Evaluating Traditional and Innovative Concentrate Treatment and Disposal Methods for Water Recycling at Big Bear Valley, California

James C. Lozier, P.E., CH2M HILL, Tempe, Arizona
Ufuk G. Erdal, Ph.D. CH2M HILL, Santa Ana California
Anne F. Lynch, P.E. CH2M HILL, Santa Ana California
Steven Schindler P.E., BBARWA, Big Bear, CA

Abstract

The Big Bear Area Regional Wastewater Agency (BBARWA) recently completed a study of advanced water reclamation as a means to augment existing potable water supplies for the residents and visitors of Big Bear Valley. Potable water is provided by local groundwater (GW); during periods of drought or prolonged dry weather water demand can exceed supply. The use of recycled water, treated to a high quality via an advanced treatment process and artificially recharged, has been identified as the best means of supplementing the native GW supply. The advanced treatment proposed at the BBARWA Facility consists of microfiltration (MF), reverse osmosis (RO), followed by ultraviolet disinfection (UV) with advanced oxidation. While backwash waste produced from MF/UF facility can be recycled back to the headworks of the BBARWA wastewater treatment facility, the concentrate (reject) flow from the RO needs to be properly disposed. In this paper, seven different treatment methods were evaluated to dispose of concentrate from a future 1.2-mgd recycled water facility: constructed wetlands, electrodialysis reversal (EDR), enhanced RO treatment, mechanical and solar evaporation, Vibratory Shear Enhanced Process (VSEP) and wastewater effluent blending. All treatments were evaluated on a paper study basis, except VSEP, which was tested on-site using concentrate from the MF/RO pilot system. The study included siting solar evaporation and constructed wetlands facilities in Lucerne Valley 25 miles from BBV, where BBARWA currently land applies their wastewater effluent. LV was selected in this evaluation, because it minimizes public perception issues (i.e., mosquito, vector issues), reduces evaporation and wetland sizes due to higher evaporation/evapotranspiration rates in this lower altitude region and leaves space in WWTP for future plant expansion. Study results showed the most cost effective approach is to combine RO concentrate volume reduction using VSEP or EDR with evaporation ponds or constructed wetlands in the LV. VSEP is preferred over EDR due to the ability to produce a high quality permeate that can be blended with BBARWA effluent and some fraction of RO concentrate while still meeting land application guidelines. Constructed wetlands offer the potential to better management wildlife issues associated with elevated concentrations of selenium but have not been demonstrated to be sustainable using a zero liquid discharge approach.

Introduction

BBV lies approximately 100 miles east of Los Angeles and contains two major ski resorts serving southern California. Potable water is provided by local groundwater during periods of drought or prolonged dry weather demand can exceed supply. With no imported water available, the area is in need of other sources that will augment and provide a drought-proof, reliable, and locally controlled water supply. Recycled water from the BBARWA Wastewater Treatment Plant (WWTP) which treats average daily flow of 2.2 mgd, has been identified as the best means of supplementing the native GW supply. Implementation of a groundwater recharge project would require the most advanced treatment available to ensure that no detrimental impacts occurred to the precious groundwater supply in the Valley. The advanced treatment proposed at the BBARWA Facility consists of MF/UF, RO and UV advanced oxidation using hydrogen peroxide. A 1.17-million-gallon-per-day (mgd) BBARWA ATF will produce approximately 160,000 gallons per day (gpd) of concentrate (reject) stream. The concentrate stream will require a proper means of disposal given it' elevated salinity and organic content and potential presence of emerging contaminants of concern. This paper identifies options for RO concentrate management generated from the proposed BBARWA ATF. BBARWA has the option to construct concentrate disposal facilities (i.e., evaporation ponds or wetlands) in either the Big Bear Valley (within the existing BBARWA facility site) or in the Lucerne Valley on land that BBARWA owns.   A number of methods are available for disposal or reduction of concentrate. The following technologies were identified as feasible for application to concentrate disposal:

