond to this need, one of the designed storage ponds was pushed to the very early part of the construction schedule. Although the pumping, conveyance, and control components of the pond were not built until much later, the earthen portion of the storage pond was constructed as soon as possible so that any brine water produced during construction could be stored there. As construction progressed, brine water from numerous dewatering activities around the site was pumped to the storage pond using temporary, mobile pumps and surface pipes. In addition, as the field subsurface drainage system was installed and immediately began yielding drainwater, this water was pumped into the storage pond.
- **Stormwater discharge permit** – Given the likelihood of intermittent run-on of high volumes of flood water and the concern for potential impacts of discharges to the brine pool. An agreement was negotiated with the regulating agencies to allow periodic spills from storage ponds in the event of larger storm events. Conditions of the discharge permits included requirements for sampling the discharge and resulting surface flows. Accordingly, facility components were incorporated to allow controlled spillage during and immediately following storm events, and appropriate discharge monitoring protocols were established.

Halophyte Agronomy and Physiology

Where halophytes are to be planted, a reliable source of planting material is required. This posed a particular challenge at Owens Lake, where only native populations of saltgrass were allowed to be planted on the Playa; there was no source of seed other than wild saltgrass, and no reliable method of sowing the sand-sized seed in the field existed. Thus, seed to produce about 30 million Owens Lake native saltgrass plants had to be procured.

Research to date had used wild seed planted in trays at nurseries, and then transplanted onto the Playa. Unfortunately, only small amounts of seed were available in storage with Great Basin Unified Air Pollution Control District, and saltgrass does not reliably produce seed in nature. The time available to produce this supply was about 2 years from planning through transplanting.

Seed supply development incorporated three tactics:

(1) Gathering local native seed, where available,
(2) Planting seed multiplication fields with local native saltgrass in Owens Valley and on the California coast, and
(3) Developing seed priming to reduce the effects of dormancy and increase timely germination.

Transplants for the seed multiplication fields included many plants propagated from rhizomes cut from flowering female plants, with the goal of increasing the proportion of seed-bearing flowers and, thus, the potential seed yields of these plots.

Ultimately, this combination of tactics succeeded in producing about double what was required for planting. Had any of the tactics not been implemented, the seed supply would not have been sufficient. As it was, germination reliably exceeded 80 percent, so that one seed could be planted in each transplant cell. These plugs developed in a greenhouse and were transported to the Playa. The plugs were mechanically transplanted much in the manner of many vegetable crops. Where soil conditions were favorable and transplants were of adequate quality, resulting saltgrass survivorship was excellent. Figure B12 shows the saltgrass stand after two and a half seasons. This approach also maintained in the planted area the native genetic diversity available in natural saltgrass stands. Substantial genetic diversity among saltgrass clones is important for tolerance of the diversity of salt, drought, waterlogging, and heat stresses present in different degrees on the Playa.

Reference material on native halophyte agronomy and plant physiology being relatively scant, a substantial amount of research on these topics was undertaken with an eye to increasing the reliability and flexibility of the site, and potentially to bring down long-term operation and maintenance costs. Trials on fertilization, irrigation, plant spacing and competition, growth rate, planting methods, and critical tissue concentrations of minerals were carried out. In addition to saltgrass, greasewood (*Sarcobatus vermiculatus*), saltbush (*Atriplex parryii*), quailbush (*Atriplex lentiformis*), and rubber rabbitbrush (*Chrysothamnus nauseosus* ssp. *consimilis*) were investigated. Some of these shrubs are shown growing on the Playa in Figure B13.

FIGURE B12
2004 view of planted and irrigated saltgrass on Owens Lake.

FIGURE B13
Halophytic shrubs that were planted on the Playa.

Among the many interesting findings were the following:

- Supplemental fertilization greatly increases seed yield, seed quality, and growth rate of shrub species.
- Fertility, not water, is often the primary constraint to halophyte growth rate in this environment.
- Salt and drought tolerance of shrubs can exceed that of saltgrass.
- All species tolerate reduced irrigation, but saltgrass requires some irrigation each year to remain viable.

Non-saltgrass species are of interest for the future, but are not currently planted at Owens Lake. Preliminary findings on dust control effectiveness of the saltgrass plantings is that, at heterogeneous cover levels ranging from 5 to 60 percent of the ground surface, the entire site seems to function to control PM_{10} emissions at a very low level. Sand (the principal engine of dust emissions) accumulates in low, vegetated dunes along the site’s margins, protecting the interior, where mobile sand is no longer detectable. Saltgrass grows in response to burial by dunes, renewing cover and sand capture capacity along the site margins. Buried drip irrigation, present throughout the site, continues to water the root zone beneath the dune, and the plant conveys this water to growing stems and leaves that cover the surface of the soil. This demonstrates that plants irrigated with saltwater can provide significant benefits in terms of land stabilization and air quality.

Approach to Permitting and General Results of Water Quality Permitting

One of the issues that can arise when saltwater is used for irrigation is environmental degradation caused by salinity or the constituents of the salinity in that particular water. Famous examples include poisoning of waterfowl in Kesterson Reservoir, a sump for saline drainage water. Elements such as selenium, arsenic, and molybdenum can be associated with elevated ecological risk, and elevated salinity can degrade freshwater supplies.

At Owens Lake, the natural environment is quite saline. However, because project operation could increase the potential for wildlife ecological risk, the project owner was considered by regulatory agencies to be responsible for the salinity within the Dust Mitigation Program (and its effects). Shallow flooded areas, including newly resident waterfowl, are illustrated in Figure B14.

Under the Porter-Cologne Act and pursuant regulations, including the State Water Code, the Los Angeles Department of Water and Power was required to file for and receive Waste Discharge Requirements (the California equivalent of a National Pollutant Discharge Elimination System [NPDES] permit) from the Lahontan Regional Water Quality Control Board (RWQCB) before operating the facility.

As a result of concerns about potential environmental impacts of operating this facility, the Los Angeles Department of Water and Power (LADWP) committed to and executed an aggressive environmental monitoring program, aimed at early detection and rapid remedy of significant impacts. Groundwater, standing water, water supply, drain water, sediment, and food chain organisms (i.e., brine fly larvae and aquatic biota) were monitored. Additionally, wildlife abundance and activity were observed, salvaged eggs and eggs that failed to hatch were analyzed, and dead bird necropsies were performed to determine the cause of death.

FIGURE B14
Views of shallow flooding facilities at Owens Lake.

To date, the following conclusions have emerged:

- No significant wildlife impacts have been observed, although the general abundance of shorebirds and snowy plover on the lakebed is greatly increased (due primarily to the great increase in wetted Playa surfaces; wildlife use of the subsurface-drip irrigated vegetation is quite minimal).
- Trace elements have not bioaccumulated to toxic tissue concentrations.
- Bird use of the saltwater storage ponds, which are maintained at a very high salinity level (greater than 100,000 mg/L TDS), is minimal.
- Agricultural chemicals, which are generally applied at very low rates, do not increase naturally occurring concentrations of nutrients, or are nondetectable (in the case of one herbicide used to prevent root intrusion into subsurface drip irrigation) off-site.

Preliminary findings suggest that phosphorus is more mobile within the site than anticipated. Focused study is underway to determine why this is so, and how to most appropriately adjust phosphorus management. No phosphorus has been added to the site since planting.

The cost of environmental monitoring under this program, excluding focused monitoring of snowy plover, exceeded $1 million during the first year. Costs have been sharply reduced since that time based on data collected each year. A formal reduction in monitoring requirements from RWQCB has been applied for in fall 2005.

Potential for Application in Drainage Reuse, Concentration, and Disposal in One-Stage Systems

In some systems, the objective is to beneficially use as much saltwater as possible for irrigation of a given area, or to use a given flow for irrigation of the smallest area possible. When conventional crops are grown, saltwater may be diluted before application, and the irrigated area expands in rough proportion to the increase in irrigation water volume. However, as demonstrated at Owens Lake and elsewhere, halophytes can be irrigated with saltwater, often without dilution. This presents an opportunity for more compact reuse sites, which although perhaps more specialized and costly per unit area, may be less costly on the whole to build, operate, monitor, and maintain. This can also be taken into account where irrigated vegetation provides ancillary benefits (such as land stabilization).

When saltwater is being applied, salt concentration in drainage can be quite elevated. Where such concentration is desired, for example to reduce the volume of saltwater that must be handled or to prepare for further evaporative concentration, this is a desirable outcome. Where elevated concentrations are a concern, for example when receiving waters are sensitive to such concentrated inflow, potential impacts must take this into account during planning and design. Saltwater irrigation of halophytes may have merit for managing and concentrating diverse sources of saltwater, such as saline subsurface drainage return flows from agriculture.

Conveyance and Storage

The unique engineering challenges of conveying, pumping, storing, and distributing saline water, relative to pure water, were significant for the Owens Lake Project. Some of these challenges have already been mentioned in previous sections of this document. These engineering challenges, when evaluated separately, are not difficult to resolve quantitatively, however, they may be easily overlooked upon first inspection as they are not common considerations in the fields of agricultural or civil engineering.

The specific gravity of brine encountered on the Owens Lake Project varies between 1.0 and 1.3, approximately. Normal seawater has an average specific gravity of 1.035. Specific gravity of fluids being conveyed affects system design and operation in some or all of the following ways:

- Pump stations at Owens Lake can draw up to 30 percent more power than an identical station pumping freshwater, a fact that required many pump motors to be designed (increased in size) to handle the additional power load.
- The static water levels of two bodies of water that are connected by an underwater culvert through a dividing road or berm will differ if the average specific gravity of the water columns on each side of the road also differ. This is an elementary concept instructed to all students of physical science, but it is rarely observed in nature on the scale of water bodies hundreds of acres in size. The percent difference in elevation of the water columns corresponds to the percent difference in the average unit weight of each water column. This phenomenon has been observed at Owens Lake and can influence water level monitoring.
- Water bodies receiving inflows of differing salinity levels may become density stratified. Lower salinity water will float on top of more dilute water that is denser. Stratification is also observed in the open ocean and in freshwater lakes, but usually due to temperature-related density differences. Density stratification can drive currents within the water body, have dramatic impacts on the results at water quality monitoring (depending on the layer sampled), and influence the location and elevation of pump intakes, culverts, and outlets.
- Evaporation rates are depressed by salinity. This affects water balance and demand calculations and reservoir sizing. Water at the surface of a stratified pond is often the most dilute. The concentration of water at the surface, not the average water body salinity, determines evaporation from water surfaces. Where elevated concentrations can be achieved at the water surface, evaporative losses from the impoundment may be significantly reduced.
- Dense, saline layers have low convective heat loss. This occurs when they are stable, underlying strata below more dilute layers, so that thermal mixing that would otherwise occur is prevented. When radiative heat gain in the lower stratum is significant, it may become much warmer than overlying layers. In some instances, this phenomenon is employed to generate power.
- Buoyancy calculations for buried concrete vaults and pipelines must also be adjusted for the specific gravity of groundwater, when that specific gravity is expected to significantly exceed that of pure water. Increased buoyancy can be compensated by wider foundations for vaults and deeper installation for pipelines, both of which normally increase construction cost.

In addition to the special design considerations imposed by the high density of concentrated brine solutions, several operational considerations related to extremely high salt concentration (greater than 350 g/L TDS, approximately) have also been identified.

- In an arid climate, impoundments receiving mostly relatively saline inflow and without regular outflow of salt, rapidly develop salt crust on dry areas, with standing water approaching saturation.

- Pumping and conveyance of hyper-saline (especially saturated) brine solutions can result in almost immediate blockage or coating (with precipitated salt crystals) of pump intake structures, stainless steel intake screens, valves, irrigation risers, pump impellers and possibly the internal surfaces of buried conveyance lines. This can be addressed locally by dilution of the saturated brine directly at the pump intake vault, allowing ongoing accumulation of salt without overwhelming pump stations with salt precipitate.
- The remaining challenge for salt management at Owens Lake will be to optimize the placement of future saline drainwater, generated by the managed vegetation areas, amongst the numerous terminal evaporation (shallow flood) basins. These flows should be directed to the shallowest of the basins that have the highest potential to maintain extremely high salinity levels. Higher water salinity in the terminal shallow flood areas will result in a lower net consumptive use of valuable aqueduct water.

Corrosion Protection

The Owens Lakebed is extremely corrosive to construction materials because of its high salt content, high groundwater levels, and seasonally elevated temperatures. Provisions to control corrosion have been incorporated in the project to extend the service life of materials. These measures protect against degraded appearance and reduce the required maintenance of facilities. However, even with upgraded protection, more attention than normal will be required for maintenance and replacement of equipment due to the extreme conditions. Protective measures incorporated in the construction are summarized below.

Materials Selection

Construction materials were selected based on the best corrosion resistance available for the required components. Plastic and nonmetallic materials were used wherever possible because they are generally not affected by saline conditions.

Corrosion-resistant metal alloys were used for applications that require metallic materials. However, the most corrosion-resistant alloys that are commercially available for many of the required components consist of stainless steels that are not completely resistant to the saline conditions at Owens Lake. Therefore, supplemental cathodic protection is provided for stainless steel where it is directly buried.

Copper alloys, which are usually well-suited for brine service, are subject to corrosion by hydrogen sulfide from decomposing organic materials buried under lakebed sediments. Therefore, their use is limited where possible, but the use of copper for electrical wires makes it inevitable that copper will be used in construction. Protection for copper electrical devices includes measures such as tin plating, high-quality wire insulation, sealing of conduit openings, and even painting where feasible to seal finished connections and prevent contact with corrosive agents.

Concrete structures incorporate several methods of protection against corrosion: concrete mix design using high-strength formulations and sulfate-resistant cement; epoxy-coated steel reinforcement; and barrier coatings.

Cathodic Protection

Cathodic protection is provided for all buried steel, stainless steel, and copper components (except electrical grounding systems) because the salt concentration exceeds the normal corrosion resistance limits of the alloy. Cathodic protection is also provided for metallic components submerged in pump stations.

Barrier Coatings

A variety of protective coatings, plastic linings, and covers are used to provide a barrier between the saline environment and the material. These include anchored sheet linings (T-Lock) in pump stations, membrane waterproofing systems outside pump stations, and epoxy painting systems on the surface of pads at fertilizer stations.

Additional information on corrosion protection can be found in Section 10 of the Operations and Maintenance Manual and other reference documents, including Technical Memoranda.

APPENDIX C

CASE STUDY – CONCENTRATE DISPOSAL ALTERNATIVES ANALYSIS, AURORA, CO

Residuals Treatment and Disposal

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DATE: September 22, 2005

Conclusions

If selected for purification, high-pressure membrane concentrate could be handled using solar evaporation ponds. This alternative provided the lowest cost per unit benefit. Other disposal options would face significant challenges in obtaining the required permits. Alternatives, such as discharging to surface water, have lower benefits due to environmental impacts or operational intensity needed to meet the likely effluent quality requirements.

High-Pressure Membrane Concentrate

Sources and Quantities

Characterization of the concentrate produced by reverse osmosis (RO) membrane filtration is one of the defining factors in the ultimate determination of treatment and disposal options. Many water quality factors are important in considering discharge or beneficial use options associated with the concentrated brine solution. Total dissolved solids (TDS), organics, volatile organic compounds (VOCs), metals and other compounds will be concentrated through this process. Regulated and nonregulated compounds will be separated by RO into permeate and concentrate streams. The concentrate stream (brine) contains all of the rejected constituents in the RO process and must be disposed.

Table C1 presents expected concentrate composition for the Aurora Water Purification Facility (ARWPF). Values for this table were calculated based on an assumed 87-percent recovery and 99-percent rejection in the RO system. From this analysis, in conjunction with drinking water maximum contaminant levels (MCLs), potential impacts and limitations on disposal alternatives have been assessed and concentrate treatment and disposal options will be discussed.

Handling and Disposal Alternatives

A variety of disposal and reuse options were identified for handling the concentrate produced in the high-pressure RO membrane filtration process. A description of each potential option is discussed in this section. The concentrate flow based on an assumed 87-percent recovery is 4.42 million gallons a day (MGD). The disposal of this concentrate is a significant factor to be considered in the design and regulatory compliance issues that are associated with the operation of the facility, should RO be incorporated. A diagram of an RO membrane is presented in Figure C1.

Discharge to Surface Water

The Colorado Water Quality Control Commission establishes use classifications and associated standards for surface water and groundwater and maintains regulations pertaining to protection of these waters. Any discharge to surface waters or to land (which can then influence the underlying groundwater) must obtain a permit from the Water Quality Control Division (WQCD). These permits contain limits on the quality of the discharge that ensure the pertinent water quality standards are protected.

TABLE C1
Predicted Concentrate Composition

Parameter	Projected Aurora WTP Concentrate
Potassium	42.5
Sodium	603
Magnesium	119
Calcium	543
Strontium	13.4
Barium	0.24
Carbonate	9.12
Bicarbonate	1,221
Nitrate	237
Chloride	503
Fluoride	7.21
Sulfate	1,238
Silicate	75.4
Carbon Dioxide	30.2
TDS	4,611
pH	7.6
Flow Rate	4.42 MGD

While there is no surface water salinity or total dissolved solids standard in Colorado other than for the Colorado River, increases in receiving water salinity due to brine discharges may result in failure to meet other water quality standards. High salinity levels would likely mean that levels of other constituents such as chloride and sulfate are also high. The toxicity of salinity is dependent on the individual concentrations of the salts. However, high levels of salinity, such as above 2,000 to 2,500[1] milligrams per liter (mg/L) can be toxic. WQCD will evaluate the resulting level of salinity in the stream when determining if brine discharge to surface water is permittable. WQCD cannot permit discharges that result in the stream being toxic.

Discharge to the South Platte River

The major concern with the discharge into surface waters is the ability to cost-effectively treat the discharge to a level that does not result in violations of water quality standards in the receiving water. The South Platte River, Segment 15, begins at 64th Avenue and the South Platte River and extends to Fort Lupton, as depicted in Figure C2. This segment is classified as a water supply.

As stated previously, there is no salinity standard for the South Platte River; however, the discharge of RO concentrate to the South Platte River has the potential to impact its ability to be used as a water supply, thus resulting in an impact to an existing use. Such an impact would force WQCD to impose a TDS or salinity standard. In addition, the potential for concentrations of individual constituents (e.g., nitrate, selenium, cadmium, etc.) pose individual risks to the use that could result in failing to meet in-stream standards. Such impacts could result in WQCD prohibiting such discharges.

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[1] The toxicity of high TDS water is dependent on the species being tested and the salts which contribute to the TDS value. There is no single concentration that can be assumed to be toxic.

Another concern with a discharge is that a large portion of the South Platte River downstream of the Metro District’s Central Treatment Plant (CTP) is effluent. Therefore, any discharge to the river has the potential to affect the ability of the CTP to discharge at this current permit limits. The Segment 15 South Platte water quality modeling effort conducted as part of the consideration of the Thornton concentrate has shown that any additional discharge of nitrate into the river will result in the need for Denver Metro to make significant treatment plant improvements and a cost approaching $100 million. Therefore, it is unlikely that Denver Metro will volunteer to make such change.

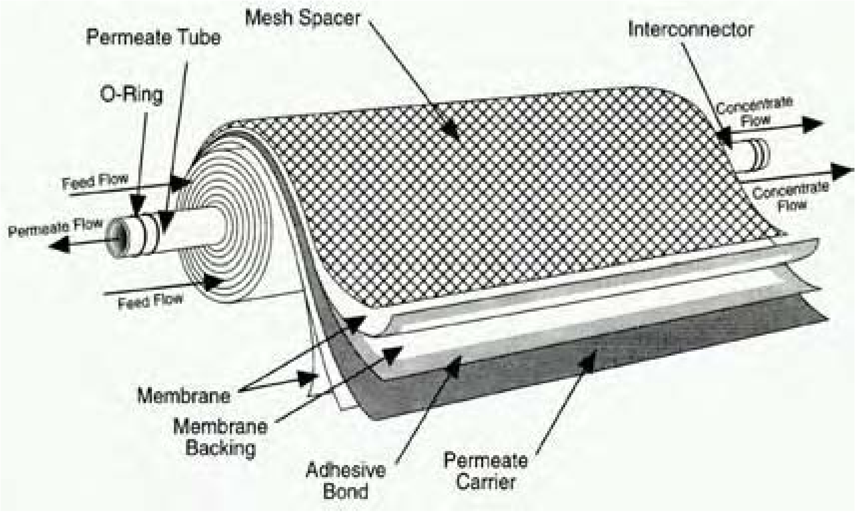

FIGURE C1
Reverse Osmosis

The City of Thornton has applied for a National Pollutant Discharge Elimination System (NPDES) permit to allow the discharge of concentrate from its new RO water treatment plant (WTP) to the South Platte River. Modeling done by SPCURE has identified that nitrate levels are currently at or near the water standard during large parts of the year. Therefore, the discharge cannot be allowed unless the City of Thornton provides additional treatment of their concentrate prior to discharge. As a result, the City of Thornton has requested a permit to discharge to the South Platte River through a unique scenario that considers the available unused nitrate load capacity not on the basis of low flow statistics, as required by state and federal regulations, but on the dilution capacity of the South Platte River for nitrate during high flow conditions.

The City of Thornton submitted a permit application to WQCD, and WQCD has stated that a permit could only be issued to Thornton if it is based on low flow conditions. As stated previously, the results of SPCURE modeling showed that the Thornton discharge could not meet the anticipated discharge limits without treatment. However, the Water Quality Control Commission has established a workgroup to look into whether its regulations should be changed to allow discharges at higher flows. It is anticipated that a final decision will be made in July 2006. If Thornton is successful in obtaining a permit through this approach, practically no remaining assimilative capacity would be available for other discharges, including a RO concentrate from the ARWPF.

Discharge to the South Platte River would involve piping the concentrate directly to the river or to a tributary of sufficient dilution capacity that flows into the South Platte River. The cost and other issues of pipeline conveyance of concentrate (obtaining right-of-way, constructing the pipeline, concern for deposition of concentrate scale in the pipeline, etc.) can be significant.

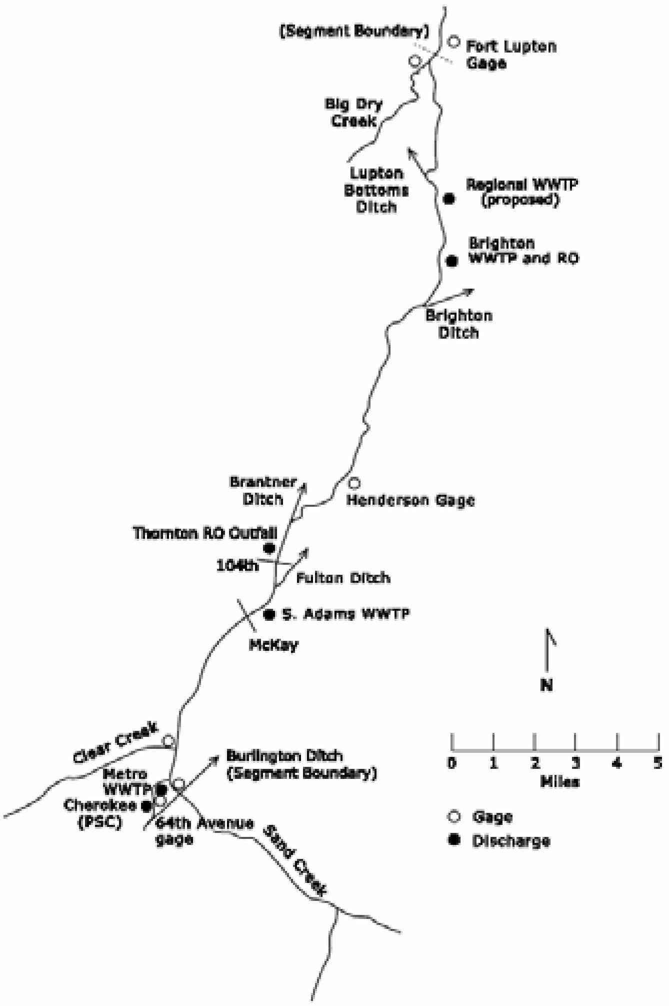

FIGURE C2
Map of South Platte River

Discharge to an Irrigation Ditch or Canal

Another concentrate surface discharge option is an irrigation ditch such as Fulton, Brantner, or Brighton ditches. These ditches are all downstream of the Denver Metro CTP discharge, which assures a reasonable flow even during droughts. Irrigation ditches upstream of the Metro plant are of lower flow volume and can be dry during drought conditions and thus do not assure the dilution flows necessary for a discharge permit. The advantage of discharge to an irrigation ditch over discharge to the South Platte River is that the irrigation ditches have no classified uses or water quality standards. Therefore, they would not have a nitrate standard.

It is possible that through implementation of best professional judgment, WQCD could impose a nitrate limit on a discharge to protect the agricultural use. The agricultural nitrate standard normally imposed by the Commission is 100 mg/L for nitrate plus nitrite. The projected nitrate level of 237 mg/L in the concentrate would be a problem in the case of discharge to irrigation water unless there was significant water in the ditch to dilute this to less than 100 mg/L. This would be an issue for discharge to the South Platte River, where the nitrate standard is 10 mg/L. In addition, approval would need to be obtained from the owner of the ditch prior to discharge. Some ditch owners, such as FRICO, are concerned about the levels of nitrogen in their ditches and may not allow the discharge.

To further evaluate the potential of this scenario, the Fulton W.W. Ditch[2] was chosen as a possible discharge location. The analysis should be representative of other irrigation ditches or canals. Historically, the Fulton W.W. Ditch opens about mid-March and closes between October 15 and November 1. For the purpose of analysis, the irrigation season is assumed to last 7 months.

For the ARWPF, if membrane plant operations were year round, the concentrate produced for 5 months would have to be stored. At 4.42 MGD, this amounts to 672 million gallons (MG) or 2,075 acre-feet. This is a sizeable storage pond depending on pond depth as shown in Table C2.

TABLE C2
Storage Pond Sizes

Pond Depth (feet)	Area (acres)
10	208
20	104

When the stored concentrate is also sent to the irrigation ditch during the irrigation season, this represents an additional TDS load on the ditch. Assuming a 7 month irrigation season and uniform use of the stored concentrate, this adds 3.15 MGD (672 MG divided by the 213 days of the irrigation season) to the 4.42 MGD being generated during the irrigation months for a total of 7.57 MGD. The irrigation water TDS in this case is projected to be from 958 mg/L to 1,173 mg/L, or an increase of 258 mg/L to 473 mg/L from the base level of about 700 mg/L. However, since irrigation ditches are not classified by the Commission, the WQCD could not impose a salinity standard. However, the owner of the ditch could require one as part of obtaining approval. The high salinity could raise concerns from the ditch owners and users of the water associated with livestock watering, and damage to crops, or other concerns. The distance from the proposed plant site to the Fulton W.W. Ditch is a minimum of about 20 miles. Issues of pipeline, pumping, and right of way would also need to be evaluated.

Discharge to a Wastewater Treatment Plant (WWTP)

Discharging concentrate to a WWTP may affect the ability of the WWTP to adequately treat the wastewater. Studies have shown that mixed liquor with high concentrations of monovalent cations or a high monovalent to divalent cation ratio causes floc to lose resistance to shear, resulting in dispersed particles that are difficult to settle and dewater, produce turbid supernatants (filtrates), and contain soluble polysaccharides that elevate the soluble organic matter content of the supernatant (filtrate). Hence, treatment of brine and other WTP wastestreams could increase the monovalent cation concentration to adversely affect both the liquid and solid stream at the WWTP. These types of effects seem to be most critical in solids dewatering and concentrating processes such as sludge filtration and centrifugation where particulate concentrations are the highest. However, many situations exist where these effects are important in the activated sludge process itself.

In the activated sludge process, the microbes are suspended with the wastewater in a reactor. In order for this process to work effectively, the biomass must be separated from the water and this is accomplished by gravity settling in the secondary clarifier. To effectively settle, the microbes must flocculate, then aggregate into units large enough and dense enough to settle out of solution. Early studies evaluated the effect of cations on settling and dewatering properties for industrial processes showed that sodium, potassium, and ammonium ions

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[2] Fulton W.W. Ditch is a proper name; “W.W.” is not an abbreviation for wastewater.

caused deterioration in settling and dewatering properties. Therefore, high levels of these substances in the RO concentrate could then affect the ability of the WWTP to meet its permit requirements. In addition, depending on the materials in the concentrate, the WWTP's discharge may be subject to additional permit limitations. Therefore, an evaluation on how the concentrate would affect the WWTP processes and effluent water quality would be necessary to fully consider this option.

Discharge to Metro Wastewater Reclamation District

This option was explored by the City of Thornton. In response to a letter from the City of Thornton, Metro stated that because the District was created to treat sewage, water treatment residuals constitute a waste the District is not required to treat under its enabling legislation and the Service Contract. If the Metro Board decided to accept RO brine, the Board's Capital Recovery Charge would apply and a connection fee of approximately $33 million would be due based on the peak flow and estimated concentration of pollutant loadings.

The Metro District calculates its Capital Recovery Charge on the value of its capital facilities, planned growth related capital projects and fund balances, and the peak discharge "use" in terms of flow and pollutant loadings necessary to treat the proposed waste stream. While the Capital Recovery Charge for the City of Aurora has not been calculated based on its projected discharge, the Metro Board's policy related to the assessment of Capital Recovery Charges applies to all discharges of wastes the Metro District is not required to treat, such as glycol-contaminated stormwater from Denver International Airport. As a result, Aurora would be assessed a Capital Recovery Charge if the Metro Board agreed to accept RO brine.

In addition, there are significant technical questions associated with the discharge of water treatment plant residuals to wastewater treatment plants. There are concerns that the introduction of such wastes could upset the treatment processes or result in significant increases in operational costs. As a result of several different water treatment plant operators contacting the District, they have commenced a study of the impacts of such discharges on their wastewater treatment plant. It is suggested that the City track this project.

Mixing of Concentrate with WWTP Effluent

WQCD has allowed RO brine to be mixed at the discharge point, prior to release into the receiving stream. Under this scenario, the WWTP effluent would dilute the brine to acceptable levels. There are several concerns with this option, including:

1. Who is responsible maintaining compliance with the discharge permit? If the two discharges are controlled by the same entity, this may not be of concern.
2. The WWTP would need to have sufficient flow to allow for adequate dilution.
3. The parameters of concern would need to be compatible. For example, if the brine had high nitrate levels and the WWTP had a low nitrate limit, the two effluents may not be a good match.

It is unlikely Metro would be willing to combine CTP effluent with an RO brine discharge. No one currently combines their discharge with the CTP effluent. Metro would be reluctant to accept a scenario because:

1. A discharge of RO brine with high nitrate levels would impact their ability to discharge nitrate from their CTP. This could be true of other parameters also.

2. Accepting the liability of the discharge from an outside party. Any permit would likely be their responsibility, but without the ability to control the RO discharge.
3. The precedent it would set for others to mix their discharge with the CTP effluent.
4. Concerns regarding the impact of future salinity standards for the South Platte River on the District's effluent limits for the CTP.

Discharge to the Aurora Sand Creek Wastewater Reclamation Facility

Many of the legal and connection cost issues would be eliminated by the discharge of WTP residuals to the City's Sand Creek Wastewater Reclamation Facility (SCWWRF). However, the treatment related issues would still be of concern. In addition, other issues would include:

1. SCWWRF facility is sized to treat only 5 MGD and pass the rest to Denver Metro. To eliminate Denver Metro from any input into the project, all residuals would need to be handled at the facility. There would be capacity concerns.
2. The cost of piping the wastewater to the plant would be significant.
3. The SCWWRF was designed to produce reuse water. The effluent from the SCWWRF is used for irrigation. It would be necessary to evaluate the effect of the discharge on the salinity of the effluent to ensure that it would still be acceptable for irrigation.

Mixing of the concentrate with the effluent of the SCWWRF may be a more acceptable alternative. The legal issues would not be of concern since both facilities are operated by the same entity. One advantage of such a discharge is that currently Sand Creek does not have nitrate standards. The mixed effluent would flow several miles before entering Segment 15, during which denitrification of the waters could occur as well as dilution. An evaluation would need to be done of the possible effects on the South Platte River of this discharge.

The concerns with this alternative are the cost of piping the concentrate to the plant and the variable flow from the facility during irrigation season. If adequate dilution is not available, high salinity in the concentrate could more readily affect the ability of the combined discharge to meet whole effluent toxicity requirements. Because of the cost of the piping, this may not be a feasible alternative.