- Solar evaporation
- Constructed wetlands
- Electrodialysis reversal (EDR)
- Non-traditional reverse osmosis (RO), including
  - Vibratory shear enhanced processing (VSEP) membrane treatment
  - Enhanced membrane system (EMS)
- Blending with wastewater effluent
- Mechanical evaporation and crystallizer

Discharge to surface water method was deemed infeasible because of the lack of perennial stream flow with sufficient capacity to assimilate the contaminants present in the concentrate. Deep well injection was also deemed not feasible in the Valley because of the geology of the area (i.e., the Valley is underlain with bedrock). Similarly, land application/irrigation was deemed not feasible due to the discharge limitations in Lucerne Valley. Discharge limitations set by the Colorado River Basin RWQCB preclude direct application of RO concentrate onto the alfalfa fields in the Lucerne Valley. Irrigation of RO concentrate requires considerable treatment and blending with low chloride, TDS water, and a source of low chloride/TDS water is not available.

The objective of this study is to identify technologies that could be used to develop multiple concentrate management alternatives that BBARWA could implement as part of advanced water reclamation and reuse, discuss specific implementation issues associated with each alternative, and develop associated capital and operation and maintenance (O&M) cost estimates to define life-cycle costs (LCC) for each alternative. This information was then used to develop and implement a decision analysis for concentrate management process selection.

Methods and Approach

RO Concentrate Water Quality

A comprehensive pilot testing and sampling and analytical program was conducted at BBARWA in December 2005 to characterize water quality in the RO feed, permeate and concentrate streams. A two-stage RO pilot facility was operated at an average flux of 11 gfd and recovery of 74 percent. Because the proposed ATF would be operated at 85 percent recovery, representative concentrate quality for 85 percent recovery operation were calculated using concentrate quality data from the pilot testing and the observed rejection of both TDS and individual ions. . The adjustment was accomplished by performing mass balance around the RO process assuming rejection rates for constituents were equivalent at 74 and 85 percent recovery assuming an equal flux.

Mass Balances

The selection of a concentrate management method depends on the projected quality and quantity of the concentrate from the proposed BBARWA ATF, site availability, cost, and regulatory issues. To meet regulatory requirements and minimize lifecycle costs, pretreatment scenarios were also considered in this analysis. For example, under some conditions, implementation of volume-reduction technologies prior to discharge to evaporation ponds can significantly reduce the size of the pond footprint. Detailed mass balances were performed to estimate flows and water quality for each design scenario. An example mass balance is shown in Figure 1 below.

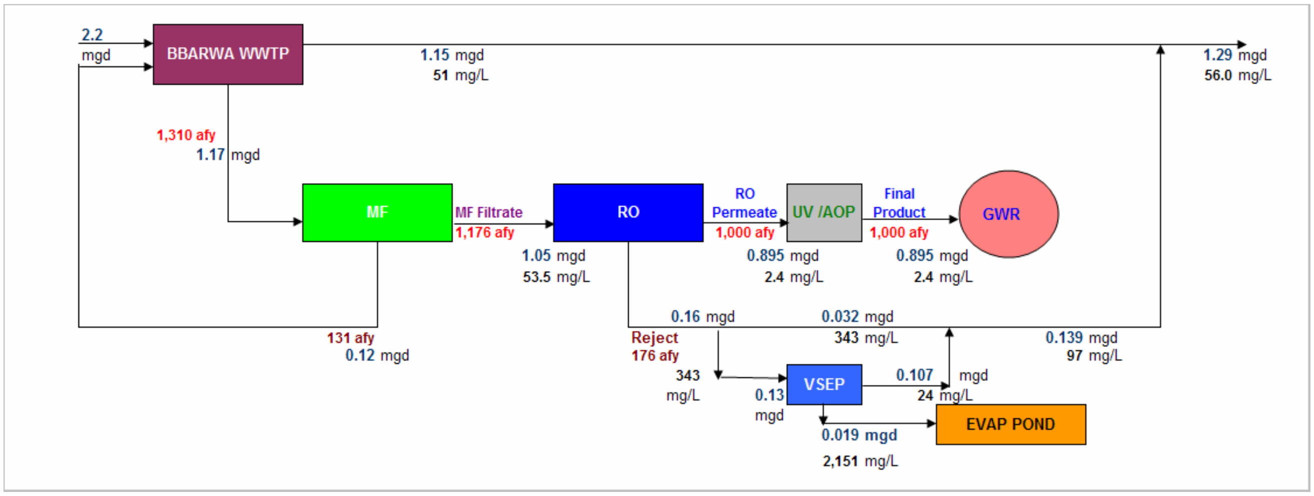

FIGURE 1
Flow Schematic and Chloride Mass Balance for VSEP-Evaporation Pond Concentrate Management Alternative

Cost Estimates

The level of detail in each of the cost estimates varied based on the amount of information available. . The preliminary cost estimates were generated using information obtained from technology vendors and from the CH2M HILL Parametric Estimating System (CPES). Planning-level (-30/+50 accuracy) cost estimates are provided herein. Conceptual design scenarios were then evaluated based on a life-cycle-cost (LCC) basis to provide impacts of both capital and O&M costs. The LCC are based on a 20-year life cycle period, with a 5.375 percent discount rate (i) and a 3 percent of inflation rate (E). The life cycle cost relationship is shown in Equation (1) below.

$$P = A\left\{\left(\frac{1+E}{i-E}\right)*\left[1-\left[\frac{1+E}{1+i}\right]^{N}\right]\right\}+\text{Capital Cost} \qquad (1)$$

Where:

P: Present worth
A: Annual O&M costs
I: Discount rate (5.375%)
E: Inflation rate (3%)
N: Period (20 years)

Evaluation of the Technologies

Concentrate management alternatives applicable at the BBARWA facility can be categorized into three broad groups:

Wastewater Effluent Mixing

Volume Reduction Processes

Zero Liquid Discharge Technologies

(1) Wastewater Effluent Mixing

Wastewater effluent mixing involves blending RO concentrate with treated wastewater effluent from a wastewater treatment plant to take advantage of the blending capacity of a lower-TDS stream to mitigate the impact of the high TDS (or other solute) concentrate. The combined stream can then be discharged in accordance with existing permits or be applied to land.

Currently, the treated wastewater from the BBARWA WWTP is discharged to alfalfa fields located in the Lucerne Valley via a 16-/18-inch cement-mortar-lined steel pipeline. Due to strict chloride and TDS requirements in the BBARWA NPDES permit for this discharge, water quality rather than hydraulic capacity of the discharge pipeline will dictate the maximum allowable volume of RO concentrate that can be blended. Based on these limits, and the concentrations of chloride and TDS in the effluent, only 32,000 gallon per day (gpd) of RO reject could be blended with secondary wastewater effluent from the BBARWA WWTP while still satisfying the NPDES discharge permit. The mass balance and discharge requirements for wastewater effluent mixing design scenario are presented in Table 2.

TABLE 2
Mass Balance and Discharge Requirements for Wastewater Effluent Mixing

Parameter	WWTP Discharge	RO Concentrate	Blended Stream of RO Concentrate and Treated Secondary Effluent	Discharge Limit at Discharge Point No. 001
Flow, gpd	1,150,000[a]	32,000	1,182,000	4,500,000
BOD5, mg/L	6.0	17	5.5	30.0
Boron, µg/L	240	835	250	750
Chloride, mg/L	51.0	343	48.2	60.0
Fluoride, mg/L	0.25	1.2	0.24	1.6[b]
TDS, mg/L	450	2,830	424	650[c]
TSS, mg/L	6.0	6.4	5.4	30.0
Sulfate, mg/L	40.0	261	36.0	60.0

[a]Based on an average secondary treated effluent flow of 2.2 mgd
[b]Annual average concentration
[c]Source water TDS + 400 mg/L. The typical source water TDS is between 250 and 275 mg/L

Since 32,000 gpd is only the small fraction of the RO concentrate generated (160,000 gpd) from the ATF, the remaining concentrate flow will need to be managed using other technologies as discussed later in this paper.

Due to the simplicity (i.e., no new equipment or pipelines) of this method of membrane concentrate disposal, implementation issues are minimal. As long as the blended flow complies with existing permit requirements, a modified permit is not required.