Deep Well Injection

Deep well injection relies on injection wells to deliver the concentrate into deep geologic formations that, in theory, have no potential to allow migration of contaminants into potable water sources. A typical injection well consists of concentric pipes, extending several thousand feet into highly saline, permeable injection zones that are confined vertically by impermeable layers.

Although deep well injection is an effective and commonly used technique for concentrate disposal, there is always the risk of the brine solution contaminating less saline waters or freshwater aquifers as well as other unknown long-term environmental affects. For this reason, characterization of the concentrate and the identification of an appropriate geologic area are important in establishing the feasibility of this disposal option.

Membrane concentrate is classified as an industrial waste, which requires a Class I well for disposal. Class I wells utilize aquifers that are structurally isolated from overlying drinking water aquifers (any aquifer of TDS less than 10,000 mg/L). Monitoring requirements stipulate a tubing and packer arrangement that prevents direct leakage of concentrate from the well. The injection tubing is surrounded by an annular space filled with a monitoring fluid that is tested for changes in salinity to monitor leaks. Total cement casing is also required. These three requirements add considerable cost to the injection wells.

Class II wells for disposal of water from oil and gas drilling do not have these restrictions. Class I wells are overseen by the U.S. Environmental Protection Agency (USEPA), while Class II wells are overseen by the Colorado Oil and Gas Conservation Commission (COGCC).

Potential injection well possibilities for disposing/reusing the brine concentrate include:

- Use of existing Class I wells
- Drilling of Class I wells
- Reworking of abandoned Class II wells

Use of Existing Class I Wells

There is only one Class I well in eastern Colorado. It is called Suckla Farms I and is owned by Wattenberg Disposal LLC. The well is located approximately 4 miles west of the South Platte River and about 1 mile south of State Route 52 in Weld County. This well was drilled to a depth of over 9,000 feet and has a 5.5-inch casing. It currently receives around 1,000 barrels per day (bbl/day; about 42,000 gallons per day [gpd]). Based on a concentrate flow of 4.42 MGD (approximately 19,500 bbl/day), it would take 105 wells of similar capacity to dispose the concentrate volume. Because there is only one Class I well available, this option is not feasible.

Drilling of Class I Wells

The Denver area, in hydrogeologic terms, is referred to as the Denver Basin. It is roughly an oval shape area extending from Greeley in the north to Colorado Springs in the south, and from the foothills in the west not quite to Limon in the east. The geological formations increase in depth from the surface as one moves from the edge to the center of the basin – regardless of compass direction. The Aurora plant site is in the central area of the basin, thus, the depth to an adequate confining layer is likely on the same order as the Suckla Farms I Class I well. Depth to a confining layer might be substantially less in the Limon area, for instance.

In general, the depth and capacity of a potential receiving aquifer are unknown. Petrotek suggested that it would take approximately 105 wells with a capacity of 42,000 gpd (similar to the Suckla Farms I well) to inject 4.42 MGD (Mickley 2005). It would be impossible to do this in a single well in Colorado, given the available information about aquifer capacities and uptake rates. Further, due to aquifer characteristics, individual wells would be thousands of feet apart.

Drilling of injection wells within a reasonable distance of the proposed plant site such that conveyance does not become the overriding cost factor raises many challenges. First, a more in-depth analysis of available data would be needed to determine if a candidate receiving formation could be identified with enough promise to warrant an exploratory bore hole. The depth and the receiving formation characteristics would still be unknowns before the drilling. Such a bore hole might cost $1 million or more.

If deep well injection was determined to be feasible based on the exploratory well, approximately 105 new wells would have to be drilled. New wells may cost in the range of $100 per foot of depth, a typical new well cost would be in approximately $1 million. Obtaining the rights to a well, unplugging the well, installing tubing and packer, and running mechanical integrity tests may cost one-half of a new well price, or about $500,000. Injection operations at high surface pressure would add electrical costs of about $3 per 1,000 gallons disposed of, which corresponds to $4.8 million per year. There is also no guarantee that the selected well will be capable of an injection rate of 42,000 gpd. Pipeline costs, power costs, and right-of-way costs must also be considered.

This deep well injection option would likely require an initial investment of more than $1 million to determine its general feasibility. If feasible, well drilling alone would initially cost approximately $157.5 million and require piping and right-of-way. At this stage, it is unclear that an adequate, structurally isolated aquifer is available. Even if an ideal aquifer was located, the amount of infrastructure required to accomplish this brine disposal method would likely be prohibitive.

Reworking of an Abandoned Class II Well

The map in Figure C3 shows many oil and gas wells in the general Denver area. Information about these Class II wells is available from the COGCC online database.

A major limitation for existing Class II wells is the small diameter, which is typically 4 to 5.5 inches in casing diameter. If Class II wells were reworked to make a Class I well, the well depth would need to be increased along with the well diameter. Hydrogeological studies similar to that needed for a new well would be necessary to establish the confined nature of the aquifer and the capacity of the aquifer for uptake rate of concentrate.

As with the drilling of a Class I well, reworking Class II wells has the following unknowns: existence of suitable underlying aquifer, depth to the aquifer, permeability/capacity of the aquifer, and well spacing for multiple wells.

This option is judged not to be feasible due to limiting hydrogeological conditions on the capacity of an individual well, the large number of wells needed over a wide area, and the complex distribution network needed.

Land Application

The land application of concentrate brine for irrigation can be an economical and simple means of handling the wastes associated with RO treatment. While this strategy provides beneficial use by conserving the already limited water resources in the area, there are several issues which may hinder the successful implementation of this reuse technique.

High salinity or major ion toxicity may preclude land application of the concentrate if levels exceed threshold levels tolerated by the irrigated crops. In most cases, dilution of the brine is required in order to prevent damage to the vegetation. Bioaccumulation of metals has also been cited as a potential concern for land application of RO concentrate. The proximity of the plant to the crop or field to be irrigated is also a factor in determining the feasibility of this option, as long conveyance systems can be cost prohibitive.

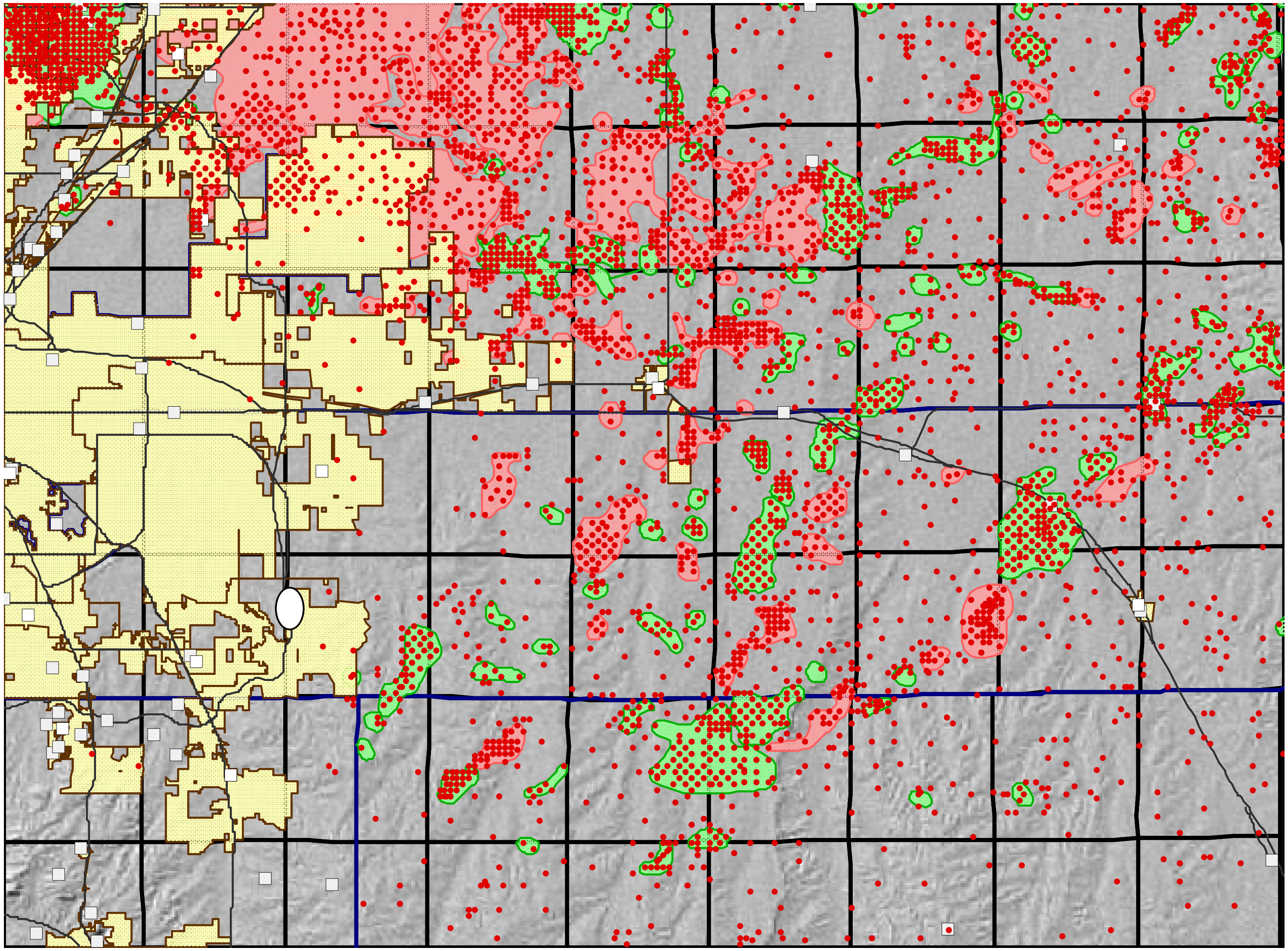

FIGURE C3
Oil and Gas Fields in Aurora Area

Using concentrate brine for irrigation must comply with all regulations pertaining to surface and groundwater quality, and would thus require a discharge permit. Basically, the concentrate brine would be treated as a wastewater discharge to the ground water through land application. The applicable Colorado regulations for this type of discharge are:

- *Colorado Discharge Permit System Regulations, Regulation No. 61* (5 CCR 1003-61) (Regulation 61) – Pursuant to Section 61.14(1) of this regulation, a permit is required for all land application discharges and for all discharges from impoundments unless the discharge is excluded by one of the stated exemptions. This regulation defines land application as any discharge being applied directly to the land for land disposal or land treatment. Land disposal is the discharge being applied to the land for which no further treatment is intended. Land treatment is the application to the land for the purpose of treatment.
- *The Basic Standards for Ground Water, Regulation No. 41* (5CCR 1002-41) (Regulation 41) – The purpose of these regulations is to establish statewide standards and a system for classifying ground water and adopting water quality standards for such classifications to protect the existing and potential beneficial uses. The regulation includes language for an interim narrative standard that is applicable to all groundwater for which standards have not yet been adopted on a site-specific basis. This language states that the groundwater quality is to be maintained to either the existing ambient quality as of January 31, 1994, or to the quality which meets the most stringent criteria set forth in the regulation, whichever is less restrictive.
- *Site-Specific Water Quality Classifications and Standards for Ground Water, Regulation No. 42* (5 CCR 1002-42) (Regulation 42) – This regulation applies the framework for groundwater classifications and standards set forth in Regulation 41 to site-specific groundwater, and adopts an interim narrative standard to protect groundwater prior to adoption of the use classifications and numerical standards.

The two concentrate management options for land application include:

- Direct discharge (after blending) for landscape or agricultural irrigation
- Direct discharge to percolation ponds

Direct Discharge (after blending) for Landscape/Agricultural Irrigation

To utilize brine concentrate for irrigation, there will be a need for cold season storage as well as blending of the concentrate prior to use for irrigation. One potential advantage might be if landscape use could be found near the plant site to simplify the conveyance challenges.

The concentrate will need to be blended with other waters to an extent necessary to ensure it is not toxic to the crop or vegetation and that groundwater standards are not exceeded. Comparison of the standards with the levels in the concentrate determines the level of blending required for each constituent.

For the purpose of establishing a basis for evaluating land application of concentrate, the following regulatory assumptions were made:

- The groundwater is not classified.
- The ambient quality of the groundwater is not known.

TABLE C3

Groundwater Standards for Selected Constituents

Constituent	Concentration (mg/L)
Barium	2.0
Chloride	250
Iron	0.3
Nitrate (as N)	10
Sulfate	250

According to Regulation 41, an interim narrative standard is applied for groundwater that is not yet classified or has standards. The interim narrative standard requires the groundwater quality to be maintained to either the existing ambient quality as of January 31, 1994, or to the quality which meets the most stringent criteria set forth in the regulation, whichever is less restrictive. Therefore, for this case, the most stringent standards would apply from among the Human Health, Drinking Water, and Agricultural standards specified in Regulation 41. The levels are at least as stringent as the drinking water standards, and in some cases, more stringent. There are restrictions for more than 25 inorganic constituents. Standards for select constituents are shown in Table C3.

Regulation 41 sets the maximum allowable TDS concentration in the groundwater based on the background TDS value. For background TDS concentrations of less than 500 mg/L, the maximum allowable TDS concentration is either 400 mg/L or 1.25 times the background level, whichever is least restrictive. If the background TDS is greater than 500 mg/L (but less than 10,000 mg/L), the maximum allowable TDS concentration is 1.25 times the background level. There is no limit if the background TDS is higher than 10,000 mg/L. Using the *Atlas of Ground Water Quality in Colorado* (Repplier et al. 1981) to obtain a preliminary estimate, it appears the TDS concentration of the shallowest groundwater on the Front Range could be less than 500 mg/L.

The minimum possible dilution of concentrate required to meet the groundwater standards for each of the Table C3 constituents may be calculated based on the concentrate levels, the standard levels, and the assumption of dilution water level of the species in question. Table C4 presents these dilution ratios to meet the requirements in Regulation 41.

Table C4 may be interpreted as follows: for a concentrate with a chloride level of 503 mg/L, if the dilution water has a chloride level of 80 percent of the standard level (80 percent of 250, or 200 mg/L), then for the mixture to reach the standard level of 250 mg/L, 5 parts of the dilution water would need to be added to 1 part of the concentrate. Based on this, it is obvious that the required level of dilution is strongly dependent on the water quality of the dilution water and the TDS of the underlying groundwater. For the purpose of allowing a calculation, it is assumed that the dilution water is of TDS 250 mg/L, which is the limiting factor. This would dictate a required dilution of 16:1. It is unlikely that this volume of dilution water is available.

Another issue has to do with the amount of land required for irrigation. In order to develop a preliminary level estimate of the required land area, the irrigation schedules used by farmers utilizing the Fulton W.W. Ditch water was studied. Irrigation schedules for 80 cubic feet per second (cfs) tend to be 2 days on and 4 days off, with the irrigation being done 24 hours per day for the 2 days. This is an equivalent of 8 hours per day over the 6-day span. When more flow is available (for example, 155 cfs), the irrigation schedule is 4 days on and 2 days off with the daily irrigation from 5 a.m. till dark. This might be 15 hours per day for the 4 days, which is equivalent to about 10 hours per day over the 6-day span.

TABLE C4

Required Dilution Ratios to Meet Standards

Species	Concentrate Level (mg/L)	Standard Level (mg/L)	Ratio dilution water to concentrate for different dilution waters		
			Level of species in dilution water as percent of standard		
			0 percent of Standard	50 percent of Standard	80 percent of Standard
Chloride	503	250	1 : 1	2 : 1	5 : 1
Nitrate	237	50	3.7 : 1	7.5 : 1	19 : 1
Sulfate	1,238	250	4 : 1	8 : 1	20 : 1
TDS if = 500	4,611	500	8 : 1	16 : 1	41 : 1

Based on the number of water shares and most of the situations being 1 share per acre (some as low as 1 share per 3 acres), and there being on average 38.4 shares per cfs, the water use ranges from 4.15 to 12.45 gallons per minute (gpm) per acre. This is an average rate over the entire irrigation season.

Based on these numbers, the acreage that can be serviced by the concentrate volume (neglecting the necessary dilution) is 246 to 739 acres. This is the additional area enabled for use from the addition of concentrate to the Fulton W.W. Ditch water. For landscape irrigation with concentrate blended by a factor of 1:16, the area required would be 17 times this or from 4,180 to 12,560 acres (9 to 27 square miles). Another estimate for land requirement based on irrigation of 3 inches per week comes to 6,494 acres (14 square miles).

Thus, the benefit of not having long conveyance distances is replaced by the need for large amounts of blending water and irrigation land and the resultant large distribution system.

Percolation Ponds

A discharge of concentrate to percolation or rapid infiltration basins could be allowed provided that the ground water standards are met at the point of compliance. According to Section 6 of Regulation 41, the point of compliance for any new activity is set at the hydrologically downgradient limit of the area below the activity potentially impacting groundwater quality. The standards that would apply at the point of compliance for a percolation pond would be the same standards that would apply for irrigation. Even if soil were found that would allow rapid infiltration, the groundwater standards could limit the concentration of the brine sent to the basin. Thus, large amounts of dilution water, large amounts of land, and the need for winter storage still remain as limiting considerations.

Each of the three land application options are judged to be infeasible due to several factors, including the requirement of large amounts of dilution water.

Zero Liquid Discharge

The additional removal of water from the already concentrated RO brine solution is pertinent in the case where a zero liquid discharge (ZLD) rule is applicable. These options are associated with dramatically increased costs due to construction as well as operation and maintenance of additional facilities. ZLD involves sufficiently concentrating the residual stream through such technologies as evaporators and crystallizers to allow remaining solids to be landfilled or reused in some beneficial use.

Much of the costs associated with these systems are due to the additional equipment as well as the energy needed for the enhanced removal of water. A brine concentrator is found in most designs of evaporation and crystallization systems. Steam production generally accounts for the bulk of operational costs associated with concentration and crystallization. The installation of numerous pumps, valves, and specific process components, as well as the overall energy costs and maintenance of the equipment, makes ZLD an expensive brine disposal/reuse alternative. Figure C4 depicts a brine concentrator system. Figure C5 presents a schematic of an overall ZLD system.

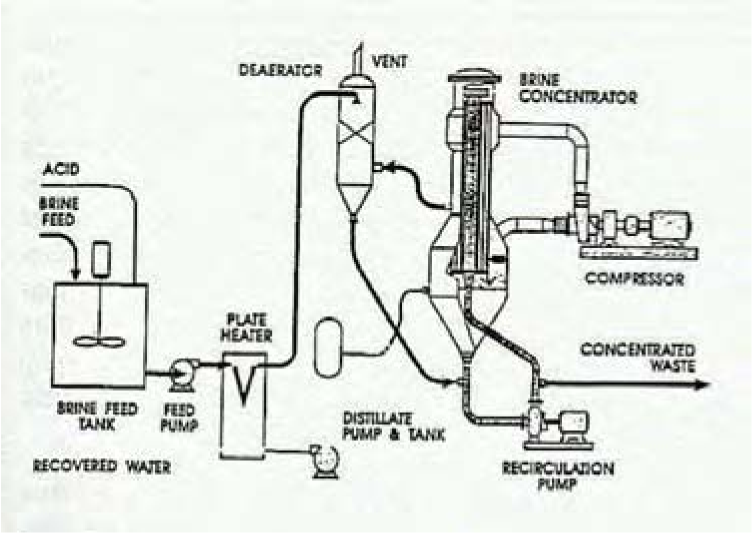

FIGURE C4
Brine Concentration System

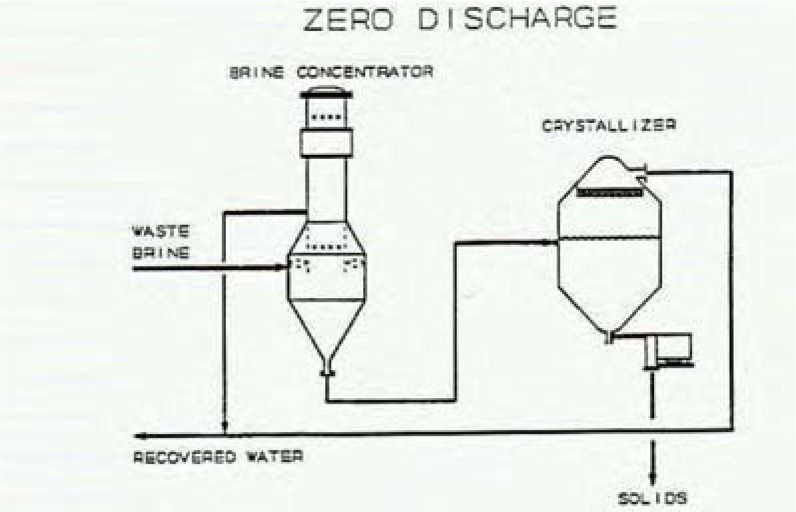

FIGURE C5
Brine Concentration and Crystallization Diagram

While ZLD relies on expensive treatment technology options, it does offer a number of advantages. These advantages include avoiding the discharge permitting process and the ability to be utilized at any location independent of factors such as the proximity to a suitable surface water body or available land for evaporation ponds or irrigation. In addition, ZLD maximizes facility recovery and has minimal environmental impact. In fact, some reuse options may actually add small amounts of revenue for the facility. Although uncommon, this option could increase in feasibility relative to other methods as environmental and discharge regulations become more stringent.

Due to the lack of markets for mixed salts and the high cost of disposing mixed salts, a promising alternative is to sequentially and selectively remove individual salts from the concentrate for market. To date, this technology has not been demonstrated in the United States. The only commercial marketer of this process, Geo-Processors, has recently formed a U.S. company. The first step in determining the applicability of the technology is a feasibility study that involves analysis of the concentrate water quality, determination of processing alternatives, and a local marketing survey specific to the salts that can be produced.

Based on preliminary water quality analyses and cost projections done for other locations in the Southwest United States, the capital cost is likely between $3 million and $6 million per MGD treated or approximately $13 to 27 million. Marketing of salts could displace some of the operating cost and in an ideal case provide a net operating income; but, receiving income from the marketing of salt is probably not feasible. Therefore, the annual operating cost could range from $3.25 million to $6.75 million per year. The operating costs make this an expensive alternative.

Evaporation Ponds

Incorporating evaporation ponds is a more natural means of brine evaporation prior to ultimate disposal. This option relies predominantly on regional climate characteristics and land availability. In terms of evaporation potential, the annual precipitation in the Denver area is about 16 inches per year while the pan evaporation rate is about 65.6 inches per year. The average net loss of water suggests that evaporation may be a feasible option in this area. Based on similar projects, the use of evaporation ponds or sand drying beds could be a practical means of concentrate dewatering in the area. Furthermore, concentrate brine from RO membrane filtration may be blended with other waste residuals produced throughout the water purification in order to consolidate residuals treatment processes at this facility.

Some municipal membrane facilities where evaporation ponds are used are presented in Table C5. Many of these facilities have less than 1 MGD capacity. This is because of the small economy of scale for evaporation ponds and the need for large areas of land. This table shows the largest municipal desalination plant in the United States (as of 2002) utilizing evaporation ponds is 1.5 MGD. This contrasts with the 50-MGD projected size of the ARWPF. At an estimated 40 inches net evaporation per year for the Aurora area with 4.42 MGD of concentrate, the area required would be over 1,500 acres including evaporative surface and land areas.

TABLE C5

Municipal Membrane Plants Using Evaporation Ponds (as of 2002)

Location	Plant Type	Size (MGD)
Buckeye, AZ	EDR	1.5
Terlingua, TX	BRO	0.05
Esperanza, TX	BRO	0.058
El Paso, TX	BRO	0.08
Lucien, OK	MF	0.12
Sarasota, FL	BRO	0.2
Los Ybanex, TX	BRO	0.022
Austin, TX	BRO	0.144

High-Rate Evaporation

Mechanical or enhanced evaporation systems have been developed to augment the evaporation rates of water purification residuals and brines in order to decrease the land area required for evaporation ponds. These methods include technologies such as TurboMist evaporators as well as Wind-Aided Intensification of eVaporation (WAIV) systems. Significant amounts of water can be removed from the residual streams prior to additional brine removal systems or disposal. These systems are designed for use in conjunction with evaporation ponds, deep well injections, or land application.

There are several different enhanced evaporation systems that have the potential to reduce required land area and capital costs. Operation concerns include drift onto adjacent property, wind sensitivity of the enhanced evaporation effect, and possible frozen mist in winter. In the best conditions, the various enhanced evaporation systems increase the net evaporation rate (reduce the evaporative surface area required) by a factor of 7. In the present case, this would reduce the area required from 1,500 acres to about 215 acres, which is still a considerable land area.

In a Fort Bliss, Texas evaluation conducted by CDM (Steele 2004) on 3.2 MGD of concentrate, the use of enhanced evaporation decreased the capital costs of evaporation ponds by 46 percent and increased the operating costs by 330 percent. The area reduction was a factor of 5.2. This shows that the capital cost of the enhanced evaporation system is significantly more per acre, but this is compensated for by the reduced acreage required.

Costs

The most feasible option for discharging to a surface water is to discharge to an irrigation ditch which feeds into the South Platte River. Costs for this alternative include conveyance to the irrigation ditch, outfall structure at the irrigation ditch, and a storage facility for brine. Capital costs for this alternative would be approximately $37 million. Annual operating costs, including pumping and maintenance of the storage ponds, are estimated at $2 million.

If the ARWPF were to discharge brine to a WWTP, Denver Metro said that disposal to the front end of its plant would require a one-time fee of $30 million. When that fee is included with the conveyance of the brine to Denver Metro, the capital cost for this alternative is $57 million. Annual operating costs would be approximately $2 million.

To determine the costs for the ZLD alternative, it was assumed that the salt product could not be sold to offset operation costs. The costs for ZLD are estimated to be $27 million for an initial capital investment and $6.75 million for annual operating expenses.

At an estimated 40 inches net evaporation for the Aurora area and 4.42 MGD of concentrate, evaporation ponds would require over 1,500 acres of land. Land costs vary widely, but the capital cost of this type of residuals handling is estimated to be $150 million. The annual operating costs would be approximately $2 million.

High-rate evaporation will require less land than conventional evaporation ponds; therefore, the capital cost is estimated to be $80 million. This is a more energy-intensive operation, so the annual operating costs will be approximately $6 million.

Residuals Disposal - Benefit Comparison

A comparative model was implemented to compare the relative benefits of each residuals disposal method for high-pressure membrane treatment. Cost was independently determined for each option based on CH2M HILL cost estimating or input from Mickley and Associates. The costs for these handling options were base on the following inputs.

- High-pressure Membrane Treatment
  - 4.42 MGD of RO concentrate waste flow

High-Pressure Membrane Treatment Residuals

The disposal alternatives for residuals produced in RO filtration, namely the concentrate stream, have unique handling options as compared to conventional purification residuals due to the nature of the waste stream. The brine waste streams from high-pressure membranes contain high levels of TDS and other contaminants.

Table C6 presents a comparison for various disposal options for residuals generated in an RO treatment facility. Capital, operating, and maintenance costs were provided by Mickley and Associates. Based on the information presented in Table C6, evaporation ponds are the most easily permitted and cost-effective residuals handling option; however, acquiring the necessary land area to utilize the evaporation ponds option may not be feasible. If this is the case, other options for brine disposal may need to be considered. Even though they are less costly, the options to discharge brine to either a WWTP or surface water are not feasible due to permitting hurdles. The brine discharge to Colorado’s waters would increase salinity and would likely not be permittable.

An important characteristic of the cost estimates and information presented in Table C6 of note is that the present worth costs for the RO residuals are all greater than $55 million with some up to $170 million. The costs are not the only consideration, but coupled with the operations, permitting, and other factors, it is apparent that RO residuals will be costly to treat and dispose.

TABLE C6

Comparison of Disposal Options for Residuals from Reverse Osmosis

Residuals Handling Method	Capital Costs	Annual Operating	Total Costs (Present Worth)	Implementation Consideration	Operational Considerations
Discharge to WWTP	$57,000,000	$2,000,000	$79,939,842	Must pipe the residuals to the WWTP. Requires extensive permitting.	Low operational effort for the pipeline.
Discharge to Surface Water	$37,000,000	$2,000,000	$59,939,842	Must pipe the residuals to the surface water. Requires extensive permitting.	Low operational effort for the pipeline.
Zero Liquid Discharge	$27,000,000	$6,750,000	$104,421,968	Requires a substantial amount of equipment. Contained in buildings.	Will require a lot of operator attention to run all of the equipment.
Evaporation Ponds	$150,000,000	$2,000,000	$172,939,842	Requires a lot of land. Little equipment needed.	Will not require much operator attention. Ponds must have salts removed every other year.
High-Rate Evaporation	$80,000,000	$6,000,000	$148,819,527	Requires a lot of land as well as some spray equipment.	Will require moderate operator attention to maintain sprayers. Ponds must have salts removed every other year.

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APPENDIX D

CASE STUDY – CONCENTRATE DISPOSAL ALTERNATIVES ANALYSIS, JORDAN VALLEY WATER CONSERVATION DISTRICT, UTAH

Evaluation of Alternative Disposal Solutions for Groundwater Extraction and Treatment Remedial Project in Southwestern Jordan Valley

Owners:	Jordan Valley Water Conservancy District Kennecott Utah Copper Corporation

Project Summary

Plans to extract and treat contaminated groundwater from a critical water supply created the need to identify a viable and sustainable solution to dispose of reverse osmosis concentrate. Efforts to identify, evaluate, and recommend a disposal solution have revolved around a unique and successful stakeholder outreach process. Stakeholders were given an equal opportunity to become informed about the problem, voice their opinions and interests, define selection criteria, identify alternatives, evaluate those alternatives, and participate in recommending a path forward. The outreach process has resulted in the successful recommendation of two alternatives requiring additional investigation and is expected to continue until the project is complete.

Background

Mining and other activities in the southwestern Salt Lake Valley have created groundwater contamination with elevated sulfate concentrations that threaten the integrity of an important municipal water supply. Under the federal Superfund law, the State of Utah, through a designated trustee, brought an action against Kennecott Utah Copper Corporation (KUCC) for injuries to groundwater in the area. The trustee’s claims were resolved in a 1995 consent decree approved by the Federal District Court for Utah. The consent decree established a trust fund to be used to restore, replace, or acquire the equivalent of the injured groundwater over a period of 40 years.

In accordance with the terms of the consent decree, the Jordan Valley Water Conservancy District (JVWCD) and KUCC have submitted a joint proposal to develop and construct a groundwater extraction and treatment project with groundwater remedial functions that will provide treated, municipal quality water to the public in southwestern Salt Lake Valley. The joint proposal involves one reverse osmosis (RO) treatment plant constructed, owned, and operated by KUCC to treat mining-related contamination in deep groundwater from the western zone of contamination (zone A) and another separate RO plant constructed, owned, and operated by JVWCD to treat mining-related contamination in deep groundwater from the eastern zone of contamination (Zone B) and shallow agricultural contaminated groundwater (shallow aquifer). The zone A RO treatment plant is expected to have a treatment capacity of 4.46 million gallons per day (MGD) with a concentrate stream of 1.0 MGD. The zone B and shallow aquifer RO treatment plant is expected to have a capacity of 4.87–4.94 MGD with a concentrate stream of 0.8–1.3 MGD (zone B, 0.8–1 MGD; shallow aquifer, 0–0.3 MGD). See Table D1 for typical chemical composition of concentrate streams.

Under the joint proposal, KUCC proposes to dispose of RO concentrate from the zone A RO treatment plant to its existing tailings slurry pipeline extending from the Bingham Canyon Mine to KUCC's tailings impoundment located near the Great Salt Lake. Disposal of the concentrate to the impoundment is authorized under KUCC's existing Utah Pollutant Discharge Elimination System (UPDES) permit. This water is largely recycled back into KUCC's water management system; however, excess water is discharged to Great Salt Lake under its UPDES permit.

As part of the joint proposal, JVWCD initially proposed to dispose of RO concentrate from zone B and shallow aquifer to the Jordan River and obtained the required UPDES discharge permit from the State of Utah. As a result of public comments focusing primarily upon selenium concentrations in the RO concentrate, JVWCD withdrew its UPDES discharge permit to the Jordan River and renewed efforts to find an alternative disposal location for concentrate waters to be produced from its treatment process. The trustee established a stakeholders' forum for groundwater remediation issues in early 2004. One of the primary functions of the forum has been to help identify and evaluate alternatives for disposal of zone B and shallow aquifer RO concentrate water.