The life cycle cost to implement effluent-concentrate blending is very low. Only a 20,000-gallon high-density polyethylene (HDPE) storage tank, a 25-gpm pump, and a few other miscellaneous items (1.5-inch pipe, pipe connector, and valves) are required. The expected capital cost is approximately $40,000. The expected O&M cost should be less than $3,000 per year.

(2) Volume Reduction Processes

Three concentrate volume reduction processes were evaluated as part of this study: Electrodialysis Reversal (EDR), Vibratory Shear-Enhanced Processing (VSEP), and Enhanced Membrane System (EMS).

Electrodialysis Reversal (EDR)

Electrodialysis (ED) is a process that uses an electrical current to remove salt ions from a solution and is based on the property that salts in solution are dissociated into positively and negatively charged ions. The ions are separated from solution by passing a direct current between a cathode and anode while passing water containing the ions across alternating pairs of cation-transfer and anion-transfer membranes (see Figure 1). The result is the production of a demineralized product stream (from which ions have migrated) and a concentrate stream (to which ions have migrated). EDR is a variant of ED in which the cathode and anode positions s are alternated several times per hour. (polarity reversal) Polarity reversal assists in control of membrane fouling, allows operation at higher feedwater recovery with less scale control chemicals. It should be noted that, unlike other membrane processes used in drinking water and reuse, water does not flow through the EDR membranes, only ions. Consequently, particulates and poorly-ionized solutes are not removed and no pathogen removal credits are given to ED/EDR under the Surface Water Treatment Rule.

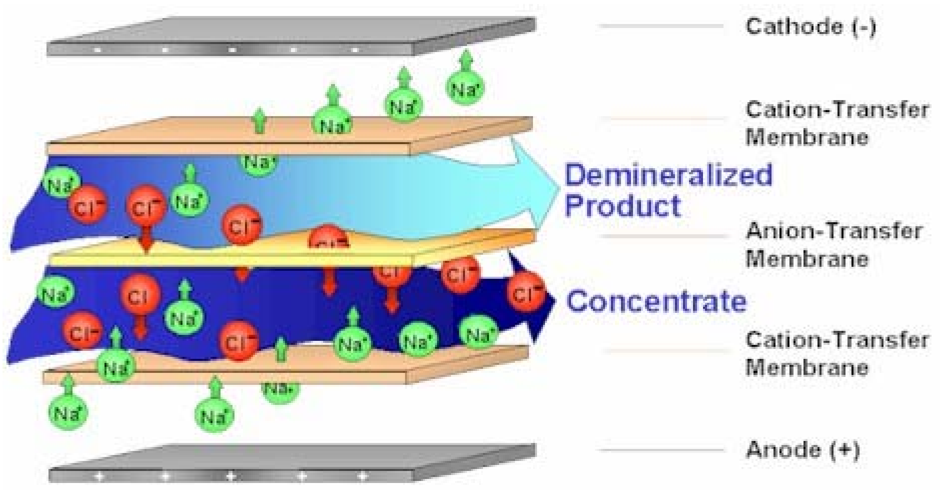

FIGURE 2
ED/EDR Process (Courtesy of GE Ionics)

Due to proprietary nature of the EDR system, the supplier of this equipment (GE Ionics) was contacted for guidance regarding the specific sizing and materials of construction for RO concentrate treatment. Given the long history of operation of EDR on brackish waters, and the limited budget, no pilot testing of EDR was conducted as part of this study. , GE Ionics, using their proprietary performance software (WATSYS), developed an EDR system design suitable for this application). The design estimated that the maximum recovery achievable with EDR was 79 percent based on a maximum level of supersaturation of calcium phosphate. At this recovery, the RO concentrate flow could be reduced from 160,000 to 34,000 gpd.

EDR product water does not satisfy Title 22 Recycled Water Criteria for turbidity or pathogens. Also, CDHS does not recognize EDR as a “surface water” treatment technology because EDR does not provide a barrier against pathogens. GE Ionics projections indicate that the EDR product water will contain high concentrations of chloride, which prohibits blending of the EDR product water with secondary treated effluent unless considerable (additional) chloride reduction is provided by other means.

The most feasible and economical method to dispose of EDR product is to reduce the chloride concentration to an acceptable level (i.e., less than 50 mg/L) and blend this water with secondary effluent. The potential technologies for chloride removal are the selective ion exchange process and RO. Table 4.1 also shows the quality of the blended water using an ion exchange process that can achieve the discharge limit requirements at Discharge Point No. 001. High silica content in the EDR product water will limit the recovery rate of RO and generate a considerable amount of reject. Therefore, RO was not considered as a feasible option for chloride treatment in EDR product water.

Capital cost estimates for the EDR were provided by GE Ionics and include a pre-assembled skid with direct current (DC) power supply, control cabinet, feed and brine recirculation pumps, sample panels, disposable cartridge filter housing, control valves, and a forced-draft decarbonator. A 40% of the total equipment cost was assumed for installation. According to 2006 prices, the capital and O&M costs for EDR system are $2,283,000 and $288,000 per year, respectively.

Vibratory Shear Enhanced Process (VSEP)

Conventional RO systems are subject to scaling by sparingly soluble salts and high concentrations of dissolved organic and colloidal matter. In the case of the BBARWA effluent, these limitations constrain conventional RO recovery to approximately 85 percent. VSEP, a patented process of New Logic, was developed to reduce polarization of suspended colloids and sparingly soluble salts on the membrane surface by introducing shear to the membrane surface through vibration. Shear waves produced on the membrane surface keep the colloidal material in suspension, thereby minimizing fouling and prevent precipitating salts from accumulating on the membrane surface as scales. As a result, high throughput and water recoveries above that of a conventional membrane system can be achieved.

VSEP employs torsional oscillation at a rate of 50 times per second (50 hertz) at the membrane surface to inhibit diffusion polarization of suspended colloids. The suspended colloids are helped in suspension where a tangential cross flow washes them away. Figure 3 compares cake formation on the membrane surface for conventional and VSEP membrane systems.

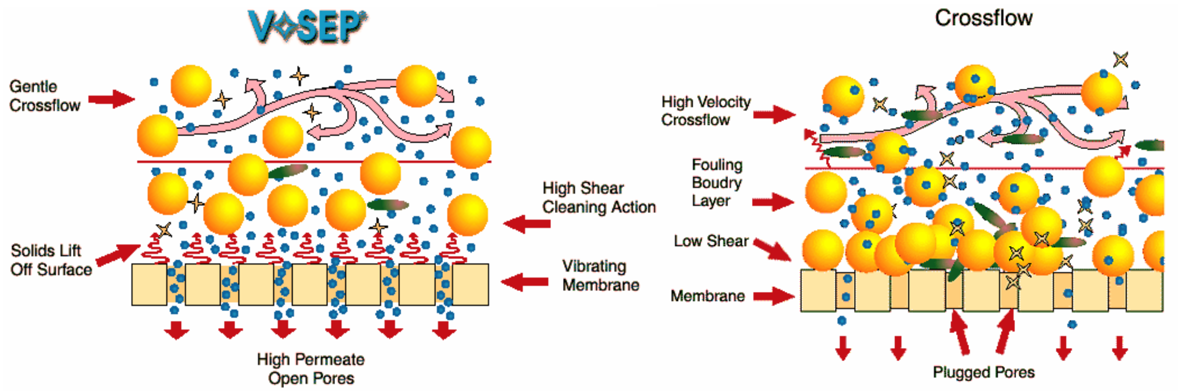

FIGURE 3
Cake Development in VSEP and Conventional RO Systems

The VSEP consists of four components: driving system than generates vibration, a membrane module, a torsion spring that transfers vibration to the membrane module and a system for controlling vibration. The vibration imparts a shear to the surface of the membrane to mitigate fouling and scaling that would occur in a conventional RO system. The membrane module houses a stack of flat membrane sheets (filter pack) in a plate-and-frame type configuration.