TABLE D1

Typical Chemical Composition of Concentrate Streams

	Concn of Component in Concentrate, mg/L		
Parameter	**Zone A**	**Zone B**	**Shallow Aquifer**
SO_4	5971	3100	1800
TDS	10,317	8304	8232
pH	7.3	7.57	7.69
Ca	2054	1500	970
Cl	680	920	1300
K	19	18	46
Mg	620	540	390
Na	294	500	860
Al	<0.010	<0.125	<0.125
As	0.023	<0.020	<0.020
Cd	<0.001	<0.0025	<0.0025
Cu	0.027	0.022	0.018
Mn	<0.010	<0.010	<0.010
Pb	<0.005	<0.0025	<0.0025
Se	0.014	0.035	0.035
Zn	0.022	<0.025	<0.025

Stakeholder Outreach Process

The State of Utah Department of Environmental Quality (UDEQ) initiated a new stakeholder outreach process in 2004 to achieve what previous outreach efforts in the 1990s had not accomplished. Previous efforts had not been formally coordinated, did not receive the focused attention they needed, and did not include effective follow-up. As a result, these efforts were not as effective as the UDEQ had hoped and left stakeholders with more questions than answers.

UDEQ, JVWCD, and KUCC were determined to implement a new, effective process that would provide all stakeholders with an equal opportunity to achieve the following:

- Become educated on the issues, technical evaluations, and alternative solutions
- Provide input from their viewpoint (e.g., questions, information needs, concerns, and technical contributions)
- Participate and contribute to the process of evaluating and selecting from numerous alternatives

Central to the success of the new program is transparency and partnership of all agencies and stakeholders involved. The process summarized below was instrumental in developing consensus and fostering progress to date and will continue to be critical to long-term success.

Forming the Stakeholder Forum

The nature of the issues at hand inherently created diverse opinions. Some viewed this diversity as a potential liability. However, UDEQ moved forward with the view that the diversity was an asset and that harnessing the diverse opinions and forging them into a common mission would lead to project success.

UDEQ worked with its partner agencies and many known stakeholders to develop a list of potential candidates for a stakeholder forum that would represent the wide spectrum of opinions and interests. The forum included 19 members representing area well owners, environmental interests, duck clubs, local government, federal agencies, state agencies, JVWCD, and KUCC. The UDEQ Executive Director serves as chairperson. Members of the forum elected the vice-chair. Each forum member serves for 2 years and is responsible and held accountable for sharing information and providing perspectives from the groups they have been asked to represent.

Ground rules were established by the stakeholder forum for its meetings. Of note, the chair and vice-chair develop meeting agendas jointly. It was important that the stakeholders had a key role in determining the agenda. Each meeting is expected to focus only on those items on the agenda. No formal votes are taken, and it was recognized that while every effort would be made to achieve consensus, it may not be achieved. Members of the public are welcome to attend and listen to presentations and discussion. Public attendees are required to route questions and comments through a forum member of their choice. It has proven very important that the attending public understand and follow the rules so as to not disrupt the productivity of the forum.

Communication

Meetings were largely moderated by the chair and vice-chair, although a professional facilitator was retained to assist the forum in developing selection criteria and evaluating alternatives during key meetings. The facilitator was independent from any participating agency or stakeholder.

The outreach process did not end with the end of each meeting. UDEQ made a specific effort to create a proactive, transparent, and continuous process. This was achieved through the following:

- Frequent and effective communication with members of the media to ensure they correctly understood the issues, had easy access to information, and accurately provided maximum coverage;
- Inclusion of all meeting agendas, minutes, and supporting documents and presentations on a project-specific website (http://www.deq.utah.gov/issues/nrd/index.htm);
- Maintaining an e-mail (and United States Postal Service, where required) mailing list through which project updates, meeting invitations, etc., were sent;
- Frequent and extensive follow-up with stakeholders and the public to listen to and understand their position and concerns (also critical to success was to help or coach them on how to effectively communicate their ideas);
- Facilitating a separate meeting with a large group of the public with a common interest (well owners) to stimulate feedback that their representative could communicate to the forum; and
- Placing three UDEQ personnel in the audience at each meeting whose role was specifically to listen to the audience, gauge reactions, and follow up with individuals with concerns. (While the public did not have an active role at stakeholder meetings, it was important that their contributions were directed to the correct stakeholder and incorporated into the process.)

Conclusions

UDEQ’s well-planned and implemented stakeholder process resulted in the successful communication of information, the effective sharing of perspectives, and several options recommended for further investigation.

There were a number of key desires that were identified by the stakeholder forum that helped shape the process. The desires raised were as follows:

- Be flexible in decision making
- Incorporate a balanced approach to all interests (economic, science, and environmental)
- Acknowledge scientific uncertainty, and err on the side of caution
- Think globally, act locally
- Implement a regional approach and consider other permitting projects and ongoing processes
- Allow sufficient time to think through alternatives, avoiding rushed decisions
- Respect individual and organizational rights

Three items that provided the most value to the process from UDEQ’s perspective were the following:

- Inclusion of a variety of opinions

- The UDEQ Executive Director, Dianne Nielson, was completely engaged in the process by interacting with stakeholders, attending all meetings, etc. Her participation gave the process critical credibility.
- Individual contact outside meetings assisted in education and communication. Individuals who may not have been comfortable voicing thoughts in public were coached and/or communicated with on an individual basis.

Three lessons that UDEQ identified as ways of improving the process as it moves forward were the following:

- Plan for follow-up. The stakeholder process was planned for the long term. It has proven difficult to keep everyone engaged during quiet periods while additional analysis is being conducted.
- A more thorough internal, critical, objective evaluation of issues and alternatives would have been useful to foresee more issues upfront and be able to more effectively address them at meetings.
- It is important to try to listen to the stakeholders, try to think like they do, and balance the stakeholders' needs with regulatory needs.

Selection Criteria

The stakeholder forum developed a number of criteria to be used in the selection process. Forum members participated in discussions aimed at subjectively evaluating each alternative by these criteria. Recommendations could be made based on how each alternative met or did not meet each criterion. Following is a summary of criteria used:

1. Alternative must meet project objectives: (1) support consent decree, and (2) workable for 40 years (life of project as defined in the consent decree)
2. Alternative must stay within budget, including operation costs
3. Alternative must meet project time constraints
4. Alternative must be environmentally sound
    a. Durability and accountability to future generations
    b. Aesthetically pleasing (complement surroundings)
    c. Consider other environmental factors (air, noise, etc.)
5. Alternative must be technically feasible and successful
    a. Use proven technology
    b. Solve problem and do not create others
6. Alternative must allow all organizations to meet their objectives
7. Alternative must not significantly impact KUCC's operation capability
8. Alternative must not preclude ongoing service of public water delivery after 40 years
9. Alternative must be compatible with JVWCD's plans for development of shallow aquifer
10. Alternative must be legal and compatible with the permitting process

Alternatives Evaluated

As described previously, JVWCD withdrew its UPDES permit to discharge the zone B and shallow aquifer RO concentrate to the Jordan River due to public comments primarily regarding selenium concentrations in the RO concentrate. The forum identified 19 alternatives to address public concerns and meet project objectives. A total of 15 of the alternatives were evaluated in conjunction with the stakeholder forum. Following is a brief summary of the identified alternatives. Further information for each alternative can be found in specific memoranda found at UDEQ’s project website, http://www.deq.utah.gov/issues/nrd/index.htm.

A. **Do Nothing**

B. **Discharge to Jordan River (WITHDRAWN)**. Pump zone B and shallow aquifer concentrate to the Jordan River. A UPDES permit for this alternative was withdrawn as a result of public comments regarding selenium in the RO concentrate. These comments resulted in JVWCD renewing efforts to find a better disposal alternative.

C. **Deep Well Injection**. Pump zone B and shallow aquifer concentrate to a deep injection well completed at a depth of approximately 5000 ft.

D. **Discharge to Great Salt Lake**. Pump zone B and shallow aquifer concentrate to the south arm of the Great Salt Lake. Net present value cost is $9.7 million.

E. **Discharge to KUCC Great Salt Lake Outfall**. Pump zone B and shallow aquifer concentrate to the existing KUCC tailings impoundment outfall pipeline to the Great Salt Lake. Net present value cost is $10.4 million.

F. **Discharge to KUCC Tailings Impoundment**. Pump zone B and shallow aquifer concentrate to the existing KUCC tailings impoundment. Net present value cost is $8.2 million.

   Note that KUCC determined small quantities of organics in shallow aquifer concentrate would be detrimental to KUCC’s water management system and could not be discharged to the tailings impoundment. The following alternatives were developed to address this concern:

   > **F.1. Discharge of Zone B Concentrate to KUCC Tailings Impoundment; Discharge of Shallow Aquifer Concentrate to Great Salt Lake.** Pump zone B concentrate to the existing KUCC tailings impoundment. Pump shallow aquifer concentrate to the south arm of the Great Salt Lake. Net present value cost is $15.6 million.
   >
   > **F.2. Discharge Zone B Concentrate to KUCC Tailings Impoundment; Discharge of Shallow Aquifer Concentrate to KUCC Great Salt Lake Outfall.** Pump zone B concentrate to the existing KUCC tailings impoundment. Pump shallow aquifer concentrate to the existing KUCC tailings impoundment outfall pipeline to the Great Salt Lake. Net present value cost is $16.1 million.
   >
   > **F.3. Discharge Zone B Concentrate to KUCC Tailings Impoundment; Distillation of Shallow Aquifer and Disposal to Landfill.** Pump zone B concentrate to the existing KUCC tailings impoundment. Convert shallow aquifer concentrate to a solid waste by distillation and dispose of solid waste (salt) to a landfill. Net present value cost is $40.4 million.

G. **Disposal to Landfill by Thermal Zero Liquid Discharge Processing**. Convert zone B and shallow aquifer concentrate to a solid waste by evaporating and recovering the water in a sequence of mechanically enhanced thermal desalination processes (for example, process referred to as zero liquid discharge) and dispose of solid waste (salt) to a landfill. Net present value cost is $93.9 million.

H. **Distillation and Disposal to Landfill**. Convert zone B and shallow aquifer concentrate to a solid waste by distillation and dispose of solid waste (salt) to a landfill.

I. **Discharge of Zone B Concentrate to KUCC Tailings Pipeline.** Pump zone B concentrate to the KUCC tailings pipeline at 7800 South. The KUCC tailings pipeline discharges to the KUCC tailings impoundment. Net present value cost is $5 million.

Note that KUCC determined small quantities of organics in shallow aquifer concentrate would be detrimental to KUCC's water management system and could not be discharged to the tailings impoundment. The following alternatives were developed to address this concern:

I.1. Discharge of Zone B Concentrate to KUCC Tailings Pipeline; Discharge of Shallow Aquifer Concentrate to Great Salt Lake. Pump zone B concentrate to the KUCC tailings pipeline at 7800 South. The KUCC tailings pipeline discharges to the KUCC tailings impoundment. Pump shallow aquifer concentrate to the south arm of the Great Salt Lake. Net present value cost is $13.1 million.

I.2. Discharge of Zone B Concentrate to KUCC Tailings Pipeline; Discharge of Shallow Aquifer Concentrate to KUCC Great Salt Lake Outfall. Pump zone B concentrate to the KUCC tailings pipeline at 7800 South. The KUCC tailings pipeline discharges to the KUCC tailings impoundment. Pump shallow aquifer concentrate to the existing KUCC tailings impoundment outfall pipeline to the Great Salt Lake. Net present value cost is $13.6 million.

I.3. Discharge of Zone B Concentrate to KUCC Tailings Pipeline; Distillation of Shallow Aquifer Concentrate and Disposal to Landfill. Pump zone B concentrate to the KUCC tailings pipeline at 7800 South. The KUCC tailings pipeline discharges to the KUCC tailings impoundment. Convert shallow aquifer concentrate to a solid waste by distillation and dispose of solid waste (salt) to a landfill. Net present value cost is $37.7 million.

Additional Alternatives Suggested but Not Investigated

J. Wetlands creation

K. Replacement water

L. Independent disposal of shallow aquifer

M. Oceanic outlet

Alternatives Discussion

All 15 alternatives were discussed at length by the stakeholder forum. Alternatives A, B, C, and G were the first to be eliminated for the following reasons:

- Alternative A did not meet project objectives and was eliminated. Remediation of the groundwater is required, thus dictating the need for a disposal method.
- Alternative B was eliminated due to public comments regarding potential impacts to the Jordan River and wetlands from selenium in the RO concentrate.
- Alternative C was eliminated due to the difficulty in assuring that there would be no impacts to underground sources of drinking water, the difficulty in obtaining the required regulatory approvals without adequate data in the required time frame, and potential operational concerns and costs with scaling.
- Alternative G was eliminated due to its extremely high cost.

Further discussions among the stakeholders and agencies resulted in cost becoming a significant determining criterion. Stakeholders determined that the selected disposal alternative could not have significant, adverse impacts upon water rates within the community. This represented a unit cost cap of $210 per acre-ft for treated water. Stakeholders also determined that additional capital costs could not exceed a threshold of $3 million above the previous funding commitment by JVWCD. This eliminated Alternatives E and H, leaving only Alternatives D (Discharge to Great Salt Lake), F (Discharge to KUCC Tailings Impoundment), and I (Discharge to KUCC Tailings Pipeline) as viable alternatives.

Discussion over the environmental soundness of the remaining alternatives largely centered upon the question of the potential impacts of selenium to the ecosystem of the Great Salt Lake. Limited data and differing opinions and findings prevented the forum from making a final recommendation.

Selected Alternative

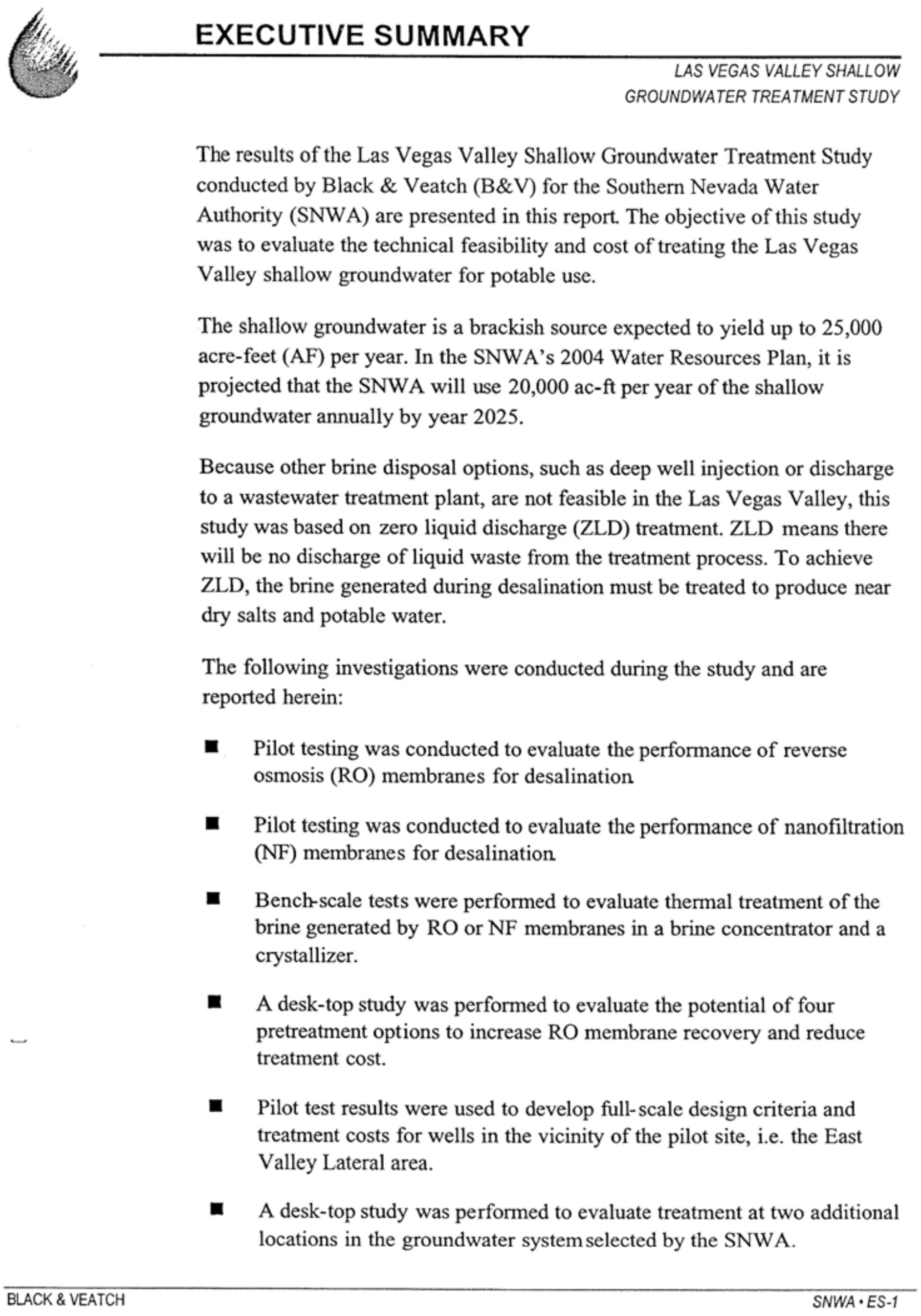
Given the time constraints imposed by the 1995 consent decree, the stakeholder forum recommended that JVWCD and KUCC move forward with plans implementing Alternative F (Discharge to KUCC Tailings Impoundment) for the zone B concentrate. KUCC has agreed to accept concentrate from zone B in its tailings impoundment for the required 40-year period. JVWCD will be required to comply with KUCC’s UPDES permit and other specifications and may only deliver a maximum of 1100 acre-ft of concentrate in a given year with a 5-year rolling average of 1000 acre-ft.

The stakeholder forum also recommended that Alternative F.1 (Discharge of Shallow Aquifer Concentrate to Great Salt Lake) and Alternative F.2 (Discharge of Shallow Aquifer Concentrate to KUCC Great Salt Lake Outfall) be considered following additional research and verification that discharge of such concentrate will not be harmful to the Great Salt Lake ecosystem. Selenium is the primary constituent of concern. The State of Utah has convened a Great Salt Lake Steering Committee, consisting of key stakeholders similar in structure to the stakeholder forum discussed above, and an expert science panel to recommend a new selenium water quality standard for the Great Salt Lake. Information developed from this process will serve as the basis for further public comment and to determine if regulatory approval of a UPDES permit for discharge to the Great Salt Lake is feasible.

New selenium water quality standards for the Great Salt Lake are not expected until the Fall of 2007. The stakeholder forum is expected to reconvene and make its final recommendation at that time.

APPENDIX E

CASE STUDY – ZLD STUDY, SOUTHERN NEVADA WATER AUTHORITY, LAS VEGAS, NEVADA



EXECUTIVE SUMMARY

LAS VEGAS VALLEY SHALLOW GROUNDWATER TREATMENT STUDY

The results of the Las Vegas Valley Shallow Groundwater Treatment Study conducted by Black & Veatch (B&V) for the Southern Nevada Water Authority (SNWA) are presented in this report. The objective of this study was to evaluate the technical feasibility and cost of treating the Las Vegas Valley shallow groundwater for potable use.

The shallow groundwater is a brackish source expected to yield up to 25,000 acre-feet (AF) per year. In the SNWA's 2004 Water Resources Plan, it is projected that the SNWA will use 20,000 ac-ft per year of the shallow groundwater annually by year 2025.

Because other brine disposal options, such as deep well injection or discharge to a wastewater treatment plant, are not feasible in the Las Vegas Valley, this study was based on zero liquid discharge (ZLD) treatment. ZLD means there will be no discharge of liquid waste from the treatment process. To achieve ZLD, the brine generated during desalination must be treated to produce near dry salts and potable water.

The following investigations were conducted during the study and are reported herein:

- Pilot testing was conducted to evaluate the performance of reverse osmosis (RO) membranes for desalination.
- Pilot testing was conducted to evaluate the performance of nanofiltration (NF) membranes for desalination.
- Bench-scale tests were performed to evaluate thermal treatment of the brine generated by RO or NF membranes in a brine concentrator and a crystallizer.
- A desk-top study was performed to evaluate the potential of four pretreatment options to increase RO membrane recovery and reduce treatment cost.
- Pilot test results were used to develop full-scale design criteria and treatment costs for wells in the vicinity of the pilot site, i.e. the East Valley Lateral area.
- A desk-top study was performed to evaluate treatment at two additional locations in the groundwater system selected by the SNWA.

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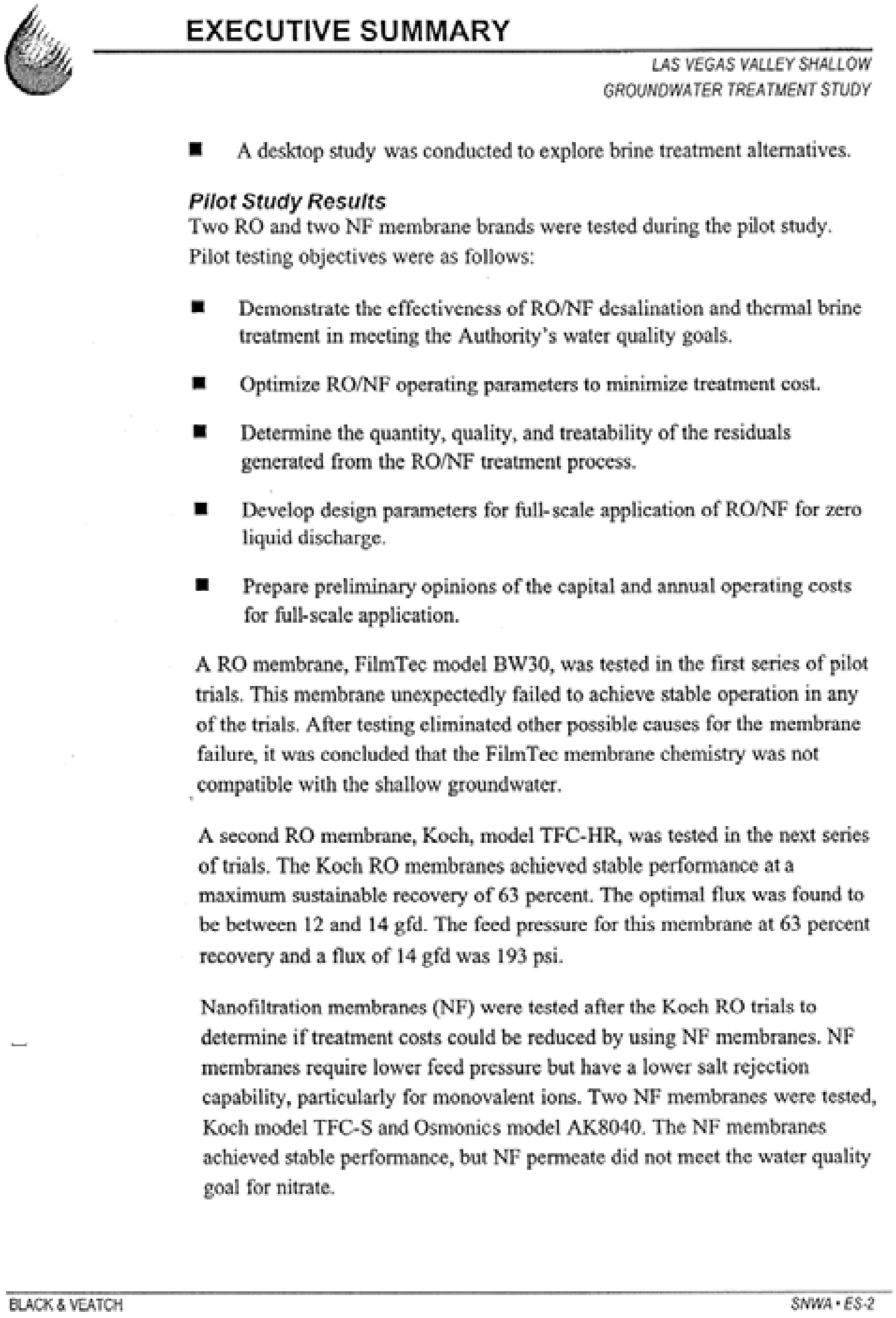

- A desktop study was conducted to explore brine treatment alternatives.

Pilot Study Results

Two RO and two NF membrane brands were tested during the pilot study. Pilot testing objectives were as follows:

- Demonstrate the effectiveness of RO/NF desalination and thermal brine treatment in meeting the Authority's water quality goals.
- Optimize RO/NF operating parameters to minimize treatment cost.
- Determine the quantity, quality, and treatability of the residuals generated from the RO/NF treatment process.
- Develop design parameters for full-scale application of RO/NF for zero liquid discharge.
- Prepare preliminary opinions of the capital and annual operating costs for full-scale application.

A RO membrane, FilmTec model BW30, was tested in the first series of pilot trials. This membrane unexpectedly failed to achieve stable operation in any of the trials. After testing eliminated other possible causes for the membrane failure, it was concluded that the FilmTec membrane chemistry was not compatible with the shallow groundwater.

A second RO membrane, Koch, model TFC-HR, was tested in the next series of trials. The Koch RO membranes achieved stable performance at a maximum sustainable recovery of 63 percent. The optimal flux was found to be between 12 and 14 gfd. The feed pressure for this membrane at 63 percent recovery and a flux of 14 gfd was 193 psi.

Nanofiltration membranes (NF) were tested after the Koch RO trials to determine if treatment costs could be reduced by using NF membranes. NF membranes require lower feed pressure but have a lower salt rejection capability, particularly for monovalent ions. Two NF membranes were tested, Koch model TFC-S and Osmonics model AK8040. The NF membranes achieved stable performance, but NF permeate did not meet the water quality goal for nitrate.

Bench-scale Results for Thermal Brine Treatment

Bench-scale tests were conducted by Resource Conservation Corporation (RCC) to evaluate the feasibility of thermally treating the RO brine with a brine concentrator and crystallizer. The test results indicated that RO brine from the pilot plant was compatible with treatment in a brine concentrator and crystallizer. It was estimated that 95 percent of the RO brine fed to the brine concentrator would be recovered as a distillate, and most of the remaining 5 percent could be recovered as a distillate in the crystallizer. The distillate would be combined with product water from RO to produce a blended product water. Hence recovery for the total system would be essentially 100 percent. The crystallizer would produce solids that are 80 percent dry. Recovery of brine as distillate in the brine concentrator and crystallizer was projected to be 99.6 percent, and the distillate is expected to have a TDS of less than 10 mg/L.

Full-scale Evaluations

The pilot- and bench-scale results and computer modeling were used to evaluate full-scale treatment at three sites in the shallow groundwater system. The sites were the East Valley Lateral (EVL) site and two synthetic water sites, designated Water 1 and Water 2. The EVL site was represented by water quality data from the pilot plant. Water quality for the two synthetic water sites were developed by the SNWA. Each site was evaluated with a well production of 3 mgd based on a hydrogeologic analysis conducted in the prepilot study. Calculations indicated that the most cost-effective brine treatment option for each site was a brine concentrator followed by an evaporation pond in lieu of a crystallizer. The full-scale evaluation results are summarized in the following table.

	EVL		Water 1		Water 2	
	RO	**NF**	**RO**	**NF**	**RO**	**NF**
Membrane Recovery	63 %	63%	64%	64%	66%	66%
Bypass	8.5%	No bypass	2%	No bypass	7%	No bypass
Total System Recovery	98 %	98 %	98 %	98 %	98 %	98 %
Cost per AF	$1457	$1537	$1509	$1506	$1472	$1519

RO treatment was determined to be a better choice than NF at each site. In pilot tests, RO product water exceeded all water quality goals. Hence RO would allow a percentage of well water to bypass the membranes and still produce blended product water meeting treatment goals. Conversely the evaluation indicated NF product water would fail to meet water quality goals for nitrate and chloride. RO treatment cost was equivalent to or lower than NF treatment cost at each site because of the ability to bypass with RO. Brine treatment comprised approximately 70 percent of the total treatment cost at each of the sites.

Evaluation of Pretreatment Alternatives

A paper study was conducted to assess the impact of additional pretreatment processes on treatment costs. The pretreatment alternatives were three levels of chemical softening and HERO™, a patented process. Each of these alternatives would reduce brine treatment costs by increasing RO recovery, but additional capital and O&M costs would be incurred for equipment and chemicals required for pretreatment. The analysis indicated that adding pretreatment processes increased rather than decreased treatment costs. Compared to a cost of $1457 per AF for RO, costs for RO with pretreatment softening ranged from $1723 to $2698 per AF and the cost for HERO™ was $2586 per AF.

Evaluation of Brine Treatment Alternatives

A paper study was conducted to evaluate new and emerging brine treatment alternatives to thermal desalination. This study included a review of technical literature to identify emerging technologies and ideas. Interviews were also conducted with researchers from academia and industry and with engineers from the U.S. Bureau of Reclamation.

Thermal treatment remains the best available technology for brine treatment, meaning it is the best technology available today with proven full-scale performance. Government agencies and drinking water professionals, however, have recognized the urgent need for affordable inland desalination. Accordingly, desalination research, particularly in the area of brine disposal, has been prioritized, and the state of knowledge for brine treatment is dynamic and rapidly expanding. Emerging technologies and ideas for brine treatment include enhanced evaporation systems and beneficial uses of brine.

A treatment concept developed for the AwwaRF research study, "Zero Liquid Discharge and Volume Minimization for Inland Desalination" is presented in the report. This treatment concept proposes use of emerging technologies with established treatment practices to achieve ZLD without thermal treatment. The SNWA is a research partner in the AwwaRF study, and the concept will be evaluated for treatment of the shallow groundwater as part of the AwwaRF study.

Conclusions

This treatment study showed that membrane treatment of the Las Vegas Valley shallow groundwater is technically feasible with a maximum sustainable recovery of 63 percent. RO membranes were shown to be a better application than NF for this water based on product water quality.

Bench-scale testing demonstrated that the RO brine was treatable with thermal processes. The desktop evaluation of full-scale treatment indicated that a brine concentrator followed by an evaporation pond would be the most cost-effective brine treatment scheme. With the combined product from RO membranes and the brine concentrator, approximately 98 percent of the shallow groundwater can be recovered as product water. The remaining 2 percent would be lost to evaporation in the pond.

Treatment costs using RO for the EVL and two synthetic water sites ranged from $1457 to $1509 per AF. Brine treatment accounted for approximately 70 percent of the treatment cost for each site. While successful membrane treatment was demonstrated in the pilot study, the failure of one of the RO membrane brands to achieve stable performance indicated that not all membrane brands may be suitable for treating the shallow groundwater.

APPENDIX F

CASE STUDY – EDR IMPROVEMENTS – CITY OF SHERMAN, TEXAS

Feasibility Study for EDR Wastewater Treatment and Recovery

PREPARED FOR:	David Gattis/City of Sherman
PREPARED BY:	Jennifer Henke/DFW Jim Lozier/PHX
DATE:	January 17, 2001

(Editor’s note: There were two objectives of the study: (1) provide additional potable water supply from the concentrate and (2) reduce the volume of discharge to the sewer. This report addresses the ultimate form of beneficial reuse - the production of potable water from concentrate. The volume of the concentrate stream will be significantly reduced if these technologies prove successful.)

Introduction and Background

The City of Sherman currently operates an 11 million gallon per day (MGD) water treatment plant (WTP) to treat surface water from Lake Texoma. The plant uses electrodialysis reversal (EDR) to demineralize a portion of the filter effluent from the conventional treatment portion of the WTP. The EDR process produces a continuous brackish wastewater of approximately 1 MGD that is currently discharged to the City's sewer system, using critical sewer transmission and treatment capacity. The wastewater consists of three streams: concentrate, off-spec product water, and electrode waste. Concentrate comprises more than 90 percent of the waste flow.