Unlike conventional RO systems, VSEP is not limited by the solubility of minerals or the presence of suspended solids. It can be used in the same applications as crystallizers or brine concentrators and is capable of high recoveries (up to 90 percent). The VSEP system can be configured employing either RO or NF membranes in a single-stage or multiple-stage arrangement. The configuration depends upon quality of the wastewater to be treated, water quality goals for the VSEP permeate, and target water recovery.

Pilot Testing of the VSEP

Because VSEP has been used primarily for the treatment of low-flow, high solids industrial wastewaters, a 4-week VSEP pilot test was conducted to develop specific design, operational and cost data for use in the concentrate management evaluation. In the study, concentrate from the pilot RO unit served as the feed to the VSEP. . Testing was undertaken to assess the feasibility of VSEP and to determine key design parameters for design of a full-scale facility. New Logic Research, patent holder of the VSEP, installed and operated a single stage VSEP pilot unit with the assistance of CH2M HILL and BBARWA operation and maintenance team.

Figure 4 illustrates feed and bleed operation mode where new RO concentrate is continuously added to the feed tank while the two discharge streams of the filtration unit (permeate and concentrate) are allowed to leave the system to the drain. (A description of VSEP technology is provided in a later section of the paper.)

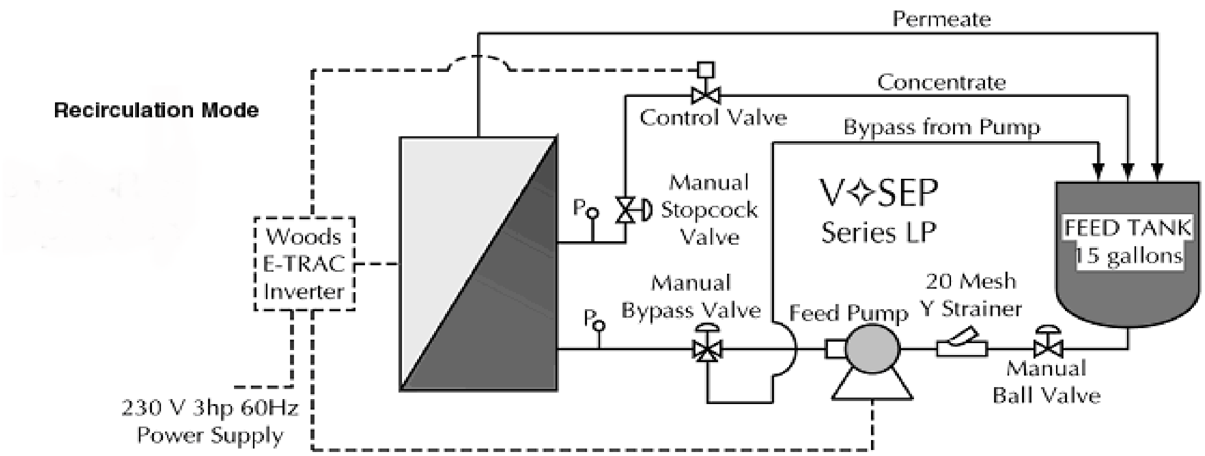

FIGURE 4
VSEP Flow Schematic

During the BBARWA testing, one RO (38 LFC 1) and one NF (NE 90) membrane were operated, each for two-week periods. Table 3 presents characteristics of each membrane used in this study.

TABLE 3
Characteristics of the Membranes Used in the VSEP Testing

	38 LFC 1	**NE 90**
Membrane category	Reverse osmosis	Nanofiltration
NaCl Rejection, %	99.5	90
Composition	Thin-film composite	TFC Polyamide
pH Tolerance	2.5-11.5	3-10
Maximum Temperature, ^oC	60	70
Chlorine Tolerance, ppm	<0.1	<0.1

The VSEP unit was operated at a recovery range of between 75 and 92 percent. Flow, pressure, temperature, pH were continuously monitored. Samples were collected from feed (ATF Pilot RO Concentrate), permeate and concentrate streams. Since concentrate management alternatives included blending VSEP permeate with secondary effluent, water quality parameters analyzed as part of the VSEP pilot included all NPDES discharge parameters (BOD, boron, chloride, fluoride, TDS, TSS, sulfate) plus TN and TOC.