The City desires to treat this wastewater to reduce sewer and wastewater plant loadings and recover a portion of the wastewater as high quality water that can be used to increase plant finished water capacity. The EDR wastewater contains several sparingly soluble salts (barium sulfate, calcium sulfate, strontium sulfate, and calcium carbonate) at concentrations greatly in excess of their theoretical solubility. The presence of these salts makes treatment and recovery of the wastewater impractical by conventional desalting technologies (EDR and reverse osmosis [RO]) using standard, commercially available scale inhibition chemicals because of the high likelihood of membrane scaling. Thus, alternative methods are required to meet the City’s objectives. The purpose of this technical memorandum (TM) is to document a bench/pilot scale feasibility study of two innovative treatment technologies for EDR wastewater treatment and recovery. The technologies are:

- GrahamTek RO, manufactured by Mineral Water Development (MWD) of Stellenbosch, South Africa
- Zeta Rod, manufactured by Zeta Corporation of Tucson, Arizona

Purpose and Objectives

The primary objective of the testing was to assess the ability of the innovative products to operate reliably on the EDR wastewater (i.e., provide stable productivity and total dissolved solids [TDS] rejection without rapid or significant fouling or scaling). The study was structured to perform a longer-term (3-month) evaluation of the GrahamTek system using a pilot unit outfitted with full-scale treatment components and operated on a continuous basis. This type of evaluation was intended to determine if RO performance could be maintained over a period of 3 months of operation, and to assess membrane cleaning frequency and cleaning effectiveness. The Zeta Rod/RO system testing was short term (2 weeks) and intended to provide data to enable a "go/no-go" decision regarding feasibility. If a "go" decision was made, a longer-term test would be necessary to develop the same applicability information as was to be developed for GrahamTek in this study. If a "no-go" decision was made, additional testing of the Zeta Rod would not be recommended.

Specific testing objectives included:

- Operate the GrahamTek pilot-scale unit for a period of approximately 3 months on a continuous basis.
- Operate the Zeta Rod (with downstream bench-scale unit) for a period of 2 weeks on a continuous basis.
- Monitor critical performance parameters for each unit as a function of operating time. These parameters included:
  - Permeate and concentrate flow;
  - Feed and concentrate (and where applicable, permeate) pressure; and
  - Feed, concentrate and permeate conductivity and analyze these data as a function of operating time to determine if and to what extent membrane fouling and/or scaling occurs during the testing period.
- Periodically collect samples of unit feed, concentrate and permeate and measure levels of the following constituents (GrahamTek system only). Together with this data and unit flows, perform a mass balance on the constituents to estimate their recovery and indirectly assess the likelihood of mineral precipitation by sparingly soluble salts containing these constituents:
  - Barium
  - Strontium
  - Calcium
  - Alkalinity
  - Sulfate
- Measure the quality of the product water to determine if it (1) meets selected federal and state drinking water regulations or (2) is of a quality that when blended with plant finished water will meet drinking water regulations.
- For the MWD unit, assess process operability (on-line factor).
- Autopsy a membrane element from operation of each unit to determine the presence/ absence of mineral scales.
- Assess the chemical stability of the MWD waste discharge relative to its tendency to precipitate minerals in the time required for waste conveyance from the WTP to the wastewater treatment plant (WWTP). (Due to the difficulty in maintaining suitable performance of the test units, this objective was not addressed in this testing.)

Test Equipment and Methodology

Analytical

Field

Field data were collected for both the GrahamTek RO system and the Zeta Rod system to evaluate performance. The data collected included:

- Membrane and concentrate pressure
- Feed pH
- Feed temperature
- Permeate, concentrate, and concentrate recycle (Zeta Rod system only) flow rate
- Feed, permeate, concentrate, and concentrate recycle (Zeta Rod system only) conductivity
- Feed total and free chlorine (GrahamTek system only)
- Feed turbidity (GrahamTek system only)
- Feed silt density index (SDI; GrahamTek system only)

All of the data collected for the GrahamTek system except the free and total chlorine, feed turbidity, and feed SDI was read from the GrahamTek pilot unit. The free and total chlorine were determined by the DPD (N, N-diethyl - p – phenylendiamine) method.

For the Zeta Rod system, only the feed temperature, feed pH, flow rates, and pressures were read from the unit. Each of the conductivity measurements was made using a conductivity meter.

Laboratory

Weekly and monthly samples were taken of the feed, permeate, and concentrate of the GrahamTek system. These samples were shipped to the CH2M HILL Applied Sciences Lab for analysis. Combined with flow data, these samples were used to perform a mass balance on constituents to determine if precipitation is occurring. Table F1 summarizes the analysis performed for each sample event.

Pilot Plant Description

A process schematic of the pilot plant is shown in Figure F1. With minor exceptions, all equipment was set up and operated in the WTP demineralization building.

Feedwater Extraction, Pumping, and Storage

Wastewater from the four full-scale EDR units served as feedwater to the GrahamTek and Zeta Rod/RO systems. Wastewater was extracted from the plant waste header and pumped to the feedwater holding tank. The tank was necessary to provide a continuous supply of feedwater to the desalting systems when a clean-in-place (CIP) was performed on the EDR units. Initially, a 600-gallon tank was installed adjacent to the GrahamTek unit (see Figure F2). This volume was determined to be insufficient to maintain flow to the GrahamTek unit when one or more EDR units were removed from service for CIP and the tank was subsequently replaced with a larger, 2,100-gallon tank, located outside the demineralization building.

TABLE F1

Laboratory Analysis Sampling Schedule

Weekly Sampling	Monthly Sampling
Anions	
Total Alkalinity	Total Alkalinity
Sulfate	Sulfate
	Chloride
	Fluoride
Other	
Total Dissolved Solids	Total Dissolved Solids
	Silica, Reactive
Cations	
Barium, Ba	Barium, Ba
Calcium, Ca	Calcium, Ca
Strontium, Sr	Strontium, Sr
	Aluminum, Al
	Iron, Fe
	Magnesium, Mg
	Manganese, Mn
	Potassium, K
	Sodium, Na

Feedwater Dechlorination

The EDR system feedwater is chlorinated to provide a low free chlorine residual through the EDR stacks (0.5 to 1.0 milligrams per liter [mg/L] target range). This is necessary to control biofouling of the membranes and spacers. The polyamide RO membranes used in this study (and most applicable to the treatment and recovery of the high salinity EDR wastewater) have very limited tolerance to free chlorine. Koch/Fluid Systems recommends that the free chlorine residual of feedwater to their elements be maintained at less than 0.1 mg/L.

To accommodate this requirement, the EDR wastewater was initially dosed with aqueous ammonia to convert the free chlorine to combined chlorine as the latter has been shown to be compatible with polyamide RO membranes and also provide excellent biofouling control. Despite the dosing of ammonia in doses well in excess of the stoichiometric requirement for free chlorine conversion, it was determined that not all of the free chlorine was being successfully converted. The presence of the residual free chlorine was considered a contributing factor to the increase in GrahamTek permeate conductivity during the first run. Consequently, dechlorination was performed with sodium metabisulfite (SMBS), a strong reducing agent, during the second GrahamTek run. SMBS proved more effective for dechlorinating the EDR wastewater, reducing the free chlorine residual from an average of 0.80 mg/L with ammonia to 0.10 mg/L.

GrahamTek System

The GrahamTek RO technology is a proprietary treatment process that utilizes patented electromagnetic membrane defouling (EMD) and flow distribution devices to inhibit fouling and mineral scaling during RO treatment. The latter is designed to improve flow distribution within the feed channel of the RO element, thereby reducing the degree of concentration polarization (CP)[1] occurring at the membrane surface and the potential for mineral precipitation from such polarization. Such reductions would reduce mineral precipitation potential. The EMD device, which is integrated into the pressure vessel housing the RO elements, is designed to apply a charge to the RO feedwater as it flows through the element and reduces interaction of colloidal and mineral particles (like the Zeta Rod)[2]. Conventional RO systems utilize six 40-inch-long RO elements in series for operation at 50 percent recovery for a total path length of 240 inches.

In contrast, the GrahamTek unit uses two elements, one 40 inches and one 60 inches in length, for a total of 100 inches of path length. The shorter path length, for a given recovery, increases CP, but reduces the time the salts such as barium sulfate and calcium carbonate are in the elements. By virtue of this design, MWD has determined the decreased residence time is a more important factor in preventing precipitation of such sparingly soluble salts than the higher CP.

The GrahamTek RO system uses standard, “off-the-shelf,” spiral wound RO elements. No chemicals are used with the GrahamTek system except for cleaning the RO elements. A production GrahamTek unit was installed in 1998 at the Palm Beach Country Club, Palm Beach, Florida, and has been operating successfully since then treating brackish groundwater. The concentrate from the unit is supersaturated in calcium carbonate. An 8-gallon per minute (gpm) nominal feedwater capacity, skid-mounted GrahamTek pilot unit was leased from the San Diego, California office of MWD for this testing. The unit was installed and operated inside of the demineralization building at the Sherman WTP. A photo of the unit is shown in Figure F2 and a process and instrumentation diagram for the unit is shown in Figure F3.

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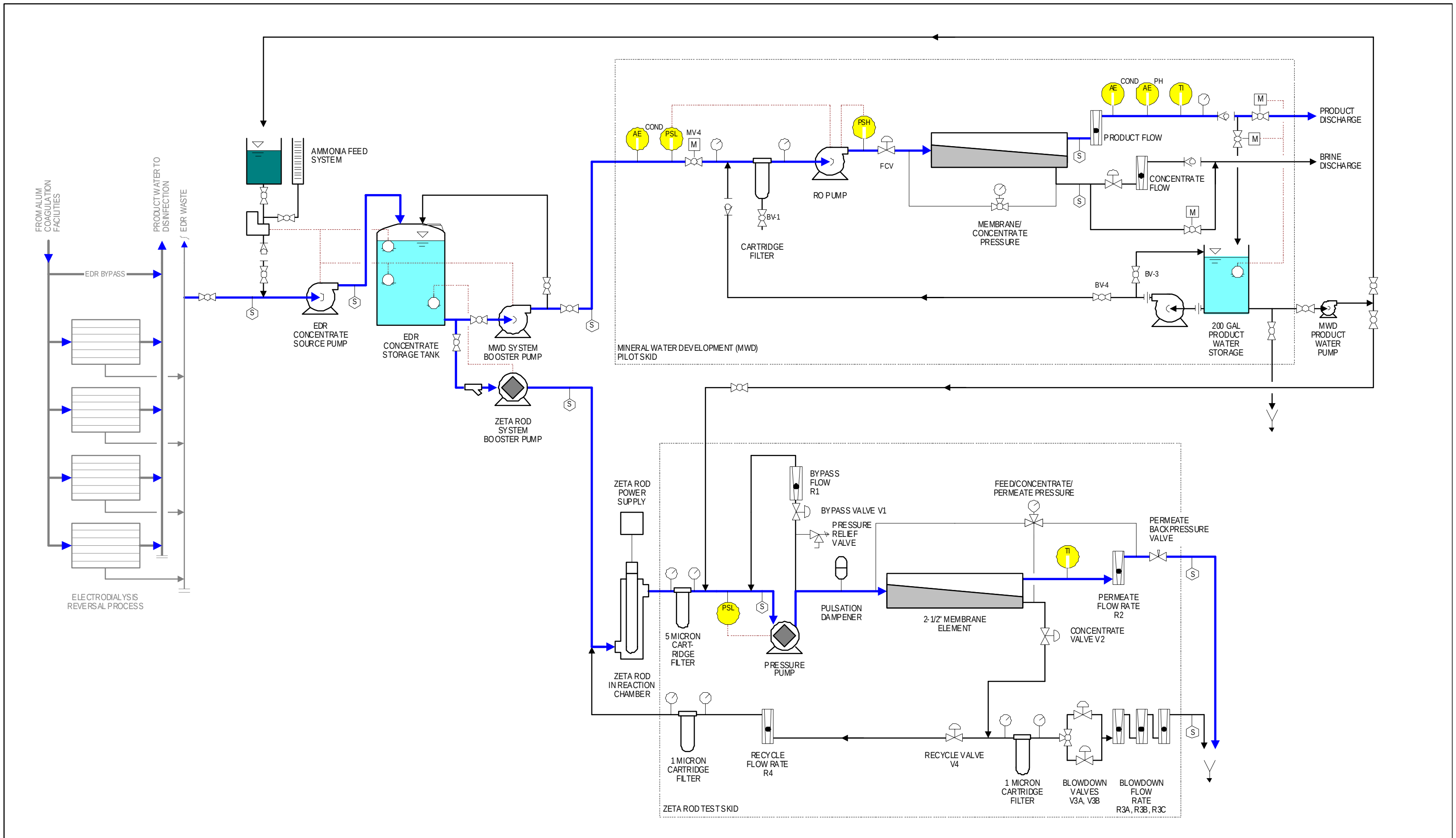
[1] Concentration polarization (CP) is the term describing the higher concentration of solutes at the membrane surface relative to their concentration in the bulk flow of feedwater passing through the RO element feed spacer. The degree of CP is a function of the rate at which feedwater flows through the membrane (flux rate), the velocity of feedwater through the spacer, the degree of mixing created by the feedwater spacer, and the diffusion coefficient of the solute. The diffusion coefficient for divalent solutes (e.g., calcium and sulfate) is lower than for monovalent solutes (sodium and chloride), resulting in a higher CP value for divalent salts, other things being equal.

[2] MWD has not published the voltage or amperage specifications for the EMD portion of their proprietary design.



CH2MHILL

DSGN	P MUELLER	1	6/19/00	ADD PERMEATE FLUSH AND ELEMENT FEED SAMPLE TAP TO ZETAROD SYSTEM	PM	
DR	P MUELLER	2	6/30/00	ADD CARTRIDGE FILTER ON CONCENTRATE RECYCLE LINE	PM	
CHK		3	7/25/00	SWAP PERM FLUSH AND CONC RECYCLE RETURN LOCATIONS	PM	
APVD	J LOZIER	NO.	DATE	REVISION	BY	APVD

REUSE OF DOCUMENTS

CITY OF SHERMAN, TEXAS

ELECTRODIALYSIS REVERSAL
CONCENTRATE RECOVERY STUDY

APPENDIX A

ON-SITE PILOT TEST SETUP

SHEET
DWG NO.
DATE JULY 2000
PROJ NO. 151901A0.ZZ

FEB 14, 2001

FIGURE F1
Process Schematic for Pilot EDR Wastewater Treatment Systems

During normal operation, flow from the pilot plant feedwater holding tank was pumped to the GrahamTek unit, where pressure of the feedwater was increased as required to produce the target permeate flow. The feedwater passed into the single pressure vessel, which contained one 8-inch-diameter by 60-inch-long and one 8-inch-diameter by 40-inch-long spiral wound RO element; Koch/Fluid Systems Model 8822HR and 8832HR TFC polyamide RO type, respectively. Permeate and concentrate from the unit was directed to the EDR wastewater holding pond. No chemical treatment was applied to the GrahamTek feedwater.

In the event of a shutdown, RO permeate stored in a holding tank on the unit skid was pumped through the pressure vessel to displace the EDR wastewater and its related concentrate. When RO feed pressure increased to a predetermined threshold, the RO elements were cleaned with citric acid.

FIGURE F2
Photo of the MWD GrahamTek RO System

Zeta Rod/RO System

Zeta Rod is a patented ceramic electrode that uses capacitance and electrostatic dispersion of mineral and colloidal dispersion to prevent scaling and fouling of surfaces. The electrode converts 110-volt alternating current to 35,000 volts direct current (at 600 microamperes) and uses this electrical potential to charge organic and inorganic particles passing by the electrode. When coupled with downstream conventional RO technology, the Zeta Rod acts as a capacitor to elevate the surface charge of particles in the RO feedwater and prevent their interaction, with the intent of eliminating or greatly inhibiting fouling and scaling of the RO membrane surface. The device has been shown to reduce biological fouling in an industrial RO facility (Romo and Pitts 1999) and was found to be compatible with both hollow fine fiber and spiral wound RO elements (Eckman 1998; Bates 1999). The device serves to pretreat the feedwater to a conventional RO system.

A Model ZR18S electrode (1 inch diameter, 18 inches long) and a Model ZRPOV power supply were installed as part of the Zeta Rod system to treat flow from the feedwater holding tank. The Zeta Rod system consisted of a power supply, ceramic electrode, and polyvinyl chloride (PVC) flow-through housing for the electrode. Tank flow was pressurized by a transfer pump, flowed through the Zeta Rod, and into the CH2M HILL bench-scale RO unit.

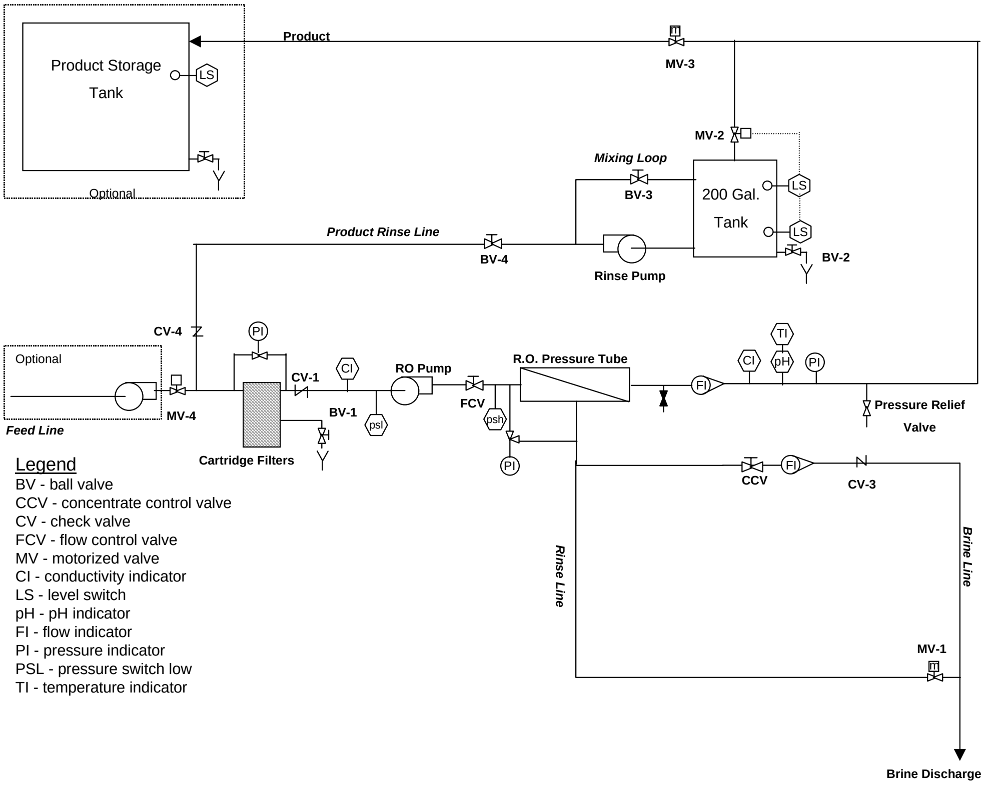


FIGURE F3
Process and Instrumentation Diagram for MWD GrahamTek RO System

Single Element Bench-Scale RO Unit

EDR wastewater pretreated by the Zeta Rod was then treated using a single element bench-scale RO unit (SETU) provided by CH2M HILL. A photo of the SETU is shown in Figure F4. Major components of the SETU included a cartridge filter, high-pressure feed pump, pressure vessel containing one 2.5-inch-diameter by 40-inch-long RO spiral wound element, Koch/Fluid Systems Model 2540HR thin film composite polyamide type membrane, and flow meters and pressure gauges.

Unlike the GrahamTek unit, which operates in a single-pass mode (feed flow entering the pressure vessel is converted to permeate and concentrate and wasted from the system), the SETU operated in both single-pass and concentrate recycle modes (a portion of the concentrate exiting the pressure vessel is recycled back and blended with the incoming feed) depending on feedwater recovery[3]. At feedwater recoveries greater than 15 percent, concentrate recycle was employed. Permeate and waste concentrate flows from the SETU were directed to the EDR wastewater holding pond. When required, the SETU element was chemically cleaned to remove foulants and scalants accumulated during operation. No chemical treatment was applied to the Zeta Rod/RO feedwater.

Startup/Shutdown

From June 16 to 25, 2000, the Zeta Rod/RO system was operated intermittently for equipment startup and shutdown. During this period, several mechanical issues were addressed with the RO unit.

Element 1 was operated for 317 hours from June 26 through July 16, 2000 at 50 percent system recovery. During this period, it became apparent that particulates were forming during treatment and impacting the operability of the system by plugging orifices of the small valves used to set and maintain concentrate waste and recycle flows. The plugging problem made it very difficult to maintain steady state operation, with feed pressures increasing, permeate flow increasing, and concentrate flow decreasing. To alleviate this problem, a 5-micrometer (μm) cartridge filter was installed upstream of the concentrate control valves to capture the particulates. Later, the rating of the filter was reduced to 1 μm to improve solids retention.

The system was offline from July 17 through August 6, 2000, during which time the cartridge filter was replaced with a stainless steel, higher pressure-rated unit, and the concentrate recycle stream was relocated to blend concentrate and feedwater directly upstream of the Zeta Rod. (This was done to enable the Zeta Rod to assist in particle formation.) A second 1-μm cartridge filter was also installed downstream of the Zeta Rod to capture solids present in the combined feed/concentrate recycle stream. A flush line from the GrahamTek permeate tank was installed to allow RO unit flushing with permeate prior to or following shutdowns. A process and instrumentation diagram for the modified Zeta Rod/RO system is shown in Figure F1.

On August 7, 2000, Element 2 was installed and the system operated at target conditions until September 1 for a total of 468 hours. During this period, the unit experienced shutdowns caused by failure of the system feedwater supply pump and of the pulse dampener. In addition, a portion of discharge flow from the high-pressure pump was diverted to waste from the pressure relief valve being set at too low a blow off pressure. The unplanned shutdowns resulted in the unit not being flushed with product water until the next calendar day, potentially resulting in mineral precipitation within the RO element. Consequently, on August 22, 2000 (at 274 hours of operation), the RO element was chemically cleaned using a 2 percent citric acid solution.

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[3] Feedwater recovery is defined as (permeate flow rate/feedwater flow rate) x 100, expressed as a percentage.

FIGURE F4
Single Element Unit Equipped with Zeta Rod Used during the EDR Recovery Testing

To determine if the Zeta Rod was contributing to the increased permeate conductivity observed during operation of Elements 1 and 2, on October 11, a third RO element was installed and operated at 15 percent element and system recovery on EDR wastewater not pretreated by the Zeta Rod. Element 3 was operated for 626 hours until December 7, 2000. This concluded Zeta Rod/RO system testing.

Testing Protocol

Tables F2 and F3 present the protocols used to evaluate the feasibility of the GrahamTek and Zeta Rod/RO systems for EDR wastewater treatment. The main intent of the protocol was to operate each unit at increasing feedwater recovery, monitoring system performance at each recovery to determine if performance declines were evident.

TABLE F2
GrahamTek System Operating Conditions

Recovery	Permeate Flow (gpm)	Concentrate Flow (gpm)
20%	3.75	15
40%	7	10.5
50%	7	7
50%	6.5	6.5

TABLE F3

Zeta Rod System Operating Conditions

Recovery	Permeate Flow (gph)	Concentrate Flow (gph)	Concentrate Recycle Flow (gpm)
50%	12	12	1.0
15%	12	68 (1.13 gpm)	--

The GrahamTek system was initially operated at 20 percent recovery. When satisfactory performance was achieved after a minimum of 2 weeks of operation, recovery was increased to 40 percent. After acceptable performance at 40 percent, recovery was then increased to 50 percent for further evaluation. The unit was operated for nearly 645 hours of testing prior to a chemical cleaning and element replacement. Following installation of the new elements, the unit was operated for an additional 530 hours.

Data was collected twice daily on flows, pressures, and conductivities; this information was input into NORMPRO[4] to determine membrane scaling and/or fouling during the testing period. Weekly samples were collected and analyzed to perform a mass balance on scaling ions. Monthly sample collection and analysis was also done for a greater suite of cations and anions. At the conclusion of the second test run, Koch/Fluid Systems performed an autopsy on one of the two elements to quantify performance changes and to indirectly assess the cause of the degradation.

Given the short planned operating duration, the Zeta Rod/RO system was operated at a target system recovery of 50 percent and an element recovery of 15%.[5] A follow-on, negative-control test was conducted at system and element recoveries of 15 percent with the Zeta Rod power supply inactive to determine if the Zeta Rod was contributing to the membrane performance degradation observed in the first run.

Data on the flows, pressures, and conductivities was collected twice daily to evaluate membrane scaling and/or fouling. One of the membrane elements used in the testing was sent to the Bureau of Reclamation Engineering and Research Center (BORERC) for an autopsy.

Results

GrahamTek System

Water Quality Characterization

Water quality analyses performed on the feed, permeate, and concentrate for the GrahamTek system are summarized in Table F4. Also presented in the table is the historical quality of the EDR wastewater. With the exception of chloride, the concentration of all ions as well as TDS is lower for the average GrahamTek feed than for the historical wastewater. With respect to the scale-forming ions (barium, calcium, strontium, sulfate, and bicarbonate), these lower levels indicate a lower potential for precipitation of the sparingly soluble salts

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[4] NORMPRO is a proprietary software program licensed by Koch/Fluid Systems to end users and consultants for use in normalizing operating data of RO systems using their elements.

[5] System recovery is calculated as [permeate flow/feed flow] x 100 where feed flow does not include concentrate recycle. Element recovery is defined similarly, except feed flow includes both feed and concentrate recycle flows.

(barium/calcium/strontium sulfates and calcium carbonate) during RO treatment by both the GrahamTek and Zeta Rod/RO systems. The reduced levels in the feed reflect either lower concentrations of these ions in the Lake Texoma water and/or reduced concentration of these salts by the EDR units (less salt cut).

The ROPRO™ RO performance projection program was used to determine the degree of supersaturation of each sparingly soluble salt in the RO concentrate resulting from GrahamTek treatment of the average feed compared with treatment of the historical wastewater assuming 50 percent feedwater recovery. This comparison provides insight into the effect of treating the lower ion-containing water on scaling potential. The following conclusions can be drawn from the results, shown in Table F5, which also presents the maximum allowable degree of supersaturation permitted when an antiscalant is present in the concentrate. :

- With the exception of calcium carbonate, the degree of supersaturation of all salts is lower in the concentrate from “average feed” treatment compared with “historical wastewater” treatment, most notably for barium sulfate.
- Barium sulfate and calcium sulfate are present in the “historical feed” concentrate at levels above those for which the antiscalant is effective.
- Only calcium sulfate is present in the “average feed” concentrate at a level above that for which the antiscalant is effective.

Taken as a whole, these results suggest there is a high likelihood that only calcium sulfate will precipitate during RO treatment of the EDR wastewater even in the absence of any benefits from GrahamTek scale control technology. Of course, this conclusion considers only theoretical saturation calculations and does not reflect the impact of kinetics or the presence of factors that could increase precipitation potential at the RO membrane surface (foulants, oxidants, and concentration polarization).

A mass balance was conducted on each ion listed in Table F1 to indirectly estimate if one or more of these ions was depositing in the RO elements of the GrahamTek unit during treatment. The results of this mass balance (not shown) indicate that the only ion for which a net loss was consistently observed over the nearly four months of sampling was barium. (A negative value in the column labeled “difference” indicates that there was a net “loss” of that ion during treatment. A positive value would indicate a net “gain” and is not possible.) The barium loss for all but two sample events was significant (greater than 25 percent). It should be noted, however, that the mass balance for barium was determined by assuming a value of barium in the RO permeate equal to the detection limit of the analytical procedure, given that the permeate barium level was less than the detection limit for each sample analyzed. This assumption provides a conservative estimate of barium loss since the actual barium limit was most likely lower than the detection limit.

The mass balance information, along with total membrane area in the two RO elements, was used to estimate the unit rate of barium precipitation in mg/day-ft^2. These results, presented in Table F6, show a relatively high rate of barium sulfate deposition. It must be made clear that the use of mass balance to determine the deposition of barium or other sparingly soluble ion during treatment is a crude measure given the level of inaccuracy intrinsic in this approach. (Inaccuracy results from errors in both ion concentration and flow rate measurement.) Mass balance determinations should be used only as a semiqualitative indicator of scaling to be confirmed by the results of element autopsy.

TABLE F4
Quality for GrahamTek System Flows and Historical EDR Wastewater

Parameter, mg/L	No. of Samples[a]	Average			Minimum			Maximum			Historical Wastewater
		Feed	Permeate	Concentrate	Feed	Permeate	Concentrate	Feed	Permeate	Concentrate	
Cations											
Aluminum	3	0.17	*0.10*	0.15	*0.10*	*0.10*	0.11	0.26	*0.10*	0.22	NR[b]
Barium	8	0.22	0.029	0.23	0.13	0.025	0.13	0.39	0.06	0.35	1.3
Calcium	8	744	15	1062	701	0.5	848	819	108	1330	822
Iron	3	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	NR
Magnesium	3	287	0.73	479	251	0.5	311	307	1.2	629	289
Manganese	3	*0.01*	*0.01*	0.011	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	0.012	NR
Potassium	3	40	1.6	69.3	34.5	0.93	43.3	44.9	2	94.8	40
Sodium	3	963	31	1702	786	20.5	986	1120	39.1	2400	1246
Strontium	8	12.1	0.36	19	10.2	0.10	12.7	14	2.14	25.3	18.4
Anions											
Bicarbonate	8	350	15.9	517	199	6.1	395	439	42.7	651	696
Chloride	3	2123	42	3403	1950	33	2340	2320	56	4410	2025
Fluoride	3	10.9	0.27	15.9	0.1	0.1	12.5	20	0.5	20	NR
Sulfate	8	2151	54	3324	1680	3	2100	2660	377	4830	2600
Other											
Silica	3	3.9	0.4	6.0	3.1	0.4	3.9	5	0.4	8.6	NR
TDS (gravimetric)	8	7266	303	11170	6500	64	8140	7910	1550	15100	7277
TDS (sum of ions)		6512	153	10339	5516	62	6855	7530	608	14074	7390

Note: Values in italics are less than detection limit.

[a] Based on sampling conducted from May 22 to September 14, 2000.

[b] Not reported.

TABLE F5

Comparison of Scaling Potential of Concentrates Produced by GrahamTek Treatment of Average Feed (during Testing) and Historical Wastewater

Sparingly Soluble Salt	Average Feed[a]	Historical Wastewater[a]	Maximum Level Using Antiscalant
Barium Sulfate	45	292	60
Calcium Sulfate	2.2	2.6	2.0
Strontium Sulfate	1.7	2.8	8
Calcium Carbonate (Stiff Davis Index)	1.48	1.17	1.8

[a] Values >1 indicate each salt is supersaturated.

TABLE F6

Barium Sulfate Deposition

Date	Difference (μg/min)	Difference (mg/day)	Ba deposition rate (mg/day-ft^2)	$BaSO_4$ deposition rate (mg/day-ft^2)
5/22/2000	3,949	5,686	5.6	9.6
6/19/2000	7,375	10,620	10.4	17.9
6/29/2000	103	148	0.1	0.3
7/6/2000	4,769	6,868	6.7	11.6
7/17/2000	7,154	10,301	10.1	17.4
8/31/2000	935	1,346	1.3	2.3
9/14/2000	4,020	5,789	5.7	9.8

System Performance

Summarized in Figures F5 through F8 are the operational results for approximately 1,700 hours of testing of the GrahamTek system. All plots are as a function of unit run time and include feedwater recovery, feed pressure, feed and product conductivity, and water and salt transport coefficients.

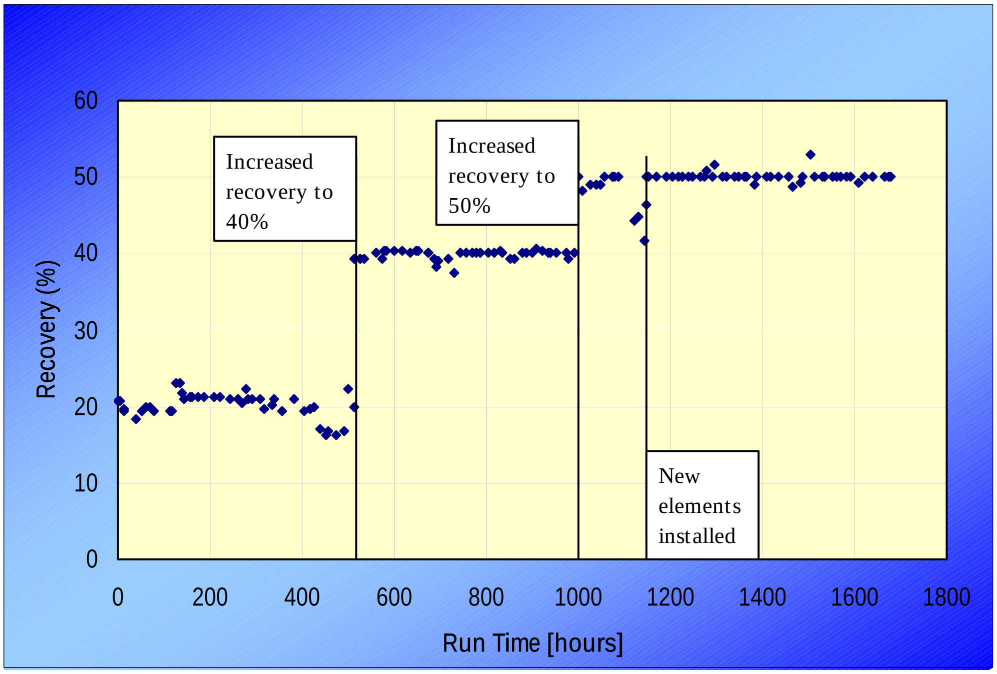

FIGURE F5
GrahamTek Feedwater Recovery

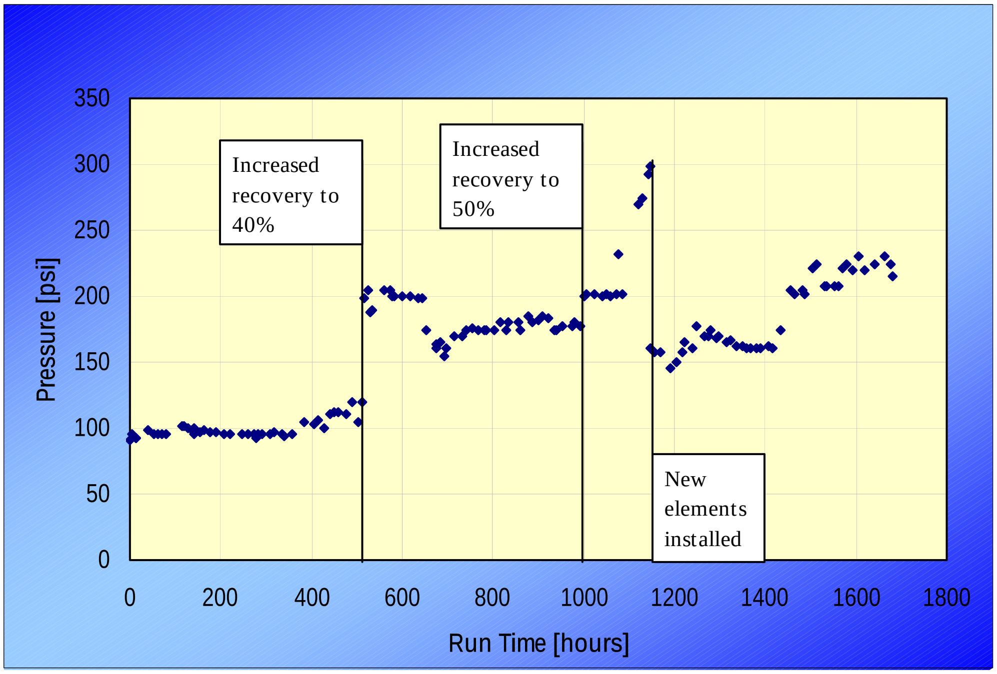

FIGURE F6
GrahamTek Feed Pressure

FIGURE F7
GrahamTek Feed and Permeate Conductivity

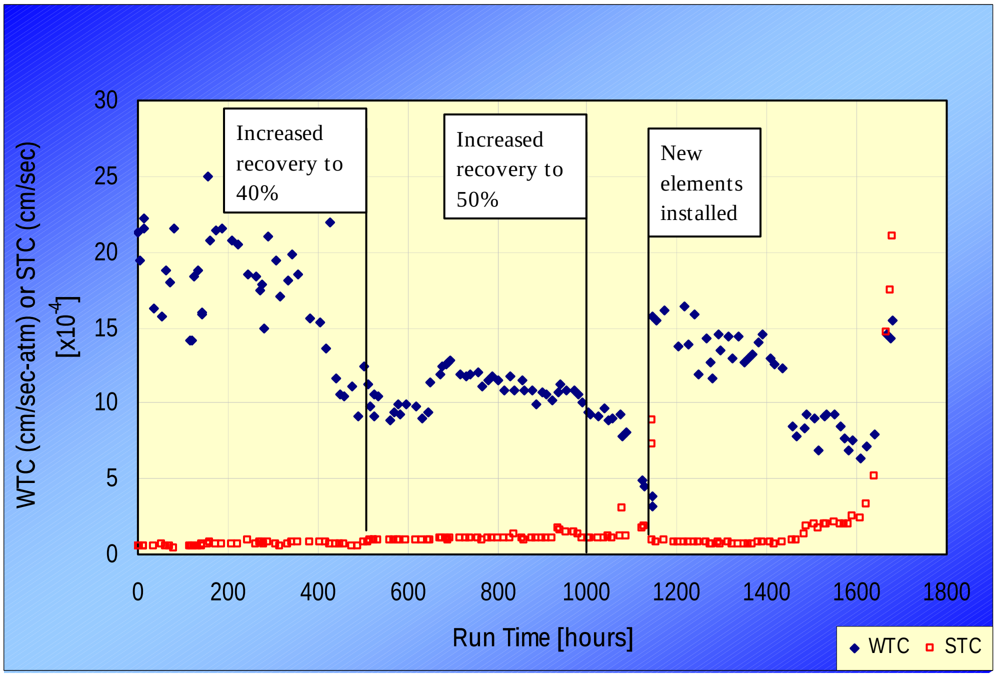

FIGURE F8
GrahamTek Water and Salt Transport Coefficients

Element Pair 1

The first pair of RO elements was operated at 20 percent recovery for 500 hours, at which time the recovery was increased to 40 percent for an additional 500 hours. Recovery was increased to 50 percent for the final 145 hours of operation. Feed pressure increased as recovery was increased; however, this is normal and reflects the greater osmotic pressure of the feed as it is more heavily concentrated at the higher recoveries. At 20 and 40 percent recovery and during the initial part of 50 percent recovery operation, feed pressure was relatively stable, indicating that membrane fouling/scaling was controlled. The rapid rise in feed pressure during the final 60 hours of 50 percent recovery operation was the result of solids loading to the elements from inadvertent discharge of EDR waste CIP solution to the GrahamTek unit. This was confirmed by the rapid plugging of the pilot unit cartridge filters and the appearance of whitish solids on the ends of the RO elements.

At startup, permeate conductivity was 133 µS/cm, reflecting excellent salt rejection by the HR membrane. Permeate conductivity increased with increasing recovery reflecting high salt loading across the membrane. However, permeate conductivity showed gradual increases during operation at each recovery and a very sharp increase at the end of 50 percent recovery operation. This gradual increase is not characteristic of thin film polyamide membranes like the HR, and suggests some sort of membrane degradation or fouling was occurring. During this time, the free chlorine residual in the GrahamTek feedwater was between 0.04 and 0.78 mg/L, which is higher than the 0.10 mg/L residual recommended by the manufacturer. The higher residual most likely was the cause or major contributing factor to the sharp increase in permeate conductivity at the end of the operating period.

The performance of RO elements is best judged by examining two parameters, water transport coefficient (WTC) and salt transport coefficient (STC)[6]. These parameters show the true change in the membrane's ability to permeate water and limit salt passage by eliminating the confounding effects of varying feedwater temperature and TDS as well as recovery. In the absence of fouling and scaling, as well as chemical degradation of the membrane, WTC and STC would be stable and show neither an increase nor decrease with increased operating time. The data for Element Pair 1 show stable WTC during the first 400 hours but a decline in the final 100 hours of operation at 20 percent recovery. No decline is observed at 40 percent operation, but a decline is noticeable at 50 percent operation even before the fouling event. Like permeate conductivity, STC increased gradually with time, with a very sharp increase during the final 100 hours of operation. These performance changes may have been the result of chlorine oxidation of the membrane, membrane fouling, and/or scaling or a combination of both.

---

[6] WTC is defined as follows:

WTC = (Qp x TCF)/(A x NDF), cm/sec-atm, where

Qp = permeate flowrate, cm^3/sec

TCF = temperature correction factor, unitless

A = membrane area, cm^2

NDF = net driving pressure, atmospheres

STC is defined as follows:

STC = (Cp x Qp x TCF)/[(Cfb – Cp) x A], cm/sec, where

Cfb = log-mean average TDS concentration of the feed/brine, g/cm^3

Cp = TDS concentration of the permeate, g/cm^3

Element Pair 2

A second pair of elements (same model) were installed on August 23, 2000, and operated for 530 hours. Trends in feed pressure and WTC were stable during this phase of testing, except for the step increase in feed pressure and decrease in WTC at 1,430 hours of operation. This change corresponded with an unplanned shutdown of the GrahamTek system without a subsequent permeate flush. The lack of flush most likely resulted in a fouling and scaling of the elements and the increase/decrease in feed pressure/WTC. This is also reflected in a step increase in the STC following this shutdown. The rapid and dramatic rise in STC during the last 100 hours of operation signal chemical attack on the membrane, which was confirmed by membrane autopsy (see later section of this report). It is interesting that such an increase occurred after only 530 hours of operation while a more gradual increase was observed over a longer period of operation with the first pair of elements. The greater rate of STC increase could be caused by a greater concentration of oxidizing chlorine at the higher recovery during the second test.

Element Autopsy

The 40-inch-long element operated during the second test was shipped to Koch/Fluid Systems for autopsy. The element was first "performance tested" to determine product flow and sodium chloride rejection for comparison to values for the element when manufactured. The element was then dissected and selected membrane sections (leaves) of the element were subjected to a battery of analytical tests: electron dispersive x-ray analysis (EDXA), loss on combustion, and dye testing. EDXA measures the inorganic elements present in the material deposit on the membrane surface. Loss on combustion is used to quantify the percentage of organic and inorganic matter (ash) comprising the deposit. Dye testing is used to determine if the membrane has been exposed to oxidants that cause damage to the rejecting layer or underlying support membrane.

The results of the autopsy are summarized in Table F7. Most notable are the poor element rejection (89.9 versus 99.6 percent) and the heavy uptake of dye. This clearly indicates damage to the membrane, most likely from free chlorine or other chlorinated oxidant in the EDR wastewater. The dye uptake was heaviest at the feed side of the element, suggesting the worst degradation occurred upon initial contact of the wastewater with the element. The element also suffered moderate fouling by material that was nearly all (95 percent) inorganic in nature (based on loss on combustion). The foulant was comprised of four primary elements: sulfur, calcium, aluminum and barium. These elements were most likely present in the form of precipitated salts, including barium and calcium sulfates and possibly calcium carbonate.[7]

What cannot be determined from either the autopsy or mass balance calculations is whether these salts were precipitated prior to entering the GrahamTek unit and simply deposited during RO treatment (like any other feedwater particle) or precipitated from solution during RO treatment. Mass balance calculations used unfiltered samples; filtering such samples in the future may provide such information. No matter what their origin, these precipitates would have to be effectively removed by chemical cleaning in order to maintain stable long-term performance.

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[7] The EDXA analytical procedure does not detect carbonate. A portion of the calcium present in the foulant may have been in the form of calcium carbonate.

TABLE F7

GrahamTek Element Autopsy Summary

Performance Test			
Pressure:	225	Feedwater:	2 g/l NaCl
	Date	**GPD**	**% Rejection**
Original	Aug 2000	7,550	99.6
Retest	October 2000	7,000	89.9
Foulant Analysis			
Appearance:	Clay-like (muddy texture and color)		
Loss on Ignition:	94.6% ash (inorganic)		
EDS:	Major Constituents	Minor Constituents	
	S = 33.3%	Cu = 3.3%	
	Ca = 24.9 %	Sr = 2.9%	
	Al = 16.3%	Fe = 2.7%	
	Ba = 15.5%	Cl = 1.1%	

The aluminum was most likely present as aluminum hydroxide, carrying over from the conventional treatment process through the EDR units.

Zeta Rod/RO System

Water Quality Characterization

No characterization of the quality of the Zeta Rod/RO system feed, permeate or concentrate was performed during the study as the focus of this testing was to characterize performance changes only.

System Performance

The Zeta Rod/RO system was evaluated for a total of 1,461 hours in which three separate RO elements were operated. The operational results for Elements 1, 2, and 3, respectively, are summarized in Figures F9 through F16. (Performance results for Element 2 span 0 to 468 hours of run time, and performance results for Element 3 span 516 to 1,143 hours of run time, as shown in Figures F13 through F16.)

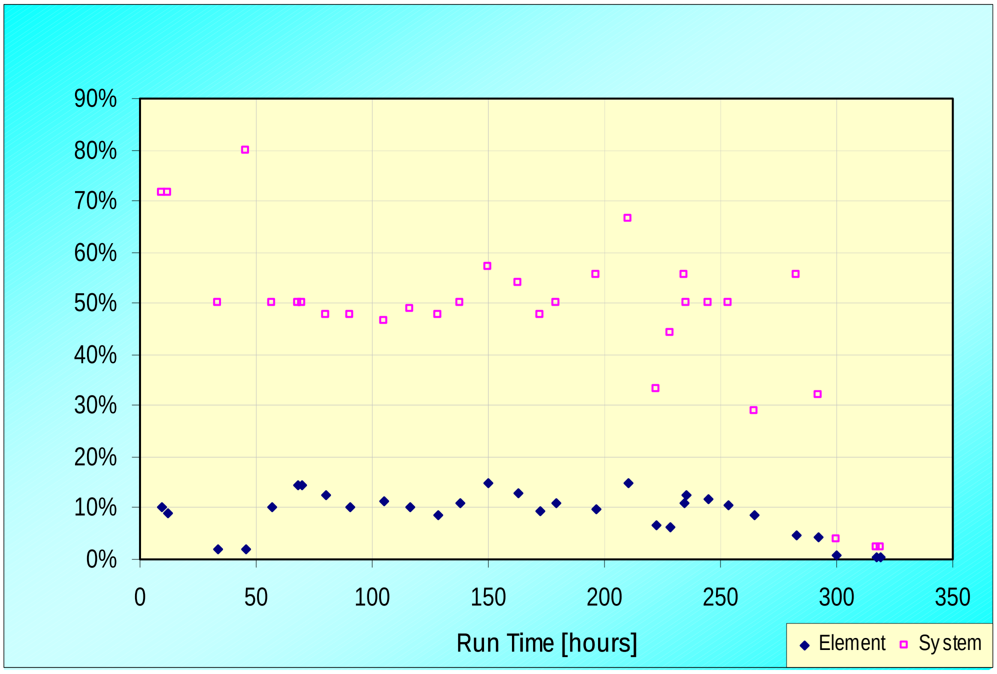

FIGURE F9
Zeta Rod Element 1 Feedwater Recovery

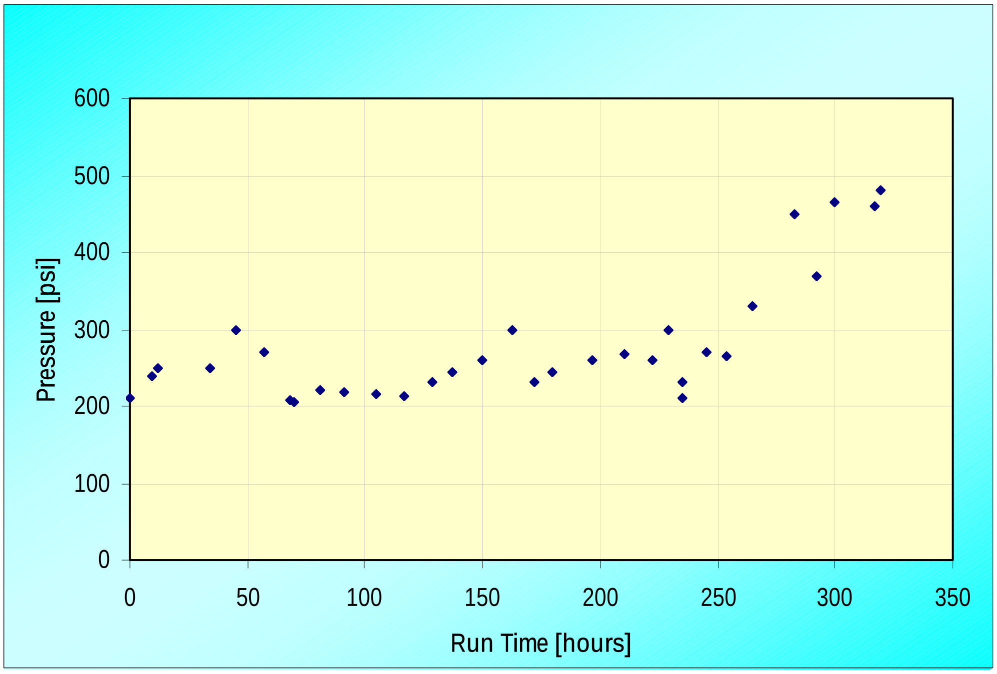

FIGURE F10
Zeta Rod Element 1 Feed Pressure

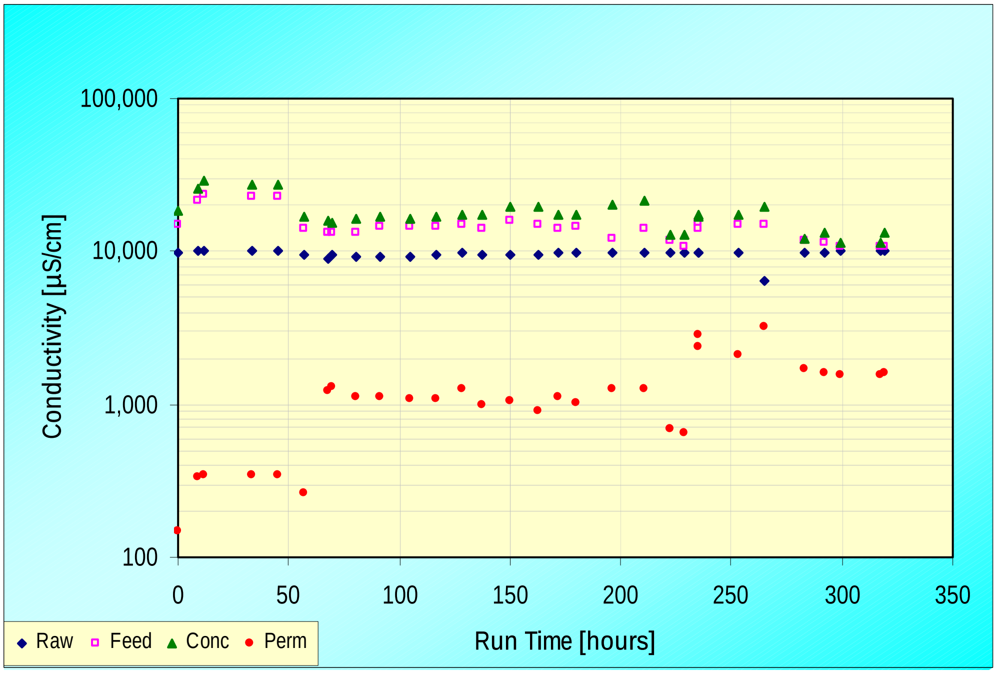

FIGURE F11
Zeta Rod Element 1 Feed and Permeate Conductivities

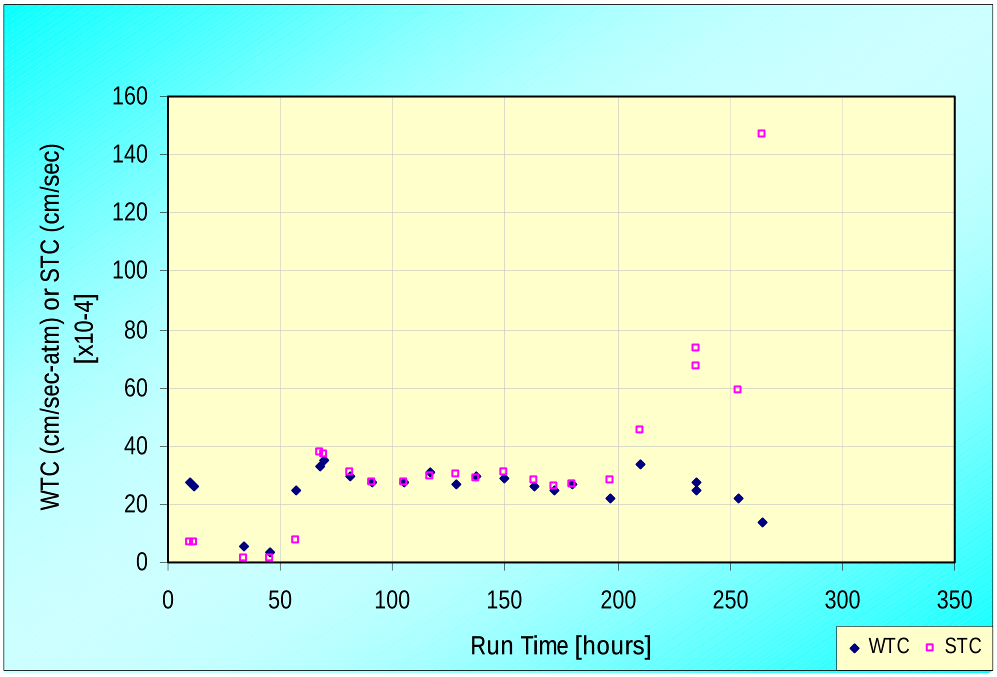

FIGURE F12
Zeta Rod Element 1 Water and Salt Transport Coefficients

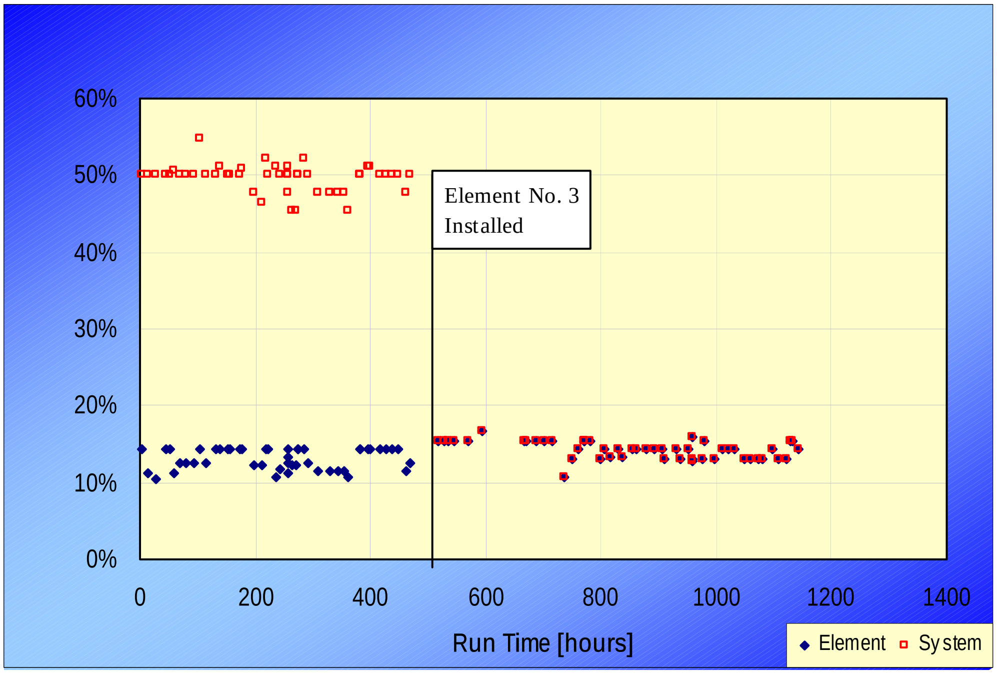

FIGURE F13
Zeta Rod Elements 2 and 3 Feedwater Recovery

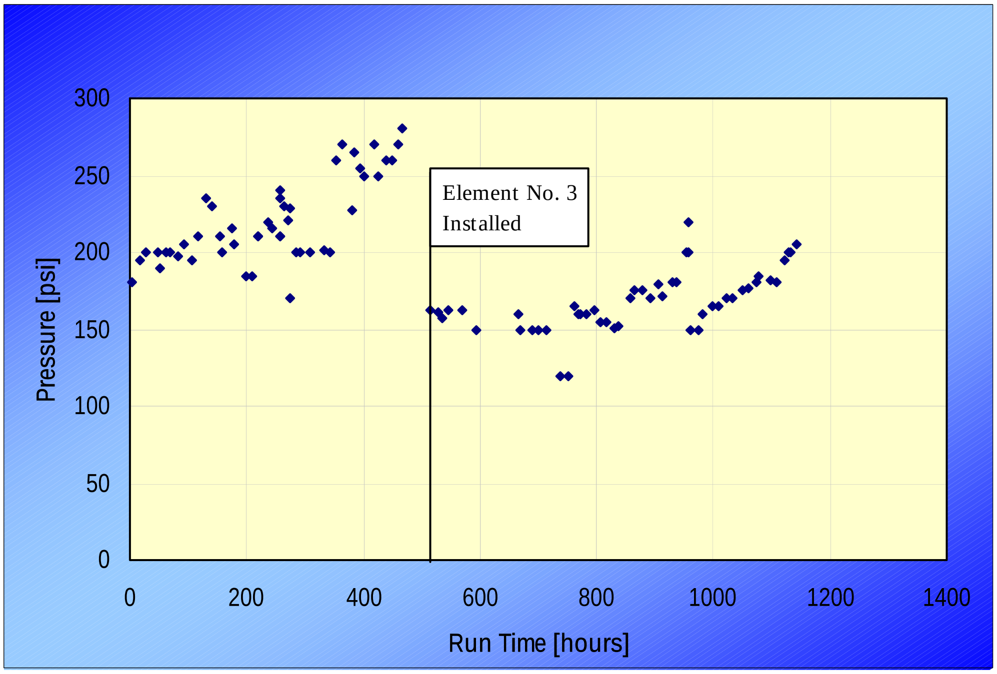

FIGURE F14
Zeta Rod Elements 2 and 3 Feed Pressure

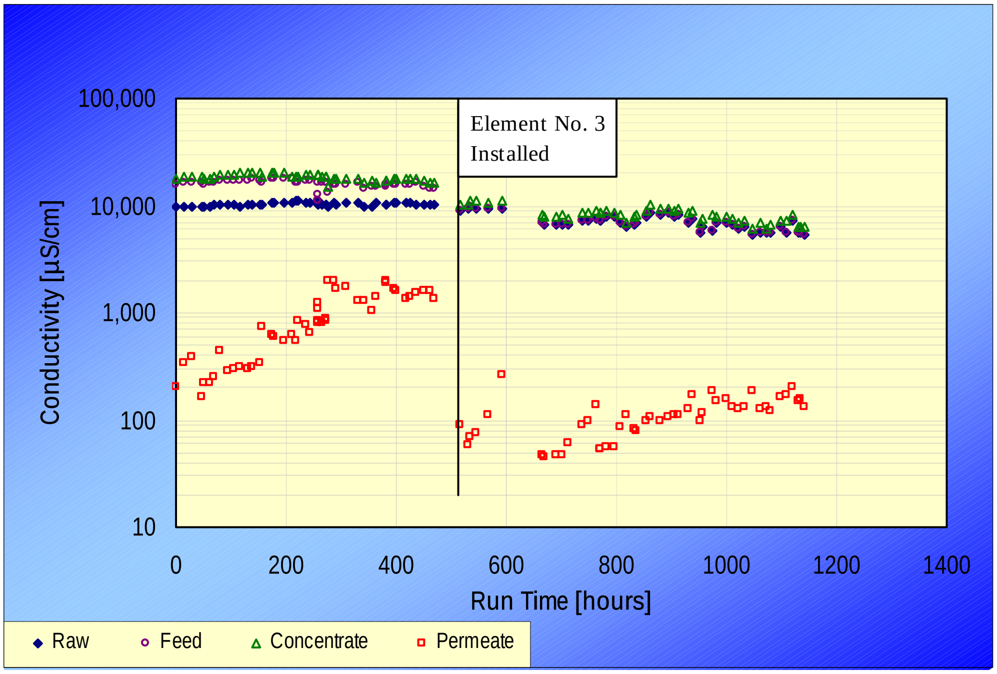

FIGURE F15
Zeta Rod Elements 2 and 3 Feed and Permeate Conductivities

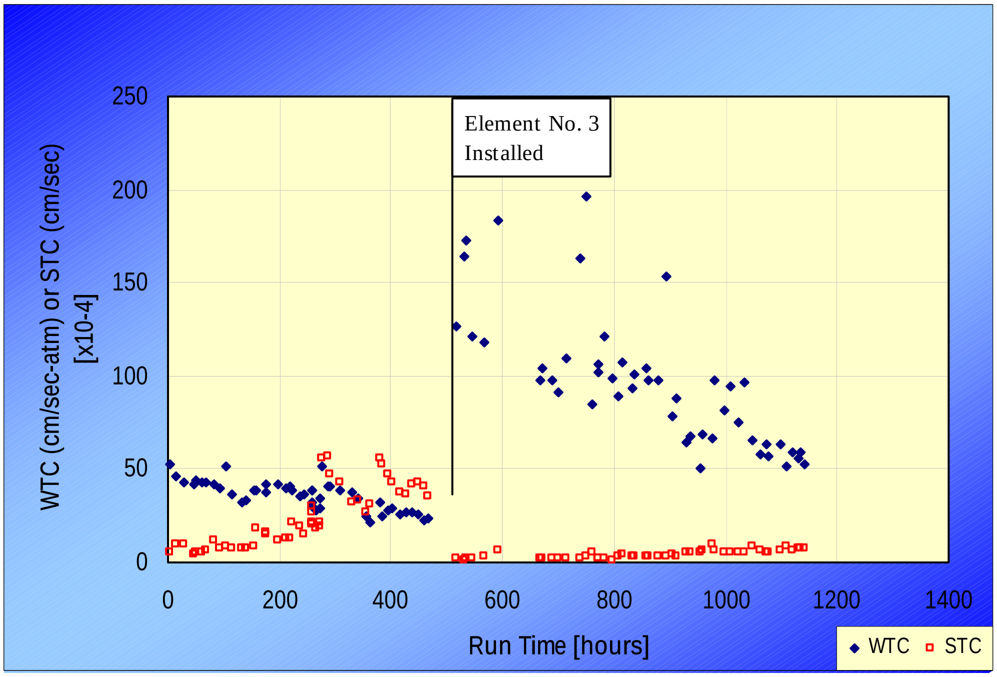

FIGURE F16
Zeta Rod Elements 2 and 3 Water and Salt Transport Coefficients

Element 1

Feedwater recovery was consistently maintained at the target value of 50 percent, although some variations did occur. These were associated with the difficulty of adequately controlling the very low waste concentrate flows. Feed pressure was quite stable during the first 250 hours of operation, at which time it increased dramatically. Product water conductivity showed a step increase from 350 to 1,300 µS/cm at ~60 hours. WTC was stable until feed pressure increased at which time it declined rapidly. Likewise, STC changes mirrored those of product water conductivity. The increases in feed pressure and product conductivity and decline in WTC are attributed to unplanned shutdowns and lack of timely feedwater flush associated with valve plugging. Following these uncontrolled shutdowns, supersaturated salts would have an opportunity to precipitate within the feed channels of the element. Based on the results of the autopsy of Element 1 (see subsequent section titled Element Autopsy), calcium sulfate was the predominant precipitated salt.

Element 2

In contrast to that of Element 1, the performance of Element 2 showed no period of stability. Feed pressure and permeate conductivity increased and WTC decreased steadily from startup through the end of testing. No autopsy was performed with this element to determine if precipitated salts were accumulating at the feed end the element (like Element 1); however, differential pressure (ΔP) was stable during the entire period of operation. This indirectly indicates that any salt buildup was minor. The cartridge filters did show a pressure drop increase indicating retention of particulate material. It may be more likely that the performance declines resulted from precipitation of sparingly soluble salts from concentration at the membrane surface (which would be more noticeable at the concentrate end), chemical oxidation of the membrane, or a combination.

Element 3 (Without Zeta Rod)

Element 3 performance was stable for the first 320 hours at which time, feed pressure increased and WTC declined steadily. Product water conductivity did increase during this latter period of operation but at a much lower rate and to a much lesser extent than for Element 2. Further, chemical cleaning was successful in reducing feed pressure and increasing WTC (see step change at 960 hours run time) but not the increase in product water conductivity. These changes indicate that fouling, rather than scaling was causing the decrease in WTC, but oxidation was responsible for the conductivity increase. Following the cleaning, the element exhibited the same rate of fouling as prior.