Pilot Testing of VSEP at BBARWA

The pilot test results showed that both the RO and NF membranes can reduce the conventional RO system concentrate volume by up to 85 percent, if a two stage VSEP unit is implemented. VSEP recoveries exceeding 85 percent resulted in less than optimal operation of the unit (e.g., decreased flux and high feed pressure) with increased lifecycle costs. Acid and caustic cleanings of the membrane module which are required to maintain flux, were performed using NLR 404 and NLR 5005, respectively. Cleaning frequency is estimated to be twice per week, a high frequency relative to conventional RO. The RO membrane exhibited better performance than the NF membrane at similar flux range; permeate quality for the RO membrane was excellent (Figure 5 and Table 4).

FIGURE 5
Comparison of RO Reject (VSEP Feed), VSEP Permeate and VSEP Reject from the Pilot VSEP Unit (85% Water Recovery)

TABLE 4
Mass Balance Results and Discharge Requirements for Conceptual Design Scenario 1 Using VSEP (RO Membrane)

Parameter	WWTP Discharge	VSEP feed	VSEP Reject	VSEP Permeate	Blended Stream of VSEP Permeate and Treated Secondary Effluent	Discharge Limit at Discharge Point No. 001
Flow, gpd	1,150,000[a]	160,000	24,000	136,000	1,286,000	4,500,000
BOD5, mg/L	6.0	17	109	1.2	5.5	30.0
Boron, µg/L	240	835	3,480	367	250	750
Chloride, mg/L	51.0	343	2,150	24.0	48.2	60.0
Fluoride, mg/L	0.25	1.2	7.1	0.18	0.24	1.6[b]
TDS, mg/L	450	2,830	17,700	198	424	650[c]
TSS, mg/L	6.0	6.4	39.7	0.1	5.4	30.0
Sulfate, mg/L	40.0	261	1,740	2.0	36.0	60.0
TN, mg/L	6.2	35.0	194	6.1	6.2	NSL
TOC, mg/L	5.8	38.0	220	3.3	5.4	NSL

[a]Based on an average secondary treated effluent flow of 2.2 mgd
[b]Annual average concentration
[c]Source water TDS+400 mg/L. The typical source water TDS is between 250 and 275 mg/L
NSL: No set limit

Based on the projected quality, the VSEP permeate could be blended with the RO permeate to increase overall recovery of the ATF. VSEP is not an approved technology by CDHS for Title 22 groundwater recharge; however, therefore direct or blended use of VSEP permeate for groundwater recharge would require additional pilot testing to more comprehensively characterize VSEP permeate quality and to meet other DHS certification testing requirements. Consequently, the option for blending VSEP permeate and RO permeate was not considered in this evaluation.

Volume Reduction Approach 2 (VSEP-1)

In this alternative, the entire RO reject flow (160,000 gpd) is treated using VSEP. At 85 percent VSEP recovery, 24,000 gpd of VSEP concentrate is produced. This flow could be applied to either wetland or evaporation pond systems for additional treatment. This analysis assumes that the VSEP permeate (136,000 gpd) is blended with the treated secondary wastewater effluent for disposal. Mass balance calculations showed that the quality of effluent/VSEP concentrate blend would fully comply with the existing BBARWA NPDES permit requirements.

Volume Reduction Approach 3 (VSEP -2)

In this alternative, approximately 32,000 gpd of RO reject is bypassed around the VSEP unit and blended with the VSEP permeate and secondary treated wastewater effluent. The purpose of this bypass is to reduce the size of the VSEP unit required for conventional RO concentrate treatment, thereby reducing treatment costs. This, in turn, reduces the volume of VSEP concentrate that must be further treated while continuing to meet the existing BBARWA NPDES discharge limits for the secondary effluent.

Capital and O&M Costs

Capital cost estimates for each VSEP-based alternative are presented in Table 5. The capital cost estimates are based on information provided by New Logic Research Incorporation (using the pilot testing data) and include VSEP equipment and installation, SCADA control system with human machine interface (HMI), a hoist crane to lift the membrane assembly during membrane replacement, acid feed, and CIP systems. The O&M cost includes, chemical for pH adjustment and CIP, membrane replacement, energy and labor for the O&M.