Element Autopsy

Element 1 was shipped to BORERC following completion of testing. The element was flushed with product water prior to shipping. BORERC autopsied the element and produced a report on their findings (not shown). Scanning electron microscopy (SEM) of the membrane surface, originally planned as part of the autopsy, was not performed. The major findings from the autopsy are:

- A large amount of salt was present in the feed channel (vexar) of the elements.
- The salt was predominantly calcium sulfate. When dissolved in acid, the solubilized fraction of this salt was 97 percent calcium sulfate.
- The manner in which the salt was deposited within the feed channel (predominant at feed end of element) suggests the salt was already present as a precipitate in the element feed and was not precipitated at the membrane surface from soluble calcium sulfate.

- The mass of deposited salt would have caused a significant increase in the feed/concentrate differential pressure (ΔP).

BORERC staff postulated that four salts, barium sulfate, calcium sulfate, strontium sulfate, and calcium carbonate, were supersaturated in the element feed. The degree of supersaturation was not above that allowed with the use of a scale inhibitor, however. At 50 percent recovery, the calcium sulfate was estimated to about 2.2 times saturation in the concentrate (see Table F5). This degree of supersaturation could have caused calcium sulfate to precipitate in the concentrate recycle loop.

Three alternatives are possible to explain the presence of precipitated salts in the element: (1) the salts present in the water held in the element precipitated when the RO unit was shutdown and the supersaturated feed/concentrate solution was not flushed prior to element removal and draining, (2) precipitation occurred during or after EDR treatment or (3) precipitation occurred in the concentrate recycle loop. Alternative 1 is not feasible as it would produce a precipitation pattern different from that observed from the autopsy and could not produce the mass of salt collected.[8] There is no way of knowing whether Alternative 2 or 3 was the cause; however, Alternative 3 is more likely given the higher concentration of calcium sulfate in this stream. It should be noted that the ΔP did increase from 5 to 10 pounds per square inch (psi) to 30 to 40 psi near the latter period of testing, consistent with the BORERC's conclusion (see Figure F17).

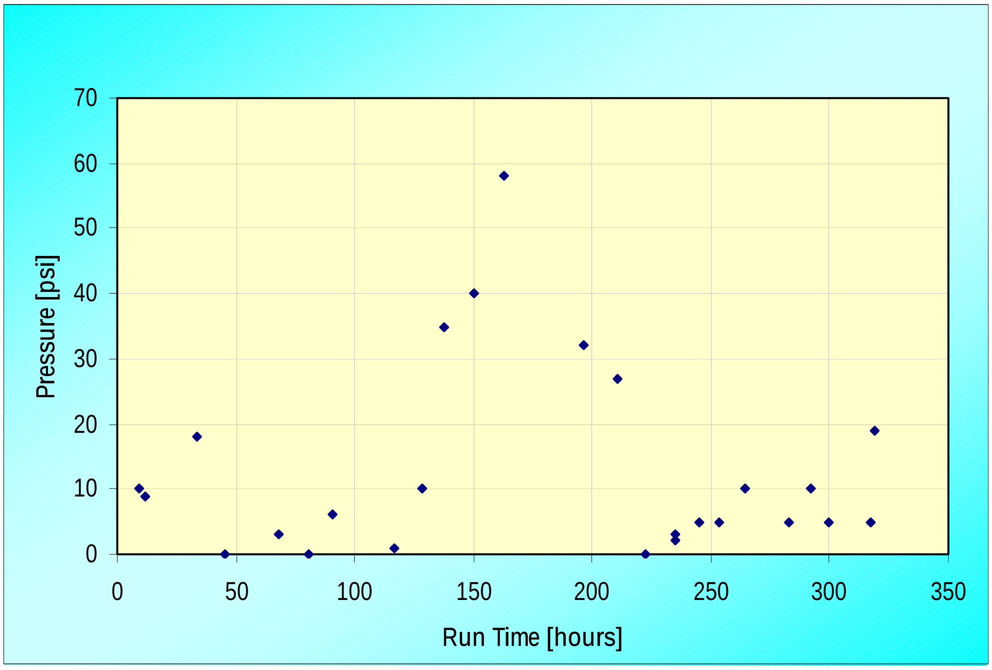

FIGURE F17
Zeta Rod Element 1 Differential Pressure

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[8] The mass of salt present in the hold-up volume of the element is calculated as follows: $(1.25\text{in}/12\text{in/ft})^2 * \pi * (40\text{in}/12\text{in/ft}) * 7.48\text{gal/ft}^3 * 3.785\text{L/gal} * 0.5 = 1.6\text{L} * 6.5\text{ g/L} = 10.4$ grams. This is <20% of the salt mass removed from one leaf and there are multiple leaves in the element.

Conclusions and Recommendations

General

At 50 percent feedwater recovery, RO treatment of the EDR wastewater produces high-quality treated water that should be acceptable for direct blending with the existing water treatment plant's filtered water. This is based on the low TDS and hardness of the RO permeate (less than 100 mg/L and ~15 mg/L as $CaCO_3$). If such treatment were to be implemented in the future, it is recommended that additional permeate testing be conducted to confirm that all applicable drinking water regulations can be met. Production of potable water from the EDR wastewater by RO appears to be limited by the scaling potential not the permeate quality. Salt removal should be sufficiently high that treatment to 80 percent recovery is feasible for direct product water blending assuming an effective scale control method can be demonstrated at this recovery.

The EDR wastewater cannot be effectively treated by RO as it currently exists. The wastewater is characterized by a high oxidation potential and contains significant concentrations of free chlorine caused primarily by the high chlorine concentration of the electrode waste stream and to a lesser extent by chlorination of the EDR feedwater. The high oxidation potential caused chemical degradation of the thin-film rejecting layer of the RO membrane and cannot be practically controlled by addition of a reducing agent (e.g., sodium bisulfite). A suitable control strategy, that would require demonstration, would be to change from free chlorine addition to chloramination of the EDR feedwater and to segregate the electrode waste stream from the EDR wastewater.

RO membrane degradation caused by exposure to the high oxidation potential of the wastewater did not allow a clear assessment of the feasibility of either EDR wastewater treatment technology (GrahamTek and Zeta Rod). Performance changes resulting from the degradation, which include increased salt passage and potentially decreased WTC, would mask similar performance changes that are expected to occur from the precipitation of sparingly soluble salts, the main concern in treating the wastewater with RO. The conclusions presented below for the GrahamTek and Zeta Rod/RO systems should be considered in this context.

GrahamTek System

When receiving representative feedwater quality, the GrahamTek system exhibited stable performance (feed pressure and WTC were consistent or showed only gradual declines) at feedwater recoveries up to 50 percent. Loss of salt rejection (increased product water conductivity) was attributed to membrane oxidation. Element autopsy showed that mineral precipitates (calcium and barium sulfates) were depositing on the membrane. It is not clear, however, if these deposits were formed in the bulk flow or at the membrane surface.

Zeta Rod/RO System

The Zeta Rod improved operability of the conventional RO treatment (relative to no pretreatment) although the mechanism responsible for the observed reduction in membrane fouling is not well understood. Feed pressures and WTC were more stable during Zeta Rod use at 50 percent recovery than without its use at 15 percent recovery. By increasing the surface charge of the ions and colloids in the EDR wastewater, the Zeta Rod may actually destabilize the sparingly soluble salts, resulting in their precipitation in the feedwater, thereby reducing the potential for these salts to scale the membrane surface. Such precipitation was evident from membrane autopsies and indirectly from valve orifice clogging and solids loading on 1-µm cartridge filters. If the precipitated salts can be effectively captured before they reach the RO element so that clogging of the feedwater spacer can be minimized, a low-cost approach to EDR treatment and recovery may be available. Longer-term testing will be necessary to successfully demonstrate this approach before a full-scale system could be implemented.

As observed with the GrahamTek system, salt passage increased dramatically during testing with and without the Zeta Rod, indicating the RO membrane was being degraded by oxidants in the EDR wastewater. The rate of increase in RO salt passage appears to be proportional to feedwater recovery, again an observation consistent with GrahamTek test results, suggesting that whatever is oxidizing the RO membrane is concentrated by RO treatment.

Recommendations

1) Prior to the testing and evaluation of any RO-based treatment and recovery system, the EDR system should be modified as follows to eliminate the high oxidation potential of the wastewater:
    a) Provide an ammonia addition point in the filter effluent line to provide the capability to dose the effluent with ammonia as well as chlorine to form chloramines. It is recommended that 1 to 2 mg/L combined chlorine residual be applied to the EDR feedwater to adequately control biological growth in the EDR stacks. CH2M HILL has discussed the use of continuous chloramination with an Ionics technical representative (Bob Allison) and has been told that chloramination is compatible with the EDR membranes and has been used previously with full-scale EDR installations.
    b) Isolate the electrode waste streams exiting in each unit degasifier, manifold these together in a dedicated waste line, and discharge this line directly to the EDR wastewater holding pond.

2) Perform an additional 3-month test of the GrahamTek system (once Recommendation 1 has been implemented). Such testing would be contingent on the following: (1) the ability of MWD to demonstrate long-term commercial stability of its company, given the current transition in ownership; and (2) MWD's acceptance of a reduced monthly fee for equipment rental to minimize additional costs to the City. Two new RO elements will have to be procured by the City from Koch Fluid Systems to conduct this testing. CH2M HILL has recently communicated with Mr. David Faber of MWD, and he has indicated that MWD is interested is continuing pilot testing at Sherman and that full-scale GrahamTek systems have been supplied to several clients during the ownership transition period. This indicates that the MWD is maintaining its commercial viability at least for the short term.

3) Conduct a 3-month pilot test of the Zeta Rod in combination with a larger-scale RO system to reduce the probability of process upsets that occurred with the small-scale (2.5-inch) unit. This could be a single 4-inch element based unit or a multistage 4-inch system similar to what is being contemplated for use in plant expansion pilot testing. A potentially cost attractive approach is to obtain a 4-inch single element unit from Osmonics for such testing. Osmonics is currently providing such a unit to CH2M HILL, complete with RO membranes, at no charge for testing at both Abilene and Wichita Falls. Either system will require outfitting with appropriate cartridge filters to retain precipitated solids that may form from Zeta Rod treatment. To better understand the effect of Zeta Rod treatment on supersaturated salts in the EDR wastewater, it is

recommended that such testing incorporate filtering of the Zeta Rod inlet, outlet and RO concentrate through 0.45-µm pore size (or smaller) filter discs to quantify the extent to which Zeta Rod use is causing mineral precipitation, directly in the RO feedwater or during RO treatment.

In addition to continuation of the GrahamTek and Zeta Rod testing, we also recommend that the City consider testing one or both of the following treatment technologies:

- *Electronic Water Purification Technology (EWPT).* This technology, manufactured by Sabrex of San Antonio, Texas under license to BioSource, uses low voltage, direct current applied by electrodes to cause adsorption of ions onto an activated carbon cloth in a process called capacitive deionization. The cloth, electrodes and feed flow channel are configured in a cell. The cloth is regenerated by first grounding the electrodes and then reversing polarity. This is not a membrane-based treatment technology. In May 2000, Sabrex performed, at no cost, a batch test with a 5-gallon sample of the EDR wastewater. The results showed that at 50 percent recovery, the process could reduce the wastewater TDS from 6,500 mg/L to 500 mg/L (92.4 percent salt removal). Each desalting cycle lasted 10 minutes before regeneration was required. No information was provided regarding loss of desalting efficiency with increased cycles. One concern would be that salts would precipitate in the feed channel when the high concentration of ions is discharged during regeneration. Sabrex reported no signs of mineral precipitation. The benefit of this process is its simplicity.

  The potential advantages of the EWPT technology over RO are (1) no or significantly reduced impact from the high oxidation potential and (2) avoidance of mineral precipitation during treatment (salts are not concentrated as co-ions). CH2M HILL has not had detailed discussions with Sabrex; however, during prior conversations they indicated they could provide a pilot EWPT unit for evaluation at Sherman WTP.

  Currently, CH2M HILL is partnering with the Electric Power Research Institute (EPRI) (through Frank Oudkirk) to submit a pre-proposal to the Bureau of Reclamation under the Desalination and Water Purification Research and Development Program (DWPR) to investigate the feasibility and cost of using EWPT to desalinate both brackish raw waters and membrane concentrates. If successful, several field testing sites will be required. Sherman WTP would be an ideal candidate for both raw water and concentrate testing. The potential disadvantage of conducting EWPT testing in conjunction with this project is schedule. It is not anticipated that testing would commence until late 2001 or early 2002. The major advantage is the significant leveraging of Bureau of Reclamation/EPRI funds for conducting work at Sherman WTP.

- *High Efficiency Reverse Osmosis (HERO).* The HERO process, licensed to Aquatech International Corporation (ATC) of Canonsburg, Pennsylvania, combines ion exchange and RO to treat difficult-to-treat wastewater streams. The EDR wastewater would first be treated by cation exchange softening to remove divalent ions, including calcium, strontium, and barium. The pH of the softened water would be increased to ~10.5 and then processed through a multiple step RO system. By softening the water, pH can be increased without causing mineral precipitation. Operating the RO system at high pH has several advertised benefits: increased silica solubility so that feedwater recovery is not constrained by its precipitation, reduced membrane fouling by bacteria, and reduced membrane fouling by dissolved organics.

The potential benefits of the HERO process include the ability to treat the concentrate to a very high recovery (up to 90 percent) and the accepted method for controlling membrane scaling (softening). The disadvantages are process complexity, and high chemical usage (softener regeneration and acidification). ATC has one reference plant treating RO concentrate and has expressed a strong desire to pilot test their process on the EDR wastewater. It should be noted that the HERO process would require elimination of the high oxidation potential to prevent RO membrane damage.

References

Bates, W.T. 1999. Letter from W.T. Bates, Hydranautics, to Rodrigo Romo, Zeta Corp. May 6.

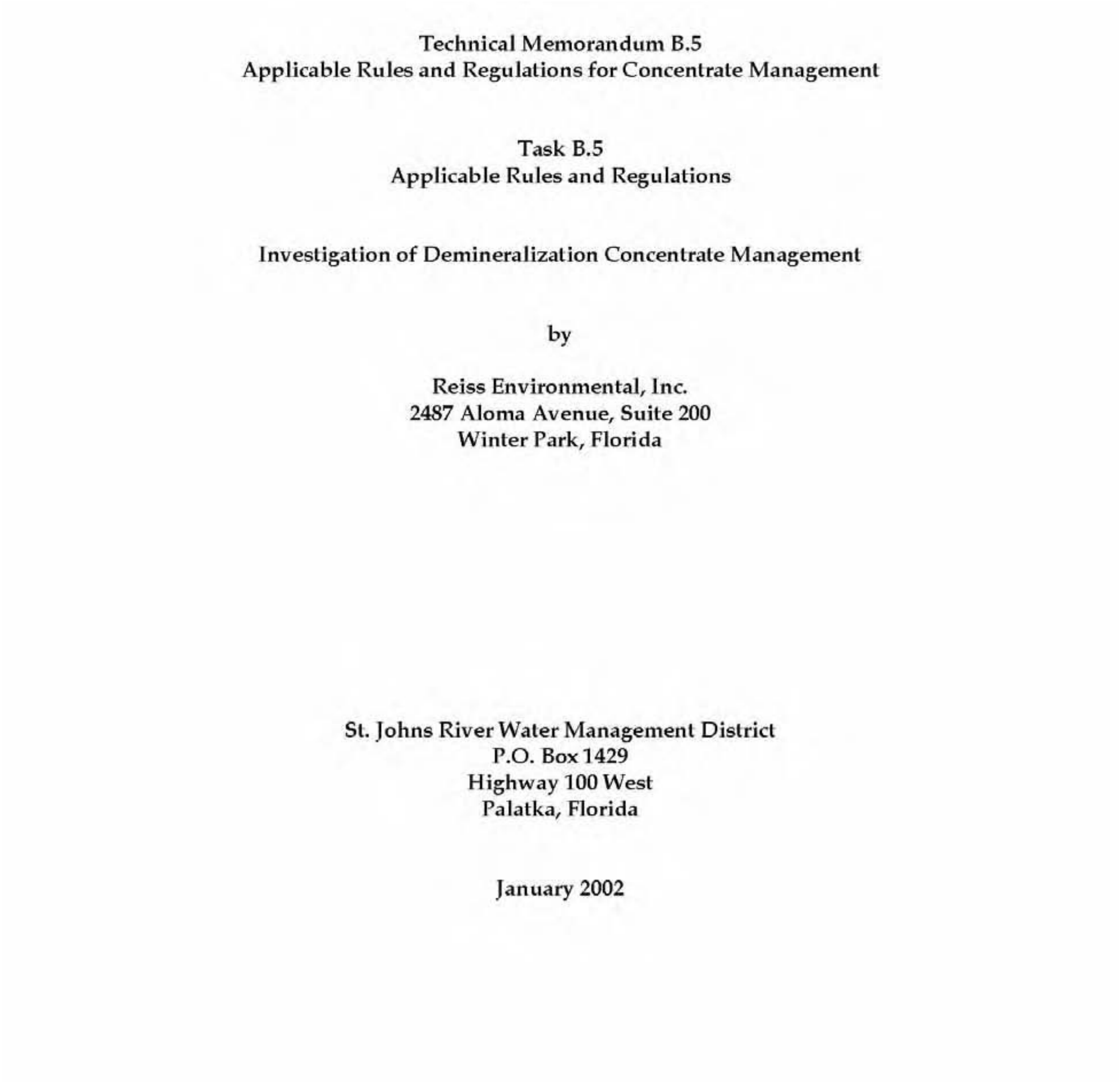
Eckman, T.J. 1998. Letter from T.J. Eckman, DuPont Fabrics & Separations, to M. Michael Pitts, Zeta Corp. September 10.

Kalish, P., W. Graham, and A. van Vugt. 1997. Novel Low Cost Reverse Osmosis System for Seawater and Brackish Water Desalination. Proceedings of the 1997 IDA World Conference. Madrid, Spain.

Romo, R.F.V., and M.M. Pitts. 1999. Application of Electrotechnology for Removal and Prevention of Reverse Osmosis Biofouling. Environmental Progress. 18 (2) 107-112.

APPENDIX G

FLORIDA REGULATORY CONSIDERATIONS – ST. JOHNS RIVER WATER MANAGEMENT DISTRICT, FLORIDA



Technical Memorandum B.5
Applicable Rules and Regulations for Concentrate Management

Task B.5
Applicable Rules and Regulations

Investigation of Demineralization Concentrate Management

by

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Palatka, Florida

January 2002

CONTENTS

TABLES

INTRODUCTION

PROJECT OVERVIEW

The St. Johns River Water Management District's (SJRWMD) water supply plan, titled District Water Supply Plan, outlines water supply options to meet projected water needs through the year 2020. Currently, the Floridan aquifer provides most of the region's existing water needs for public supply. The high quality, economical and reliable characteristics of this groundwater source have made it the water supply of choice. However, the Floridan aquifer cannot provide all future water supply needs in the region without damaging water resources and related natural systems. Therefore, SJRWMD investigated the feasibility of alternative water supply strategies and identified brackish groundwater, brackish surface water, and seawater as potential sources of supply to meet future demands. These alternative water sources will require treatment using demineralization technologies. These technologies are primarily pressure driven membrane processes that include reverse osmosis or nanofiltration. During this process, minerals in the source water, including salt, are removed, producing potable water as well as a byproduct known as demineralization concentrate.

Developing acceptable management strategies for demineralization concentrate is the goal of this project, Investigation of Demineralization Concentrate Management (the Project). A primary component of the Project will be the development of a Demineralization Concentrate Management Plan. The plan will outline environmentally acceptable options for concentrate management. Currently, some available concentrate management options include deep well injection, land spreading, discharge to surface waters, discharge to domestic wastewater treatment facilities, and various forms of reuse (including blending with reclaimed water). This project is part of SJRWMD's water supply plan implementation to meet future water supply needs. Prior to development of the plan or implementation of the concentrate management alternatives mentioned, it is important to have an understanding of applicable rules and regulations governing concentrate management.

PURPOSE AND SCOPE

The purpose of this technical memorandum is to identify and summarize relevant demineralization concentrate management rules and regulations. The contents of this technical memorandum will be used to support the Project and the development of the Demineralization Concentrate

Management Plan. Addressing this topic is very important since demineralization concentrate management and the associated regulations are primary considerations associated with the development of demineralization facilities within SJRWMD.

Applicable rules and regulations have been collected, reviewed and summarized as they relate to demineralization concentrate management. In addition, recommendations have been provided regarding potential actions to support an environmentally sound, logical, and clear regulatory process.

The information presented herein does not represent a legal or binding interpretation of Florida laws and statutes. Legal counsel is the responsibility of the user.

METHODOLOGY

This technical memorandum was prepared by identifying agencies that have a direct or indirect impact on permitting of demineralization concentrate management, followed by the collecting and summarizing of specific rules and regulations. Information was obtained through a literature search and by contacting regulatory agency officials, other experts in the field, and utilities currently using demineralization processes.

REGULATORY AGENCIES

Demineralization concentrate management projects require permits, approvals, or authorizations from a number of governmental agencies. The need for interaction with these agencies may not be self evident when considering a demineralization project and associated concentrate management strategy. In considering the issues related to demineralization concentrate management, there are a number of agencies that would be considered "secondary," as their review is related to ancillary facilities for concentrate disposal, such as pipelines and outfall structures. **Clearly, the Florida Department of Environmental Regulation is the primary agency responsible for the review and issuance of permits for demineralization concentrate management.**

This section identifies agencies that may have review and approval requirements for any portion of a demineralization concentrate management project. Agencies responsible for approval of components of a demineralization facility other than concentrate are also referenced if the agency's authority or the language of its governing regulations is broad enough to allow expansion of the review process into the area of demineralization concentrate management.

Agencies are summarized in Table 1 below, followed by brief descriptions of each organization and its potential role in approval of a demineralization concentrate management project. The order in which these agencies are listed does not represent their relative level of importance, nor does it represent functional hierarchy related to a demineralization concentrate management project.

Table 1. Summary of agencies potentially requiring permits, approvals, or authorization for demineralization concentrate management projects

Responsible Agency
Federal
U.S. Environmental Protection Agency, Region IV
U.S. Army Corps of Engineers
Occupational Safety and Health Administration
U.S. Geological Survey
U.S. Fish and Wildlife Service
National Marine Fisheries Service
State
Florida Department of Environmental Protection (Primary Agency)
Florida Department of Transportation
Florida Fish and Wildlife Conservation Commission
Regional
Water management districts
Local
Health department
Local pollution control
Environmental resource management department or Natural resource management department
City/county building and/or zoning departments
CSX Railroad Corporation

U.S. ENVIRONMENTAL PROTECTION AGENCY

The U.S. Environmental Protection Agency (EPA) mission is to protect human health and to safeguard the natural environment (air, water, and land) upon which life depends. EPA is structured into 10 regions with Region 4 responsible for Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee.

EPA Region 4 office information is as follows:
Atlanta Federal Center
61 Forsyth Street, SW
Atlanta, GA 30303-3104
Telephone: (404) 562-9900 or (800) 241-1754
www.epa.gov

EPA has given full delegation to the Florida Department of Environmental Protection (FDEP) for the regulation of underground injection and surface water discharge permitting of demineralization concentrate and the associated management issues. However, EPA does participate in the review of demineralization concentrate management permits and related topics concerning demineralization concentrate subject matter in cooperation with FDEP. An EPA member sits on the Technical Advisory Committees for proposed underground injection control projects. Although the EPA's permitting authority is delegated to FDEP, their oversight and technical input are important factors in FDEP consideration of permitting for demineralization concentrate disposal.

U.S. ARMY CORPS OF ENGINEERS

The U.S. Army Corps of Engineers (USACE) is made up of civilian and military men and women, which include a diverse workforce of biologists, engineers, geologists, hydrologists, natural resource managers, and other professionals. The USACE mission is to provide quality, responsive engineering services to the nation, including planning, designing, building, and operating water resources and other civil works projects (navigation, flood control, environmental protection, disaster response, etc.); designing and managing the construction of military facilities for the Army and Air Force (military construction); and providing design and construction management support for other defense and federal agencies (interagency and international services).

USACE involvement in a desalination project and concentrate disposal would revolve around construction in navigable waterways of the United

States, for example, construction of ocean outfall; intracoastal waterway pipe crossing that requires dredge and fill permitting procedures; wetland modifications; construction, operation, or abandonment of facilities on land under federal jurisdiction; or actions requiring major federal action.

USACE district office information is as follows:
400 W. Bay Street or P.O. Box 4970
Jacksonville, FL 32202
Telephone: (904) 232-2568 or (800) 291-9405
www.usace.army.mil

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

The Occupational Safety and Health Administration (OSHA) was created under the Occupational Health and Safety Act to monitor health and safety in the work environment and to prevent work-related injuries, illnesses, and death. This agency may play a role in any construction aspects related to a demineralization project, especially concerning any trenching and confined-spaces issues encountered during the construction phase.

OSHA Region 4 office information is as follows:
St 61 Forsyth Street, SW
Atlanta, GA 30303
Telephone: (404) 562-2300
www.osha.gov

U.S. GEOLOGICAL SURVEY

The U.S. Geological Survey (USGS) serves the nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life. USGS would play a role in concentrate discharge related to a demineralization project when the discharge concerns underground injection. USGS is part of a Technical Advisory Committee that is established by FDEP to evaluate the permitting of underground injection control projects.

USGS Florida office information is as follows:
227 N. Bronough St., Suite 3015
Tallahassee, FL 32301
Telephone: (850) 942-9500
www.usgs.gov

U.S. FISH AND WILDLIFE SERVICE

The U.S. Fish and Wildlife Service (FWS) serves the nation by working, with others, to conserve, protect, and enhance fish and wildlife and their habitats for the continuing benefit of the American people. Major responsibilities of FWS involve managing migratory birds, endangered species, certain marine mammals, and freshwater and anadromous fish; conserving wetlands; and restoring nationally significant fisheries. In addition, FWS enforces federal wildlife protection laws, such as the Endangered Species Act (ESA).

The ESA allows the listing of species as either "endangered" or "threatened." A species classified as endangered means it is in danger of extinction throughout all or a significant portion of its range. A threatened classification means a species is likely to become endangered within the foreseeable future. All species of plants and animals (i.e., plants, mammals, birds, fish, reptiles, and clams/mussels), except pest insects, are eligible for listing as endangered or threatened. Therefore, the purpose of the ESA is to conserve "the ecosystem upon which endangered and threatened species depend" and to conserve and recover these listed species.

FWS and the National Marine Fisheries Service share the responsibility for administration of the ESA. The primary responsibility of FWS is for terrestrial and freshwater species, while NMFS responsibilities are mainly for marine species such as salmon and whales. Therefore, FWS could become involved if the proposed demineralization project could potentially impact listed species such as marine mammals (e.g., manatees) or other fish and/or wildlife habitats.

FWS Southeast Regional Office information is as follows:
1875 Century Blvd., Suite 400
Atlanta, GA 30345
Telephone: (404) 679-4000
www.fws.gov

NATIONAL MARINE FISHERIES SERVICE

The mission of the National Marine Fisheries Service (NMFS) is stewardship of the nation's living marine resources. Through conservation and wise use, these resources and their habitat are managed by NMFS to benefit the nation without jeopardizing options for the future. In addition, NMFS shares the responsibility with USFWS for administration of the Endangered Species Act. The agency could become involved in a similar role as USFWS if the proposed demineralization project could potentially impact marine resources such as fish and/or marine habitats.

NMFS Southeast Regional Office information is as follows:
9721 Executive Center Drive North
St. Petersburg, FL 33702
Telephone: (727) 570-5301
www.nmfs.noaa.gov

FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

The Florida Department of Environmental Protection (FDEP) is the state agency whose mission is to "protect, conserve, and manage Florida's environment and natural resources." The FDEP accomplishes this mission through an established regulatory program of permitting, compliance, and enforcement actions for activities that could have a negative impact on public health and the natural environment. FDEP is also responsible for purchase and conservation of environmentally significant lands, management of the state park system, and outreach and environmental education. FDEP also provides water quality data on many surface waters throughout the state and coordinates the monitoring activities associated with ambient sampling with other agencies. FDEP has received federal delegation of the underground injection control (UIC) and surface water discharge (NPDES) permitting programs.

The state of Florida is divided into six regulatory districts: Northwest District, Northeast District, Southwest District, Central District, South District, and Southeast District. Headquarters of the FDEP are located in Tallahassee. The Central District and Northeast District cover the area that is within SJRWMD. FDEP office information for these two districts is as follows:

Northeast District 7825 Baymeadows Way, Suite 200B Jacksonville, FL 32256-7590 (904) 448-4300 / sc 880-4300 x201 Fax (904) 448-4366 / scfax 880-4366 www.dep.state.fl.us	Central District 3319 Maguire Boulevard, Suite 232 Orlando, FL 32803-3767 (407) 894-7555 / sc 325-2290 Fax (407) 897-2966 / scfax 342-2966

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

SJRWMD is one of five water management districts in the state of Florida dedicated to the preservation and management of Florida's precious water resources. Duties of SJRWMD include:

- Issuing permits for various water use activities and/or activities that have the potential to adversely impact ground or surface water resources and adjacent lands
- Buying land to preserve or restore vital wetlands and water resources
- Conducting research about the quality and quantity of ground and surface water resources
- Mapping ground and surface water resources
- Conducting outreach and public education programs

SJRWMD is responsible for issuing many types of permits; however, some of the most common are the consumptive use permit (CUP) and the environmental resource permit (ERP). These source water permits include evaluation of environmental impacts and public water supply, which could include evaluation of impacts from the concentrate management component of a demineralization project. In addition, artificial recharge permitting could become an issue relating to injection wells associated with demineralization projects if the water is not being beneficially used or if the injection could adversely affect existing beneficial uses of water. Artificial recharge is addressed under the District's 40C-5 permitting program.

SJRWMD headquarters office information is as follows:
P.O. Box 1429
Palatka, FL 32178-1429
Telephone: (386) 329-4500
www.sjrwmd.com or sjr.state.fl.us

FLORIDA DEPARTMENT OF TRANSPORTATION

The Florida Department of Transportation's (FDOT) responsibilities impact nearly every facet of transportation — from highways to railways and airports to seaports. FDOT's mission is to provide a safe transportation system that ensures the mobility of people and goods, enhances economic prosperity, and preserves the quality of our environment and communities. Therefore, FDOT involvement with a demineralization project would be associated with transportation of any oversized structures or pipes on state or federal roadways during the construction phase, and/or any construction that takes place in state or federal road right-of-way would require utilization permits. Multiple permits could be required for various activities proposed in FDOT right-of-way.

FDOT office information is as follows:
605 Suwannee Street
Tallahassee, FL 32399-0450
Telephone: (850) 414-4100
www.dot.state.fl.us

FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION

The Florida Fish and Wildlife Conservation Commission's (FWC) responsibility is to manage fish and wildlife resources for their long-term well being and the benefit of people. The agency could become involved if the proposed demineralization project could potentially impact listed species such as manatees or other fish and/or wildlife habitats. In addition, this agency is provided the opportunity to comment on proposed FDEP NPDES permits.

FWC Northeast Region Office information is as follows:
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OTHERS

The remaining agencies that could be involved in concentrate discharge from a demineralization project include local city and county government agencies. Depending on the location and extent of the project, many different departments from the local county and/or city could be involved. Some of these departments include building and zoning, health, local drainage, and environmental resources management or natural resource management. These departments' involvement is associated with permits for construction, changes in zoning, public health and welfare, easement acquisitions, issues concerning rights-of-way as well as to restore, enhance, conserve and manage the air, water, and land resources in the local area. In addition, CSX Railroad Corporation, which is responsible for operating the rail network in the eastern United States, could require permits for any pipelines associated with a demineralization project when these pipelines cross over/under properties and/or tracks related to the rail network.

The degree of involvement and the compliance requirements from the agencies will differ depending on the city and/or county; however, their involvement has to be addressed because depending on the situations or different circumstances such as location, source regime, discharge regime, capacity, etc., could lead to methods requiring additional time, effort, policy decisions, and/or compliance requirements affecting the demineralization project. No contact information is provided since it will be based on location.

SUMMARY

As defined above, a large number of agencies could directly or indirectly affect permitting of demineralization concentrate management. However, the requirements of the EPA and the FDEP are the most pertinent to demineralization concentrate management and represent the critical test of the viability of any demineralization concentrate management project. Given that FDEP has primacy, the role of EPA is secondary and consists of review and comment on FDEP draft NPDES permits and associated information about the project. However, EPA can object to an FDEP-issued permit, which emphasizes the importance of both agencies in demineralization projects. Given that the focus of this technical memorandum is demineralization concentrate regulations, the following rules and regulations section specifically delineates the FDEP regulations that affect demineralization concentrate management.

APPLICABLE RULES AND REGULATIONS

FDEP regulates demineralization concentrate management based on the *Florida Statutes* (*FS*) and the associated *Florida Administrative Code* (*F.A.C.*). In general, the *Florida Statutes* is an edited compilation of general laws of the state and the *Florida Administrative Code* is a compilation of the rules and regulations of state agencies that have been filed with the Department of State pursuant to the provisions of the *Florida Statutes*.

The federal acts that contributed to the development of these regulations were researched and are presented herein. In addition, the sections of the *Florida Administrative Code* that govern demineralization concentrate management have been identified and summarized.

REGULATORY DEVELOPMENT

The regulations that govern demineralization concentrate in the state of Florida have evolved with the increase in numbers of demineralization plants within the state, the availability of more detailed information on concentrate characteristics, and the promulgation of new federal regulations. Florida regulations have incorporated the federal requirements and, in some cases, have developed more stringent requirements consistent with the unique characteristics of Florida's natural environment.

Federal acts that impact demineralization concentrate management include the Clean Water Act (CWA), the Safe Drinking Water Act (SDWA), and the Resource Conservation and Recovery Act (RCRA). The role of each federal act is described below.

The Federal Water Pollution Control Act, enacted in 1972, was amended in 1977 with the Clean Water Act (CWA). This act addresses the discharge of pollutants to surface water of the United States. The CWA established a National Pollutant Discharge Elimination System (NPDES) under which the administrator of EPA may issue permits for discharge of pollutants from a point source into waters of the United States that meet applicable CWA requirements. These requirements include effluent limitations, waste load allocations, monitoring and entry provisions, toxic and pretreatment effluent standards, and guidelines for ocean discharge criteria, among others. The CWA directly affects discharge of demineralization concentrate to surface waters and municipal wastewater treatment plants that subsequently discharge to surface waters, via the

NPDES permitting process. However, there is no known, specific reference to demineralization concentrate in the CWA.

The Safe Drinking Water Act (SDWA), enacted initially in 1974, contains provisions for the protection of groundwater. Subtitle C is designed to prevent endangerment of underground drinking water sources. It contains the Underground Injection Control (UIC) program provisions and the sole source aquifer provision, which are the only provisions of the SDWA specifically addressing groundwater protection. The UIC program directs EPA to establish minimum requirements for state regulation of injection of liquids into wells. This program directly affects deep well injection of concentrate, via the UIC permitting process.

The Resource Conservation and Recovery Act (RCRA), enacted in 1970, provided legislation for solid waste management that includes guidelines and standards for solid waste storage, treatment, and disposal of hazardous and non-hazardous wastes. RCRA requirements would apply to the disposal of solid or crystallized concentrate in landfills. There is no known specific reference to demineralization concentrate in the RCRA.

In summary, the CWA and the SDWA provide the primary basis for federal criteria that apply to the most common demineralization concentrate management methods (underground injection control alternatives and the various surface water discharge options). The RCRA provides criteria related to disposal of materials to landfills and would encompass solidified demineralization concentrate.

Under federal regulations, demineralization concentrate is a category of industrial wastewater. The state of Florida has enacted legislation and is developing regulations specific to demineralization concentrate. State law classifies concentrate as a drinking water treatment byproduct, which is permitted as an industrial wastewater through the Industrial Wastewater Permitting Section of FDEP.

CURRENT REGULATIONS

Current FDEP regulations that affect demineralization concentrate permitting are listed in Table 2 and summarized below. The table includes regulations that directly affect the disposal of concentrate, such as the State Water Quality Criteria in 62-302, as well as regulations that may have secondary or indirect effects on a concentrate disposal option such as ERP review in section 62-330. These sections from Chapter 62, *F.A.C.*, include all known references to demineralization concentrate as well as the sections generally used by FDEP as part of concentrate permitting efforts.

The purpose of this information is to provide a reference point for rapid identification of pertinent sections of the *Florida Administrative Code*. However, permitting of concentrate management alternatives is site-specific and complex. As with most regulations, a step-wise checklist of permit feasibility cannot be gleaned from the regulations due to the numerous factors that are considered in permitting of discharges to the environment. Therefore, more detailed comparison of regulations with project-specific factors is necessary on a case-by-case basis to more accurately determine viable options for concentrate management.

Table 2. State regulations from the *Florida Administrative Code*

Reference	Description	Keyword
62-4	Permits	Surface water discharge, ocean outfall, underground injection control, non-surface water discharge, mixing zones
62-160	Quality Assurance	Sampling, analyses, laboratories, surface water, ground water, wastewater
62-301	Surface Waters of the State	Surface water, ocean outfall
62-302	Surface Water Quality Standards	Toxicity, Outstanding Florida Waters
62-330	Environmental Resource Permitting	Dredge and fill, pipelines
62-343	Environmental Resource Permit Procedures	Dredge and fill, pipelines
62-520	Ground Water Classes, Standards, and Exemptions	Ground water disposal
62-522	Ground Water Permitting and Monitoring Requirements	Ground water disposal
62-528	Underground Injection Control	Underground injection control wells
62-550	Drinking Water Standards, Monitoring, and Reporting	Land application
62-610	Reuse of Reclaimed Water and Land Application	Reuse, land application
62-620	Wastewater Facility and Activities Permitting	Industrial wastewater, permit applications
62-650	Water Quality Based Effluent Limitations	Surface water discharge
62-660	Industrial Wastewater Facilities	Industrial wastewater, effluent limitations

62-4: Permits

Chapter 62-4, *F.A.C.*, outlines procedures for obtaining permits of all types from FDEP. This regulation contains Part 1 – General, Part 2 –Specific Permits; Requirements, and Part 3 – Procedures for General Permits.

Part 1 – Generally identifies procedures and fees associated with permits and includes 62-4.001 through 62-4.160. The majority of this information consists of administrative procedures and fees related to permit issuance, renewal, transfer, and revocation.

Part 2 – Specific Permits; Requirements includes Rule 62-4.200 through Rule 62-4.250 and specifies criteria that are important for determining the viability of a concentrate management project that involves a discharge to surface waters. Sections of particular interest are described below.

Rule 62-4.242, *F.A.C.* – Antidegradation Permitting Requirements; Outstanding Florida Waters; Outstanding National Resource Waters; Equitable Abatement. This regulation includes criteria to balance the value of a project with the associated impacts to surface waters to determine if issuance of the permit is clearly in the public interest. In addition, the regulation requires confirmation that no other viable alternative exists in lieu of the proposed surface water discharge. Specific water quality criteria are not presented but are contained in other, referenced regulations. This regulation is a critical test of the viability of a surface water discharge option for concentrate disposal and can be a primary permitting focus point. Anti-degradation requirements are applicable to new and/or expanding surface discharge projects.

Rule 62-4.244, *F.A.C.* – Mixing Zones: Surface Waters. Requirements for mixing zones, including dilution ratios, water quality requirements, and toxicity requirements are identified. This section is critical to many demineralization concentrate management projects discharging to surface waters, including open ocean waters, in those situations where the demineralization concentrate does not meet water quality criteria established for the classification of the water body.

Rule 62-4.246, *F.A.C.* – Sampling, Testing Methods, and Method Detection Limits for Water Pollution Sources. A portion of this section addresses method detection limits (MDLs) and practical quantification limits (PQLs). It is possible that FDEP would deem the PQL of a parameter(s) to be the necessary and acceptable effluent limit for issuance of a permit. It is important to ensure that laboratories conducting analyses for a permit, in addition to being certified, are able to meet the MDLs and PQLs established through this regulation.

62-160: Quality Assurance

Chapter 62-160, *F.A.C.*, applies to all programs, projects, studies or other activities that involve the measurement, use or submission of environmental data or reports to FDEP. The section address quality assurance plans, laboratory and field procedures, record keeping requirements, sampling and analytical requirements for FDEP programs, which would govern monitoring procedures for demineralization concentrate projects.

62-301: Surface Waters of the State

This chapter defines the landward demarcation of surface waters of the state. This connection point to Surface Waters of the State is where the state's jurisdiction — and thus application of rules and water quality standards — begins. This demarcation is also used for permitting of pipelines and other physical improvements that may be associated with construction of a demineralization concentrate outfall.

62-302: Surface Water Quality Standards

Chapter 62-302, *F.A.C.*, defines many water quality-related factors and requirements important to demineralization concentrate permitting efforts. This information is material to most permitting efforts and includes such data as the state water quality standards for each classification of surface water, thermal surface water criteria, and special protection requirements for Outstanding Florida Waters and Outstanding National Resource Waters.

62-302.400: Classification of Surface Waters, Usage, Reclassification, Classified Waters

This subsection classifies waters of the state according to their designated use or uses, as follows:

Class I	Potable water supplies
Class II	Shellfish propagation or harvesting
Class III	Recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife
Class IV	Agricultural water supplies
Class V	Navigation, utility and industrial use

Water quality classifications are ordered in the degree of protection required, with Class I generally having the most stringent water quality criteria and Class V the least stringent. The classification of any water considered for concentrate disposal is critical in determining the viability of the project. Most surface waters in the state are Class I, II, or III waters. Class IV waters are described in 62-302.400(12) as wholly artificial canals or ditches contained on agricultural lands behind a control structure which is part of a water control system that is connected to the works of a water management district and which is permitted by such water management district. There are currently no Class V waters remaining in the state of Florida.

62-302.530: Table: Surface Water Quality Criteria

This section includes water quality criteria for different classes of water, including a differentiation between fresh and marine waters. For tidally influenced waters, requirements may include dual limits to encompass both fresh and marine conditions. Over 70 water quality parameters are listed and represent a significant body of data required for approval of any surface water discharge of demineralization concentrate. Surface water discharges must meet all of the water quality criteria established for the classification of waters or be granted a mixing zone or other administrative relief by FDEP. Revisions to the water quality criteria are considered by FDEP every three years (triennial review). FDEP is currently working on revision to the water quality criteria, including revisions to the antidegradation permitting requirements and risk-based assessment of numeric criteria that were established based on human health.

62-302.700: Special Protection, Outstanding Florida Waters, Outstanding National Resource Waters

This section lists water bodies designated by the Environmental Regulation Commission (the Commission) as Outstanding Florida Waters (OFWs) or Outstanding National Resource Waters (ONRWs). These waters are designated as worthy of special protection because of their natural attributes. In addition, the ONRWs are designated as such exceptional recreational and ecological significance that water quality should be maintained and protected under all circumstances. Discharge of demineralization concentrate to OFWs and ONRWs is extremely limited in scope and will not be acceptable in most instances. Discharges to OFWs may not degrade the natural background water quality established at the time that they were classified as an OFW.

62-330: Environmental Resource Permitting

This chapter authorizes FDEP to adopt by reference certain environmental resource permit rules of the water management districts to be used in conjunction with certain regulations, thus giving FDEP independent authority to regulate surface water management systems including activities in, on, or over wetlands or other surface waters. The environmental resource permitting process applies to concentrate discharge permitting in relation to construction of pipelines and outfalls within waters of the state.

62-340: Delineation of the Landward Extent of Wetlands and Surface Waters

This chapter defines the landward demarcation of wetlands and surface waters of the state. This connection point to Surface Waters of the State is where the state's jurisdiction – and thus application of rules and water quality standard – begins. In addition, this information is used for permitting of pipelines and other physical improvements that may be associated with construction of a demineralization concentrate outfall.

62-341: Noticed General Environmental Resource Permits

General environmental resource permits are defined in this chapter for a broad range of activities, primarily related to construction, installation, or maintenance of various types of infrastructure. While over 25 permits are included in this chapter, examples that may be pertinent to concentrate management projects include construction or installation of riprap, fences, pipelines, and subaqueous utility crossings.

62-343: Environmental Resource Permit Procedures

This chapter provides the procedural requirements for processing environmental resource permits and for obtaining formal determinations of the landward extent of wetlands and surface waters. This connection point to Surface Waters of the State is where the state's jurisdiction – and thus application of rules and water quality standards – begins. In addition, this information is used for permitting of pipelines and other physical improvements that may be associated with construction of a demineralization concentrate outfall.

62-520: Groundwater Classes, Standards, and Exemptions

Groundwater classes are defined in this chapter as shown in Table 3 below. Groundwater classifications are ordered in the degree of protection required, with Class G-I generally having the most stringent water quality criteria and Class G-IV the least stringent. Among other requirements, discharges into Class G-I and G-II groundwaters must meet the primary and secondary drinking water standards for public water systems. This standard is difficult to meet for virtually any concentrate stream. Typically, underground injection of demineralization concentrate occurs in Class G-IV groundwater aquifers.

Finally, Chapter 62-520, *F.A.C.*, defines exemptions for installations discharging into groundwater and exemptions from secondary drinking water standards in Class G-II groundwater.

The standards and requirements in this section relate to percolation ponds, deep well injection, land spraying, reuse, and any other concentrate management alternative that could result in migration of concentrate into underground sources of drinking water (USDWs).

Table 3. Definition of groundwater classes

Class F-I	Potable water use, groundwater in a single source aquifer described in Rule 62-520.460, *F.A.C.*, which has a total dissolved solids content of less than 3,000 mg/L and was specifically reclassified as Class F-I by the Commission
Class G-I	Potable water use, groundwater in single source aquifers which has a total dissolved solids content of less than 3,000 mg/L
Class G-II	Potable water use, groundwater in aquifers which has a total dissolved solids content of less than 10,000 mg/L, unless otherwise classified by the Commission
Class G-III	Non-potable water use, groundwater in unconfined aquifers which has a total dissolved solids content of 10,000 mg/L or greater; or which has total dissolved solids of 3,000–10,000 mg/L and either has been reclassified by the Commission as having no reasonable potential as a future source of drinking water or has been designated by the Department as an exempted aquifer pursuant to Rule 62-28.130(3), *F.A.C.*
Class G-IV	Non-potable water use, groundwater in confined aquifers which has a total dissolved solids content of 10,000 mg/L or greater

62-522: Groundwater Permitting and Monitoring Requirements

Permitting and monitoring requirements for discharge to groundwater are defined, including general provisions, dimensions of zones of discharge, permit renewal and modification procedures, exemptions, and monitoring requirements. These criteria are applicable to percolation ponds, deep well injection, land spraying, reuse, and any other concentrate management alternative that could result in migration of demineralization concentrate into groundwater.

Per 62-522.300.5, *F.A.C.*, concentrate from potable water demineralization plants is exempt from obtaining a zone of discharge in order to discharge to groundwater, provided the applicant demonstrates that the receiving unconfined aquifer exhibits a natural background total dissolved solids concentration exceeding 1,500 mg/L. Such installations cannot cause violation of primary or secondary drinking water standards at any private or public water supply well outside of the installation's property boundary.

62-528: Underground Injection Control

Chapter 62-528, *F.A.C.*, is the primary regulation governing underground injection of demineralization concentrate. The UIC regulations protect the groundwater sources of drinking water within the state and prevent the degradation of aquifer water quality adjacent to the injection zone that could potentially be used for other purposes. This chapter governs the construction and operation of injection wells in such a manner that the injection fluid remains in the determined injection zone and is not allowed to interchange between aquifers.

The chapter includes eight sections, defined as follows:

Part I (general information)
Part II — Criteria and Standards for Class I and Class III Wells
Part III — Class I Well and Class III Well Permitting
Part IV — Criteria and Standards for Class IV Wells
Part V — Criteria and Standards for Class V Wells
Part VI — Class V Well Permitting
Part VII — Specific Permits; Requirements
Part VIII — General Permits

General descriptions of each class of well are as follows:

Class I wells are technologically sophisticated wells that inject large volumes of hazardous and non-hazardous wastes, including municipal wastewater, into deep, isolated rock formations that are below the lowermost underground source of drinking water.

Class II wells inject fluids associated with oil and natural gas production. Most of the injected fluid is brine that is produced when oil and gas are extracted from the earth.

Class III wells inject super-hot steam, water, or other fluids into mineral formations, which is then pumped to the surface and extracted.

Class IV wells inject hazardous or radioactive wastes into or above underground sources of drinking water. These wells are banned under the UIC program because they directly threaten the quality of underground sources of drinking water.

Class V wells use injection practices that are not included in the other classes. Some Class V wells are technologically advanced wastewater disposal systems used by the desalination industry for disposal of concentrate.

Under current regulations, concentrate from desalination plants may only be injected via a Class I or Class V well. Underground injection regulations are organized almost entirely in this single chapter (62-528, *F.A.C.*) and facilitate a clear understanding of the potential acceptability of subsurface injection of concentrate. Sections of Chapter 62-528 that are pertinent to Class I and Class V wells are described below.

Part I (Sections 62-528.100–360) provides general provisions, permit processing information, public notification requirements, and other general information necessary for all classes of wells.

Parts II and III provide information on Class I and Class III wells. Class I wells require injection into an aquifer with a total dissolved solids (TDS) concentration of greater than 10,000 mg/L, acceptable transmissivity, and a secure confining unit. Concentrate injection wells are most commonly Class I. Tubing and packer are required. In addition, an emergency disposal option is required for up to three days of flow. Specific requirements are contained in Sections 62-528.400–460.

Part V — Criteria and Standards for Class V Wells (Sections 62-528.600-625) and Part VI — Class V Well Permitting (Sections 62-528.630–645) address Class V wells specifically and include general criteria, exploratory well and testing permitting information, well construction standards, operating and monitoring requirements, and other relevant information. Class V wells apply to aquifers with a TDS of less than 10,000 mg/L and therefore may not be applicable for direct concentrate discharge.

Section 62-528.600 defines groups of Class V wells based on usage, to facilitate the determination of permitting, operating, or monitoring requirements for these wells. A total of eight groups are defined in Section 62-528.300(1)(e). Demineralization concentrate falls under Group 4, Type d:

> *Non-hazardous industrial and commercial disposal wells, which include laundry waste wells, dry wells, injection wells associated with aquifer remediation projects, desalination process concentrate wells, and nuclear disposal wells used to inject radioactive wastes, provided the concentrations of the waste do not exceed drinking water standards contained in Chapter 62-550, F.A.C.*

To obtain a permit for a Class V demineralization concentrate well, an exploratory well is required to determine the feasibility of the underground injection at the proposed site. Section 62-528.603 defines exploratory well construction and testing requirements.

Section 62-528.605 defines construction standards for Class V wells. Both exploratory and operational Class V concentrate wells are required to have tubing and packer, among other requirements.

Section 62-528.610 characterizes operational requirements for Class V wells, including the need for pretreatment of fluids as necessary for the fluid to comply with applicable water quality standards. Typical pretreatment of concentrate includes dilution with freshwater and/or mixing with treated reclaimed water.

Sections 62-528.615–625 provide Class V requirements for monitoring, reporting, and plugging and abandonment.

In Part VI, 62-528.630–645, specific permitting requirements are defined. A Class V concentrate well involves a multi-phased approval process. A permit application must be submitted for construction of an exploratory well. Following collection and submission of data from the exploratory well, approval must be granted for construction of the full-scale well. Following collection and submission of data from the full-scale well, approval must be granted for operation of the well. A necessary and critical measure of the viability of a Class V well is the adequacy and preservation of the integrity of the confining beds between aquifers. These criteria are outlined in Part VI.

62-550: Drinking Water Standards, Monitoring, and Reporting

The drinking water standards and associated requirements are defined in this chapter. This information is relevant to concentrate management for those alternatives that require compliance with drinking water standards. Chloride can be one of the most critical parameters, and it is a violation of Secondary Standards when it increases above a maximum contaminant level of 250 mg/L. The regulations in this chapter include restrictions on discharge or migration of concentrate to certain classes of groundwater, such as Classes G-I and G-II. These concerns would apply to land spraying, percolation ponds and potentially other alternatives. Demineralization concentrate generally will not comply with drinking water standards. Therefore, options that require compliance with drinking water standards are not typically viable. However, exceptions for up to three parameters may be granted under the UIC rules. This opens up the opportunity for dilution and mixing of demineralization concentrate with treated domestic effluent and for combined disposal.

62-600: Domestic Wastewater Facilities

The requirements for domestic wastewater facilities are defined in this chapter, including the characteristics of the influent water necessary to meet the domestic wastewater classification (62-600.200(25), *F.A.C.*). The maximum amount of demineralization concentrate that can be discharged to a domestic wastewater facility is dependent upon the resulting changes to influent quality and the ability to meet the classification requirements. In addition, each FDEP office, depending on the type of industrial waste, may require pretreatment of the waste consistent with Chapter 62-625 prior to mixing. Therefore, at this time the demineralization concentrate must be mixed with the raw wastewater and receive complete treatment with the domestic wastewater.

62-610: Reuse of Reclaimed Water and Land Application

This chapter addresses all forms of domestic wastewater reuse, reclaimed water, and land application. It only applies to demineralization concentrate when it is blended with domestic reclaimed water. Sections include the following:

Part I – General
Part II – Slow-Rate Land Application Systems; Restricted Public Access
Part III – Slow-rate Land Application Systems; Public Access Areas, Residential Irrigation, and Edible Crops
Part IV – Rapid-Rate Land Application Systems (Rapid Infiltration Basins and Absorption Fields)
Part V – Ground Water Recharge and Indirect Potable Reuse
Part VI – Overland Flow Systems
Part VII – Industrial Uses of Reclaimed Water
Part VIII – Permitting
Part IX – Forms and Instructions

Parts II and III address slow-rate land application systems such as spray irrigation. Part IV identifies rules and regulations associated with rapid-rate land application systems such as rapid infiltration basins and percolation ponds. These sections provide pertinent information regarding the requirements for such disposal methods. While the FDEP office governing the SJRWMD service area has granted permits for concentrate mixing with reclaimed domestic wastewater and disposal via rapid infiltration basins and percolation ponds, this practice is limited.

Parts V, VI, and VII are generally not applicable to demineralization concentrate management.

Part VIII – Permitting provides detailed information related to issuance of domestic wastewater reuse permits. Of most importance is subsection 62-610.865 – Blending of Demineralization Concentrate with Reclaimed Water. Per this regulation, all land application and reuse projects must be designed to meet the groundwater standards at the edge of a zone of discharge. These standards, for the most part, are the primary and secondary drinking water standards. Given the high concentration of inorganic constituents in concentrate and the relatively limited opportunity for dilution, the reclaimed water blend normally must come close to meeting the groundwater standard as it is applied to the land. This puts practical limits on using large quantities of demineralization concentrate in a blending operation with reclaimed water.

62-620: Wastewater Facility and Activities Permitting

This chapter addresses permitting requirements for any wastewater facility or activity that will reasonably be expected to be a source of pollution. This includes domestic and industrial facilities and is the key chapter associated with demineralization concentrate permitting. Permit applications necessary for a demineralization concentrate project are identified in 62-620.910. This chapter will likely undergo amendment in pending rule-making efforts, described in the Proposed and Pending Regulations section of this document.

62-650: Water Quality Based Effluent Limitations

This chapter contains the procedures for establishing water quality based effluent limitations (WQBELs) and applies to all surface water discharges. The intent of the regulation is to ensure that no wastes are discharged to any waters of the state without first being given the level of treatment necessary to protect the designated uses of the water. Criteria are provided to establish discharge water quality requirements based on one of the following:

- Technology based effluent limit
- Level 1 WQBEL
- Level 2 WQBEL

Criteria for each method of establishing an effluent limit are provided. Technology based effluent limits do not preclude compliance with surface water quality criteria. Level 1 WQBELs are based on the availability of sufficient data to determine that the current quality of the receiving water body meets standards and will continue to do so with the introduction of the concentrate. Level 2 WQBELs involve an assessment of the assimilative capacity of a water body and setting WQBELs by simulating and predicting water quality impacts.

62-660: Industrial Wastewater Facilities

This chapter contains the procedures for permitting an industrial wastewater facility. This includes definitions for industrial wastewater and effluent limitations, both applicable to demineralization concentrate. In addition, there are specific definitions for exemptions that may apply to certain demineralization concentrate projects or situations.

Proposed and Pending Regulations

Pursuant to Senate Bill 536, signed in June 2001, Section 403.0882, *FS*, was amended. The amended statute states that the Legislature finds and declares that it is in the public interest to conserve and protect water resources, provide adequate water supplies and provide for natural systems, and promote brackish water demineralization as an alternative to withdrawals of freshwater, groundwater, and surface water. This is to be accomplished by removing institutional barriers to demineralization and through research to advance water and wastewater byproduct treatment technology, sound waste byproduct disposal methods, and regional solutions to water resource issues.

Key changes to Section 403.0882, *FS*, include:

1. FDEP is to develop rules that will address demineralization concentrate regulatory issues, including:
   a. Permit application forms for demineralization concentrate disposal
   b. Specific options and requirements for demineralization concentrate disposal
   c. Specific requirements and accepted methods for evaluating mixing of effluent in receiving waters
   d. Specific toxicity provisions
2. For surface water discharges, failure of whole effluent toxicity tests predominately due to the presence of constituents to be specifically identified in the regulations as naturally occurring in the source water may not be the basis for denial of a permit, provided that the volume of water necessary to achieve water quality standards is available within a distance less than or equal to two times the natural water depth at the point of discharge under all flow conditions
3. Specific permitting requirements for small water utility businesses (i.e., those discharging <50,000 gallons per day)
4. Specific permitting requirements for discharge of demineralization concentrate to Outstanding Florida Waters

Senate Bill 536 will result in revised regulations that should provide a clearer permitting process for demineralization concentrate management and discharge. Therefore, the information presented herein regarding the permitting process will require revision following development of the new rules.

In addition, and not directly associated with legislation or rulemaking for demineralization concentrate discharge, FDEP is considering changes to the surface water quality standards, antidegradation permitting requirements, identification of impaired waters, and potential reclassification of certain waters. These changes could ultimately impact discharges of all types, including demineralization concentrate.

OVERVIEW OF PERMITTING PROCESS

Developing a viable demineralization water treatment plant in Florida is contingent upon obtaining necessary permits for the demineralization concentrate management component of the project. As described previously, FDEP represents the primary and most important agency associated with concentrate management. Demineralization concentrate is regulated by FDEP through issuance of the appropriate permit for any of the management alternatives proposed. Various components of the *Florida Administrative Code* are integrated into FDEP's evaluation of the permit application.

Given the varying requirements depending upon application, this section defines the primary steps associated with a demineralization concentrate management permitting effort, as determined by the management approach.

The following demineralization concentrate management options are addressed:

1. Underground injection
2. Surface water discharge
3. Ocean outfalls
4. Blending with wastewater effluent
5. Brackish wetlands discharge
6. Other methods

The information presented herein is representative of a typical application and provides an initial guide as to FDEP's permitting requirements and processes that should be expected. However, site-specific conditions render every concentrate permit effort unique. In addition, agencies other than FDEP may become the critical factor in determining the acceptability of a project, such as projects that would impact endangered or threatened species.

The regulations contained within the *Florida Administrative Code* are not specific to concentrate and in many cases require policy decisions on the part of FDEP for interpretation of a permit application and issuance of a permit. Therefore, it is critical to understand the challenges faced by FDEP industrial wastewater permitting personnel and the need to begin pre-application permitting efforts well in advance of any demineralization water treatment plant project.

In addition, the lack of a specific regulation for concentrate permitting creates an uncertain environment for the municipal water treatment community. The amendments to Section 403.0882, *FS*, pursuant to Senate Bill 536, will result in development of concentrate-specific regulations and is intended to provide a consistent approach for FDEP permitting personnel to follow. Therefore, future permitting efforts may differ from those presented below.

UNDERGROUND INJECTION

Obtaining an FDEP permit for underground injection of demineralization concentrate begins with the requirements of Chapter 62-528, *F.A.C.*, and identification of the type of well to be constructed. Class I and Class V wells are the two viable candidates for concentrate projects.

Primary aquifer considerations for a Class I well are:
- Suitable transmissivity
- Aquifer TDS greater than 10,000 mg/L
- Confining zone is present

If the fluid is non-hazardous, as is typical for demineralization concentrate streams, and suitable geology exists, then the demineralization concentrate will not need to meet other water quality standards and the project has reasonably high probability of being permitted. Class I wells are most common.

Aquifer considerations for a Class V well are as follows:
- Suitable transmissivity
- Confining zone is present

If the aquifer TDS is less than 10,000 mg/L or if the fluid can migrate to an underground source of drinking water (USDW), then fluid must meet drinking water standards. If the aquifer TDS is greater than 10,000 mg/L and confined from a USDW or absent of a USDW, then it will not need to meet other groundwater quality standards. Given the elevated levels of TDS and other constituents in many concentrate streams, drinking water standards typically cannot be met.

However, certain projects, such as softening applications or treatment of fresh or slightly brackish water, may be eligible for a Class V well permit. In addition, FDEP has the authority to issue an exemption for parameters that exceed drinking water standards. An exemption will only be granted if exceeding secondary standards and the state primary standard for sodium. An exemption is renewable with the permit and requires a fee that is currently $6,000 per parameter. At least one reverse osmosis WTP operates a Class V concentrate well, with a TDS less than 10,000 mg/L and exemptions for certain secondary standards.

Once the class of well has been selected, FDEP will review information provided by the applicant to determine the steps that will be required for issuance of a UIC permit. If insufficient information is available on the hydrogeologic environment, then FDEP may require an exploratory well, in which case a three-phased permit process would result:

1. Approval for construction of the exploratory well. This well will be used to obtain additional subsurface information and may eventually be used as a monitoring well.
2. Approval for construction of the full-scale well. If the information from the exploratory well is acceptable, the permit for construction of the full-scale well may be issued. Information gained following construction of the full-scale well must be submitted as part of an engineering report and will be used to evaluate issuance of an operating permit.
3. Approval of an operating permit. Only following receipt of acceptable information from both the exploratory well and the full-scale well will an operating permit be issued.

Of great importance is the potential for FDEP to deny further and subsequent approvals at any point in the process described above. A municipality may invest funds in an exploratory well and possibly a full-scale well only to find that FDEP will not issue the operating permit due to concerns over transmissivity, confining layers, or other issues. The large capital expenditure (typically over $2M) and the uncertainty and financial risk associated with deep well injection are such that careful consideration should be given before a decision is made. Collection of detailed hydrogeologic information as well as preliminary meetings with FDEP is recommended.

One specific area of interest to FDEP is the solubility level of the various constituents concentrated by the desalination process. The main concern is with the potential for precipitation when some parameters at near supersaturated levels in the concentrate mix with the same parameters at nearly saturated levels in the native waters of the receiving formation. This potential for the creation of precipitates of various concentrated salts inside the well would endanger the permeability of the receiving aquifer. FDEP often requires bench studies of solubility and precipitate formation in mixed media with similar hydrologic characteristics as the receiving aquifer.

Once an underground injection well has been approved, the mechanical integrity of the well must be demonstrated every five years. A minimum of two monitoring wells will need to be constructed to provide monthly monitoring of the injection well. In addition, an emergency disposal alternative is required and will need to accommodate at least three days of flow. In some cases, the redundancy requirements for the continued operation of potable water treatment facilities can lead to the requirement for two separate injection wells. Any additional permits associated with this alternative disposal method must also be procured. This duplicate permitting effort may also be a critical factor in determining viability of underground injection alternatives.

Finally, the construction of Class I or Class V wells must follow design standards outlined by FDEP, which include tubing and packer construction, testing during drilling and construction, and testing upon completion of well. Due to high construction costs, with drilling and construction costs on the order of \$2-5M per well, underground injection is most applicable for larger water treatment plants.

In summary, a feasibility study is recommended prior to pursuing underground injection. Also, FDEP is required under their primacy agreement with EPA to form a Technical Advisory Committee (TAC). This TAC brings into the permit process the opinions of diverse agencies including EPA, USGS, SJRWMD, the local county health department, and the local county environmental regulatory agency, in addition to the local office of FDEP and the FDEP UIC Tallahassee office.

SURFACE WATER DISCHARGE

Discharge of concentrate to a surface water requires an NPDES permit. The permitting process brings together numerous portions of the *Florida Administrative Code* and can be complex. Surface water discharges are more likely to result in the need for discretionary decisions by FDEP permitting staff when compared to other alternatives such as underground injection.

The first and foremost factor associated with a surface water discharge is the classification of the receiving water. The definition for each class is presented below.

Class I	Potable water supplies
Class II	Shellfish propagation or harvesting
Class III	Recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife
Class IV	Agricultural water supplies
Class V	Navigation, utility, and industrial use

While each situation is unique and the regulations are complex, every surface water permit application is reviewed for compliance in four main areas:

1. Antidegradation policy and WQBEL (antidegradation is only applicable to new or increased discharges)
2. Compliance with surface water criteria and mixing zone limitations
3. Impacts of tidal influence
4. Toxicity of demineralization concentrate
5. Whether the demineralization concentrate contributes to an existing impairment of the surface water/WQBEL

The antidegradation policy is defined in 62-302.300, *F.A.C.*, and requires abatement of water pollution and conservation and protection of Florida's natural resources and scenic beauty. The antidegradation policy was adopted by the Commission in 1989. In addition to requiring compliance with water quality standards that were originally developed and adopted in 1979, the policy requires that any degradation of existing background quality be found to be clearly in the public interest. Revisions to the water quality standards are considered every three years (triennial review) in accordance with the Clean Water Act. The water quality criteria are listed in 62-302.500–530, *F.A.C.*

FDEP's application of the antidegradation policy includes a variety of intentionally subjective criteria that are applied uniquely to each specific permit scenario. There is a "weighing" of various public interest criteria, including economic and social concerns, against the potential for degradation of the state's valuable water resources. An excerpt from 62-302.300, *F.A.C.*, best explains the purpose behind the flexibility:

62-302.300.10.b.1 – The Department's rules that were adopted on March 1, 1979, regarding water quality standards are based upon the best scientific knowledge related to the protection of the various designated uses of waters of the state.

62-302.300.10.b.2 – The mixing zone, zone of discharge, site-specific alternative criteria, exemption, and equitable allocation provisions are designed to provide an opportunity for the future consideration of factors relating to localized situations which could not adequately be addressed in this proceeding, including economic and social consequences, attainability, irretrievable conditions, natural background, and detectability.

62-302.300.10.d – Without the moderating provisions described in b.2 above, the Commission would not have adopted the revisions described in b.1 above nor determined that they are attainable as generally applicable water quality standards.

While some latitude may exist depending upon site-specific conditions, it is important to compare the expected concentrate quality with the water quality standards as soon as possible. Projects that meet all water quality criteria, although rare, greatly simplify the permitting process.

In addition, the anti-degradation policy requires that the Department consider and balance four factors, paraphrased below (see 62-4.242, *F.A.C.*):

1. Whether the proposed project is important to and is beneficial to the public health, safety, or welfare
2. Whether the proposed discharge will adversely affect conservation of fish and wildlife, including endangered or threatened species, or their habitats
3. Whether the proposed discharge will adversely affect the fishing or water-based recreational values or marine productivity in the vicinity of the proposed discharge
4. Whether the proposed discharge is consistent with any applicable Surface Water Improvement and Management Plan that has been adopted by a water management district and approved by the Department

Each permit application is evaluated on an individual basis to ensure that the Department has reasonable assurance that the proposed facility will meet applicable water quality standards. Staff members and the Department must make discretionary decisions, balancing these factors, with each surface water permit application. Since the majority of membrane concentrate discharges are related to public water supply facilities, they are considered to be beneficial to the public health, safety, and welfare in most, but not all, cases. However, the economic analysis requirements may often point to other alternatives for disposal (e.g., underground injection control) that, although more costly, can be implemented and avoid any degradation of surface waters.

Mixing zones may be granted for dilution of concentrate, if no pre-dilution takes place at the treatment facility. The applicant must demonstrate a current and continuing need for the mixing zone. Mixing zones are commonly needed for concentrate projects due to exceedance of water quality criteria such as radionuclides and acute or chronic toxicity. Criteria for mixing zones are complex and are dependent upon the type of receiving water body. Three categories of water bodies are defined and addressed differently:

1. Canals, rivers, streams, and other similar water bodies
2. Lakes, estuaries, bays, lagoons, bayous, sounds, and coastal waters
3. Open ocean waters

Open ocean waters are defined as all surface waters extending seaward from the most seaward natural 90-foot (15-fathom) isobath.

For additional information on mixing zones, 62-4.244, *F.A.C.*, should be referenced. In addition, the passage in June 2001 of Senate Bill 536 allows for approval of mixing zones for toxicity due to ionic imbalance in Outstanding Florida Waters, if certain criteria are met. This expands the classes of surface waters eligible for consideration.

Tidal influences are addressed via identification of the chloride concentrations of the water body and flow patterns. Predominately freshwaters are defined as waters in which the chloride concentration at the surface is less than 1,500 mg/L. Marine waters are those with chloride concentrations greater than 1,500 mg/L. In tidally influenced water bodies, FDEP may require dual limits, addressing both fresh and marine waters. In addition, tidally influenced water bodies pose difficult flow modeling challenges since there is reduced flow during tide reversal and, at least for a short period of time, concentrate is accumulating at the discharge location. Identification of the range of chloride concentrations for the receiving water body should be conducted as soon as possible to determine if tidal influence will be an issue in the permitting process as well as whether the receiving waters will be considered predominantly marine.

Biotoxicity requirements are identified in 62-302, *F.A.C.* — Surface Water Quality Standards for acute and chronic toxicity. For discharge of concentrate to marine waters, FDEP typically requires assessment of the mortality rates for the mysid shrimp and silverside minnow. Certified laboratories are available in Florida and are familiar with FDEP's testing procedure requirements.

In many cases, demineralization concentrate has been found to fail biotoxicity tests due to naturally occurring constituents such as calcium, potassium, and sodium. In many cases, the relative ratio of these constituents is different than that of the proposed receiving water body, even though the concentration of total dissolved solids may be equal. This difference in the ratio of constituents has been found to cause mortality in test organisms that can be corrected by adjustment of the ratio of these ions, such as naturally occurs in free flowing surface water bodies via dilution effects. Due to the source of and solution to this toxicity, Senate Bill 536 has dictated that failure of toxicity tests due to naturally occurring constituents cannot be the cause for rejection of a permit application. Therefore, demineralization concentrate streams that fail biotoxicity tests should be evaluated to determine if naturally occurring constituents are the cause. In 1995, FDEP published a methodology for testing membrane demineralization concentrate to determine whether and to what degree observed toxicity is the result of naturally occurring constituents.

In summary, permitting of concentrate discharge to surface waters involves balancing numerous factors and considerations. The viability of a permit application is highly dependant on site-specific conditions and interpretation of regulations.

OCEAN OUTFALLS

Discharge of demineralization concentrate to the open ocean falls under the NPDES permitting requirements presented herein for surface water discharge. This section should be referenced for basic requirements of ocean discharge. Note that 'open ocean waters' are defined as all surface waters extending seaward from the most seaward natural 90-foot (15-fathom) isobath. In many instances, ocean discharges may not meet this criteria and thus would fall under the criteria for coastal waters, also addressed in the surface water discharge section herein.

As defined in 62-4.244, *F.A.C.*, requirements for ocean discharges are less stringent than that for other surface water bodies. Specific differences are:

1. Compliance with the antidegradation policy is more likely
2. Dissolved oxygen requirements are less stringent

3. Biotoxicity requirements are less stringent: the discharge can be diluted one-third its normal concentration for toxicity testing
4. Water quality standards must be met at the point of 20:1 dilution, not at the point of discharge
5. If water quality standards are met at the point of 20:1 dilution, a mixing zone exemption is not required
6. A larger mixing zone is allowed (four times larger than other surface water discharges)

Regulations require the use of a diffuser system that results in at least a 20:1 dilution before the effluent reaches the surface. In addition, the relative density of demineralization concentrate should be considered (e.g., in ocean waters, brackish demineralization concentrate will be less dense and seawater demineralization concentrate would be more dense) and appropriate diffuser and outfall structures constructed.

While FDEP requirements may be less stringent, additional agencies may become involved in an ocean outfall project. These may include the Coast Guard (navigable waterways), USACE (navigable waterways), FWC (well-being of fish and wildlife resources), and local coastal and ocean protection agencies.

In summary, ocean outfalls are a subcategory of surface water discharge, with similar permitting requirements. However, the reduced water quality requirements and the ability to discharge large quantities of water treatment plant concentrate are such that ocean discharge may be a reasonable alternative for large municipal demineralization water treatment plant projects.

BRACKISH WETLANDS DISCHARGE

Discharge of demineralization concentrate to brackish wetlands is considered a surface water discharge and requires an NPDES permit. FDEP requirements are consistent with those presented for surface water discharges.

BLENDING WITH WASTEWATER

The permitting process associated with blending of demineralization concentrate with wastewater is application-specific. Primary methods for combining demineralization concentrate and wastewater are listed below, followed by a description of the permitting approach.

1. Discharge to sewerage system or at the headworks of a wastewater treatment plant
2. Blending with wastewater effluent for
   a. Discharge to a surface water
   b. Subsurface injection
   c. Reuse

Concentrate may be discharged into the sewerage system or conveyed to the headworks of a domestic wastewater treatment facility. This method is commonly used by small demineralization facilities due to the low capital costs involved. The maximum amount of industrial waste, including demineralization concentrate a domestic wastewater treatment plant may receive, is limited by the domestic wastewater facility capacity to accept the discharge as well as meet the appropriate effluent regulations. Depending on the type of industrial waste, pretreatment may be required prior to mixing. The utility selects the pretreatment in accordance with the approved pretreatment program for the utility.

Additional considerations include confirmation that the introduction of the concentrate will not affect the treatment process and that the wastewater effluent discharge permit requirements will not be impacted. If introduction of concentrate into the sewerage system does not increase the total influent flow of industrial waste above 10%, no separate permitting requirements are expected from FDEP.

Permitting requirements for blending of concentrate with treated wastewater effluent are dependant upon the fate of the combined stream. Typical management methods include surface water discharge, deep well injection, and reuse.

Discharge of blended water to a surface water must comply with NPDES permitting requirements, as described previously herein. In the event the concentrate is introduced to a wastewater effluent with an existing NPDES permit, a new or updated permit application will be required to confirm compliance with surface water discharge requirements.

Underground injection of blended water must comply with UIC permitting requirements. Given the differing requirements for concentrate and wastewater effluent, permit modification or construction of a different Class of well may be required. It is also possible that improvements will likely be required of an existing and permitted Class I well if it is to receive a blend of reclaimed water and desalination concentrate and the ratio of concentrate to reclaimed water exceeds 10%. The improvements required will likely include a need for tubing and packer as well as fluid filled annulus and hydropneumatic fluid level control of the annular fluid.

Reuse of blended concentrate/wastewater effluent is approached cautiously by FDEP due to concerns over violation of water quality standards and impact to the environment. The applicant must submit an engineering report addressing an array of issues. Major points that should be addressed in the engineering report include:

1. Compliance with groundwater quality criteria at the edge of the zone of discharge. For the most part, water quality criteria are the primary and secondary drinking water standards. The high concentration of inorganic ions in demineralization concentrate limits the ability to meet such standards. In addition, rainfall exceeds evapotranspiration by less than 10 inches per year over much of Florida. Therefore, rainfall at the land application sites provides a limited dilution before the edge of the zone of discharge. Detailed water balances will be required in the report and possibly monitoring wells to confirm compliance.
2. Impact of sodium on percolation rates. The sodium adsorption ratio and other factors should be evaluated to determine if an adverse impact to percolation rate would occur. FDEP generally views a sodium adsorption ratio of less than 15 to be acceptable.
3. Vegetation concerns. Vegetative concerns may result from salinity, boron, selenium, beryllium, and other specific constituents. The report must provide reasonable assurances that the blend will not harm vegetation or crops grown on the land application site(s).
4. Operating protocol. Given the interruptible nature of a reuse supply, the report must include an operating protocol for the disinfection process (for the wastewater) and for the blending operation.
5. Monitoring requirements must be addressed and must include multiple locations (individual supplies, blend, and groundwater).

Concentrate/wastewater reuse projects will be required to have a minimum of three days of demineralization concentrate and reclaimed water storage. Storage for extended wet weather conditions must be evaluated as part of any project involving slow rate irrigation. Finally, an annual summary must be prepared and submitted to FDEP for review. Concentrate reuse has been addressed in detail via 62-610.865, *F.A.C.*, and Program Guidance Memo DOM-00-04 – Blending of Concentrate with Reclaimed Water.

OTHER METHODS

While a number of lesser-known demineralization concentrate management methods are available, most fall into one of the categories described previously. These lesser-known methods and the permitting approach are defined as follows:

1. Land Spraying and Percolation Ponds. Demineralization concentrate addressed via land spraying or percolation ponds must meet groundwater standards at edge of zone of discharge. Given the issues of percolation rates and land area required, these methods are typically not used for large-scale facilities.

   Nevertheless, permits can be issued and have similar requirements as those described previously for reuse of blended concentrate and wastewater effluent. Primary concerns that must be addressed by the applicant include impact of sodium on percolation rates, protection of vegetation and crops, operational and monitoring procedures, concentrate storage, and the ability to meet drinking water standards at the edge of the zone of discharge. This latter requirement can be the most difficult to meet.

2. Evaporation Ponds. The use of evaporation ponds for management of concentrate is typically restricted to small-scale water systems in areas with a warm, dry climate, high evaporation rates, level terrain, and low land costs. As a result, most applications are in the western United States. However, a survey of Florida demineralization WTPs indicates at least one concentrate evaporation pond is operating in the state.

   Permitting of an evaporation pond requires an impervious liner and development of monitoring wells. While evaporation ponds are typically designed to accommodate concentrate for the projected life of the demineralization facility, precipitation of salts is expected and must be incorporated into the depth requirements of the pond. These precipitated salts or the liquid brine may ultimately have concentrations of constituents at levels that result in a hazardous waste classification. Therefore, the ultimate fate of the concentrated salts and the future regulatory implications should be considered for any evaporation pond project.

3. Zero Discharge. Zero discharge systems have been designed for concentrate from industrial applications. The most cost-effective method involves increasing the TDS of the stream via use of a

concentrator evaporator, followed by solidification via a crystalizer. The resulting wet cake can readily be transported for disposal in a landfill. Both a concentrator evaporator and a crystalizer are thermal processes and require a source of steam or electrical power for heating. Amortized capital costs (excluding operation and maintenance costs) for a zero discharge system are typically over $12 per 1,000 gallons of potable water produced (Mickley et al.). Therefore, zero discharge applications have been limited to select industrial applications.

Permitting of a zero discharge system would be limited to the RCRA requirements for landfill disposal. Considerations include the ability of the material to pass a toxicity characteristic leaching procedure test and confirmation that the cake does not contain levels of constituents that result in a hazardous waste classification.

4. Coastal Exfiltration Galleries — Surface water discharges include coastal exfiltration galleries, given their direct connection to coastal and ocean waters. Based on input from FDEP, standard NPDES permitting requirements would apply as described herein. However, it is also possible that the FDEP UIC group would become involved to confirm that the design and location of the galleries were such that they did not fall under UIC domain.

5. Bore Holes. A bore hole represents a Class V UIC system under the Safe Drinking Water Act. Requirements for Class V systems were defined in the Deep Well Injection section herein.

In summary, the alternative disposal methods described can all be permitted in Florida, pending compliance with specific criteria. Other factors such as costs may have more bearing on the use of these methods.

SUMMARY AND CONCLUSIONS

The rules and regulations governing the management of demineralization concentrate in Florida are primarily associated with FDEP, with additional requirements from a broad base of local, state, and federal agencies. While FDEP must grant approval for any and all concentrate projects, the involvement of other agencies may be dependant upon project-specific factors such as the selected concentrate management alternative or the location of the project.

The complexity of FDEP's regulations are such that the acceptability of a demineralization concentrate management alternative to FDEP is difficult to determine prior to detailed development of the permit application. In addition, the specifics of individual demineralization water treatment projects render each concentrate permitting effort unique.

The amendments to Section 403.0882, *FS*, pursuant to passage of Senate Bill 536, will result in rule making by FDEP that will, at a minimum, result in permit applications specific to demineralization concentrate and clarification of options and requirements for demineralization concentrate disposal. Therefore, the permitting approach defined in this document will change following this rule making. However, the federal industrial wastewater requirements that form the base of FDEP's regulations have not changed. Therefore, technical criteria may remain as stringent, but the level of effort to determine permit viability and the intentions of FDEP should be reduced. This summary of rules and regulations should be updated following completion of the rule making pursuant to Senate Bill 536.

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APPENDIX H

UTILITY SURVEY RESULTS

BENEFICIAL AND NONTRADITIONAL USES OF CONCENTRATE

(WRF-02-006B)

UTILITY SURVEY REPORT

SEPTEMBER 2005

Prepared for
CH2M HILL

Prepared by
Brandy Kelso
City of Phoenix

Introduction

As the development of potable water resources from seawater and brackish groundwater increases to meet population growth, the use of advanced treatment processes such as reverse osmosis increases. The use of membranes not only creates potable water but also creates a concentrated brine stream. For many seawater desalination plants, the brine stream is discharged back into the source water. However, for inland desalination plants, this is not usually an option. Therefore, the need to develop technologies to deal with brine concentrate is becoming increasingly critical to the use of membrane technologies.

The WateReuse Foundation has begun looking at ways to develop these types of technologies, and one area of particular interest is beneficial uses of concentrate, such as select salt separation. In order to determine what types of existing and future beneficial uses of concentrate are needed in the water industry, a utility survey was developed as part of the research being conducted by CH2M HILL for the WateReuse Foundation project entitled *Beneficial and Nontraditional Uses of Concentrate*. This report summarizes the results of this survey.

Survey Recipients

To meet the objectives of the survey, a list of survey recipients was developed by region. Table H1 shows a list of the utilities contacted for participation in the survey.

Survey Tool

The survey was conducted using a Web-based survey tool called *SurveyMonkey.com*. The benefits of this tool included:

- Quick, easy development of a professional looking online survey
- Ability to monitor and track survey responses online in real time
- Management of survey recipients
- Easy data download

First, the survey was input into the tool, and then organized in a logical flow. Once the survey was input and the format was approved by the research team, the survey was e-mailed to the list of survey recipients. Reminder e-mails and follow-up phone calls were made in an attempt to receive as many survey responses as possible.

Survey Questions

The survey questions were developed by the research team with input from the Project Advisory Committee. The questions are shown in Table H2. Each main heading represents one page of the survey. The first and last pages contained only a welcome/thank you message for the utility being surveyed and did not contain questions. Any questions marked with an asterisk (*) required an answer in order to continue, as shown on the flow diagram represented in Figure H1. Items within brackets show the allowable answers for that question. On multiple choice questions, multiple selections were allowed. At the end of the survey or if the “Exit Survey” was pushed, the survey defaulted to the WateReuse Foundation Web site.

TABLE H1
Survey Recipients

ORGANIZATION	CITY	STATE
Arizona Water Company		AZ
Arizona American Water Company		AZ
City of Avondale	Avondale	AZ
Town of Buckeye	Buckeye	AZ
City of Casa Grande	Casa Grande	AZ
City of Chandler	Chandler	AZ
Town of Gilbert	Gilbert	AZ
City of Glendale	Glendale	AZ
City of Goodyear	Goodyear	AZ
Town of Marana	Marana	AZ
City of Mesa	Mesa	AZ
Oro Valley Water Utility	Oro Valley	AZ
City of Peoria	Peoria	AZ
City of Phoenix	Phoenix	AZ
Queen Creek Water Company	Queen Creek	AZ
City of Scottsdale	Scottsdale	AZ
City of Surprise	Surprise	AZ
City of Tempe	Tempe	AZ
City of Tolleson	Tolleson	AZ
Tucson Water	Tucson	AZ
City of Tucson	Tucson	AZ
Pima County Wastewater	Tucson	AZ
Metro Water District	Tucson	AZ
Delta Diablo Sanitation District	Antioch	CA
West & Central Basin Municipal District	Carson	CA
Inland Empire Utilities Agency	Chino	CA
Coachella Valley Water District	Coachella	CA
Contra Costa Water District	Concord	CA
Marin Municipal Water District	Corte Madera	CA
Orange County Water District	Fountain Valley	CA
Alameda County Water District	Freemont	CA
San Benito County Water District	Hollister	CA
Irvine Ranch Water District	Irvine	CA
Long Beach Water Department	Long Beach	CA
Metropolitan Water District of Southern California	Los Angeles	CA
Los Angeles Dept. of Water and Power	Los Angeles	CA
Sacramento Regional Co. Sanitation Distrist	Mather	CA
Monterey Regional Water Pollution Control Agency	Monterey	CA
East Bay Municipal Utility District	Oakland	CA
Diablo Water District	Oakley	CA
City of Oxnard	Oxnard	CA

TABLE H1
Survey Recipients

ORGANIZATION	CITY	STATE
Santa Ana Watershed Project Authority	Riverside	CA
San Diego County Water Authority	San Diego	CA
San Francisco Public Utilities Commission	San Francisco	CA
Santa Clara Valley Water District	San Jose	CA
Solano County Water Agency	Vacaville	CA
Yucaipa Valley Water District	Yucaipa	CA
Southwest Florida Water Management District	Brooksville	FL
St. Johns River Water Management	Palataka	FL
Tampa Bay Water	Tampa Bay	FL
City of Alamogordo	Alamogordo	NM
City of Las Cruces	Las Cruces	NM
City of Henderson	Henderson	NV
City of North Las Vegas	Las Vegas	NV
Las Vegas Valley Water District	Las Vegas	NV
City of Las Vegas	Las Vegas	NV
Southern Nevada Water Authority	Las Vegas	NV
Clark County Water Reclamation	Las Vegas	NV
Virgin Valley Water District	Mesquite	NV
Brownsville PUB	Brownsville	TX
City of Corpus Christi Water Department	Corpus Christi	TX
El Paso Water Utilities	El Paso	TX
San Antonio Water System	San Antonio	TX
Canadian River Municipal Water Authority	Sanford	TX

TABLE H2
Survey Questions

Welcome!

This survey is being conducted by the City of Phoenix in order to fulfill in-kind work contributions for the WateReuse Foundation project entitled "Beneficial and Non-Traditional Uses of Concentrate (WRF 02-006b)". The project's primary investigator is CH2M Hill. If you have questions or would like additional information about this project, please contact Jim Jordahl with CH2M Hill at 515-270-2700 ext. 26 or jjordahl@CH2M.com OR Brandy Kelso with City of Phoenix at 602-495-7676 or brandy.kelso@phoenix.gov.

If you manage concentrate from several desalination facilities in the same manner, please complete this survey with all facilities lumped together. If concentrate management varies by facility, please complete this survey for each facility.

Thank you for taking a few minutes to answer the following questions related to your concentrate management strategies.

Salt Management

1. Is salt management even without membrane concentrate discharge an issue for your utility (i.e., does more water enter than leave your watershed, leaving salts to accumulate)? *{Yes/No}*
2. If salt management is an emerging issue for your utility, what are your concerns and concepts for managing the issue? *{Open Ended – Essay}*

Current Facilities

*3. Do you manage a facility that produces concentrate? *{Yes/No}*

Existing Facility Information

4. Please provide the location (City, State) of your desalination treatment plant. *{Open Ended – One line}*
5. What is the size of your current desalination facility (mgd)? *{Open Ended – One line}*
6. What technology is used at your facility to produce concentrate? *{RO, ED/EDR, NF, Other – Please Specify}*

*7. Do you plan significant increases in desalination plant capacity in the next 10 years? *{Yes/No}*

Expanded Facilities Size

8. What will be the size of your facility in 2015 (mgd)? *{Open Ended – One line}*

Power Source

9. If the normal power source is electricity at your facility, what is the cost? ($/kWh) *{Open Ended – One line}*
10. If the normal power source is thermal at your facility, what is the cost of energy? *{Open Ended – One line}*
11. Is an alternate source of energy available (e.g. steam, waste heat, etc.)? *{Yes/No}*

Disposal

12. How do you currently dispose of concentrate? *{Surface water discharge – inland, Surface water discharge – ocean, Sewer discharge, Deep well injection, Evaporation pond, Land application, Recycle, Other-please specify}*
13. How do you plan to dispose of concentrate by 2015? *{Surface water discharge – inland, Surface water discharge – ocean, Sewer discharge, Deep well injection, Beach well injection, Evaporation pond, Land application, Recycle, Other-please specify}*
14. What are the cost/benefit issues associated with membrane disposal and reuse for your facility? *{Open Ended – Essay}*

TABLE H2
Survey Questions

Beneficial Uses

15. If you currently use “other” disposal options (beneficial uses) for concentrate, what are they? *{Not Applicable, Oil well field injection, Cooling towers, Stormwater blending, Aquaculture, Coal slurry transport, Salt marsh (wetland) restoration, Solar ponds, Separated salts recovery, Other- please specify}*
16. If you are considering “other” disposal options (beneficial uses) for concentrate, what are they? *{Not Applicable, Oil well field injection, Cooling towers, Stormwater blending, Aquaculture, Coal slurry transport, Salt marsh (wetland) restoration, Solar ponds, Separated salts recovery, Other- please specify}*
17. If you currently have a beneficial use (i.e., something other than surface water, sewer, or deep well injection), what are the advantages and constraints? *{Open Ended – Essay}*
18. If you would like to develop a beneficial use, what would be required for it to be implemented? *{Open Ended – Essay}*

Facility Planning

*19. Are you planning to construct a new membrane based facility in the next 10 years? *{Yes/No}*

New Facilities

20. What technology will be used for your new facility? *{RO, ED/EDR, NF, Don’t Know, Other – Please specify}*
21. How do you plan to dispose of concentrate? *{Surface water discharge – inland, Surface water discharge – ocean, Sewer discharge, Deep well injection, Beach well injection, Oil well field injection, Evaporation pond, Solar pond, Land application, Recycle, Cooling towers, Salt marsh (wetland) restoration, Stormwater blending, Aquaculture, Coal slurry transport, Separated salts recovery, Don't Know, Other – Please specify }*
22. If you would like to develop a beneficial use, what would be required for it to be implemented? *{Open Ended – Essay}*

Area Water Costs

23. What is the total cost of water to the residential consumer in your area? ($/1000 gal) (Note: assume nuances of base charges, impact fees, special charges, seasonal charges, etc. are included in the cost). *{Open Ended – One line}*
24. What is the total cost of water to the industrial consumer in your area? ($/1000 gal) (Note: assumes nuances of base charges, impact fees, special charges, seasonal charges, etc. are included in the cost) *{Open Ended – One line}*
25. What is the cost of raw water in your area? ($/1000 gal) *{Open Ended – One line}*

Regulatory Issues

26. What are the existing or emerging regulatory issues for membrane concentrate disposal in your region? *{Open Ended – Essay}*

Thank You!

Thank you for taking time to complete this survey! For more information, please contact Jim Jordahl with CH2M Hill at 515-270-2700 ext. 26 or jjordahl@CH2M.com OR Brandy Kelso with City of Phoenix at 602-495-7676 or brandy.kelso@phoenix.gov

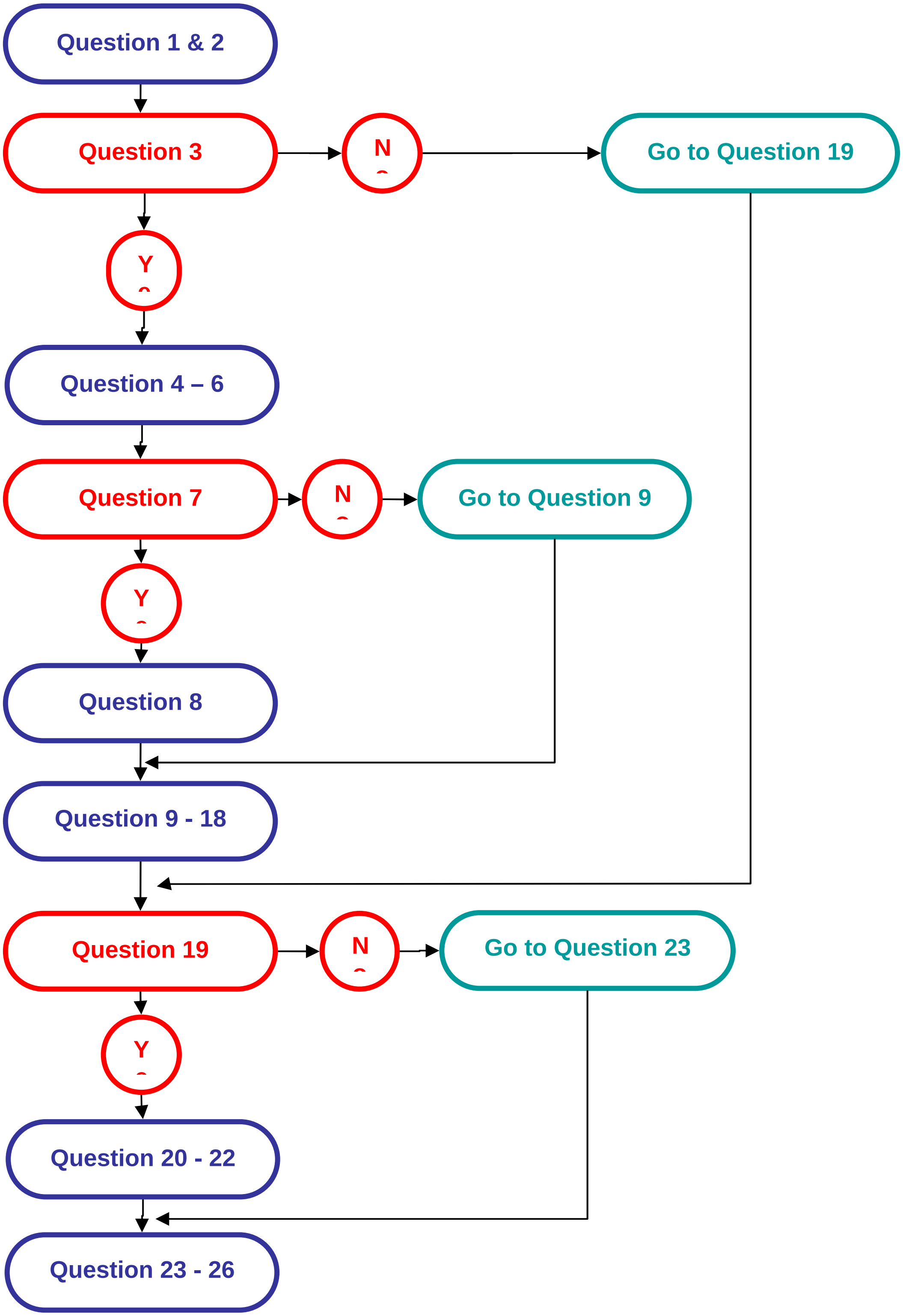

FIGURE H1
Survey Flowchart

Survey Results

Seventy-three utilities were contacted to participate in the survey. Of the utilities contacted, 27 responded to the survey (37 percent), 12 declined to take the survey (16 percent), and 34 did not respond (47 percent). Many of the utilities that declined to take the survey did not have existing or planned treatment processes that would generate concentrate.

The survey basically contained two parts: existing facilities and planned facilities. Of the utilities that responded, nine currently have existing facilities. The majority of these existing facilities produce concentrate from reverse osmosis membranes; however, one utility used ED/EDR. Facility sizes ranged from 0.75 to 28 million gallons per day. Current concentrate management strategies included surface (11 percent), ocean (22 percent), or sewer discharge (67 percent). For the facilities expecting to expand by 2015, the concentrate management strategies were still expected to be primarily ocean or sewer discharge; however, several utilities are reviewing alternative concentrate management methods, such as evaporation ponds or land application. The use of other concentrate management technologies would need to be cost effective in order for these utilities to consider beneficial use options.

Nineteen of the utilities are planning to have treatment facilities within the next 10 years that will produce a brine concentrate stream. A majority of these facilities will be reverse osmosis membranes. Concentrate management strategies are still being investigated for many of these facilities. A tally of the technologies being considered is summarized in Table H3.

TABLE H3
Concentrate Management Technologies for Future Facilities

Technology	Number of facilities considering
Surface water discharge – inland	2
Surface water discharge – ocean	4
Sewer discharge	7
Deep well injection	1
Beach well injection	0
Oil well field injection	0
Evaporation pond	6
Solar pond	0
Land application	3
Recycle	3
Cooling towers	0
Salt marsh (wetland) restoration	1
Stormwater blending	0
Aquaculture	1
Coal slurry transport	0
Separated salts recovery	2
Don't Know	5
Other – Please specify	1 – Halophyte irrigation 2 – ZLD processes

Advancing the Science of Water Reuse and Desalination

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