TABLE 5
Capital and O&M Costs for VSEP Concentrate Volume Reduction

	Conceptual Design Scenario 1 (VSEP 1)	Conceptual Design Scenario 2 (VSEP 2)
Capital Cost, $	2,087,000[a]	2,087,000[a]
O&M Cost, $/year	279,000	235,000

[a]Cost is same as higher flow because same equipment is used, but operated at lower flux, hence lower chemical and membrane replacement costs are expected

Enhanced Membrane Systems (EMS)

EMS refers to the use of a non-conventional RO system to permit operation at higher recovery and at higher flux. One type of EMS is the patented High-Efficiency Reverse Osmosis (HERO™) system. This process uses ion-exchange softening to pretreat the conventional RO concentrate to reduce it’s scaling potential, followed by the high-pH operation of a three-stage RO system using standard spiral wound RO elements. Caustic is added to raise the pH to approximately 11 to retard silica scaling and biofouling. Historically, the HERO process has been applied for industrial use, for example, to treat cooling tower blowdown as part of a zero liquid discharge treatment system.

EMS is a relatively new type of membrane system and will require approximately 6 months of pilot testing prior to implementation. Pilot testing could be complex because a mainstream RO pilot of sufficient capacity would be required to generate the concentrate as feed to the EMS pilot. Because of the complexity of the process and the need to provide greater RO concentrate volumes than were available from the BBARWA pilot unit, field evaluation of the HERO process was not conducted.

One of the major drawbacks of the EMS is the complexity of the process (i.e., it requires chemical addition for softening, ion exchange, pH adjustment, and an RO system). Although softening, ion exchange, and RO are all proven technologies for drinking water applications, the combination of these technologies in the EMS requires a very skilled staff to operate the facility. Capital and O&M costs are relatively high due to high energy and chemical consumption and brine waste disposal.

The product water quality is projected to be similar to VSEP permeate water quality as each technology uses RO membranes. Some of the EMS product water could potentially be blended with the RO permeate of the ATF if approval is granted from CDHS and the RWQB. Approval would require a lengthy pilot test to demonstrate the water quality meets Title 22 groundwater recharge requirements. For purposes of this study, all product water from the EMS system was assumed to be blended with wastewater effluent and discharged to the alfalfa fields in the Lucerne Valley, similar to the VSEP alternatives.

Estimated Cost for EMS Treatment

Because no testing was conducted to characterize the permeate quality from the HERO process, this alternative assumed that the entire conventional RO concentrate flow is treated through EMS (no concentrate flow bypassing the EMS). So design flow for the facility was 160,000 gpd. Capital and O&M costs for HERO were obtained from the Bureau of Reclamation’s Southern California Water Recycling Projects Initiative Water Quality Report. (Water Quality Technical Memorandum No. 4 Regional Approaches to Brine/Concentrate Management, CH2M HILL, 2006)

Table 6 provides the capital and O&M costs for an EMS system.

TABLE 6
Capital and O&M Costs for EMS Concentrate Volume Reduction

	Value
Capital Cost, $	5,600,000
O&M Cost, $/year	306,000

Zero Liquid Discharge Processes

Processes capable of reducing the concentrate, either directly from the conventional RO or the volume reducing processes to zero liquid discharge (ZLD, i.e., sufficiently dry salt or other solid to be landfilled) were evaluated as a means for final concentrate disposal. Specifically, the analysis focused on mechanical evaporation, solar evaporation (evaporation ponds), and constructed wetlands. ZLD processes are considered in conjunction with wastewater effluent mixing and volume reduction technologies, where applicable.

Mechanical Evaporation

Mechanical evaporation can process concentrate by converting the water component to condensable water vapor, leaving behind a wet salt to be landfilled. Many different options for mechanical evaporation equipment exist. The most common combination of technologies used for this purpose is a vertical tube falling film brine concentrator followed by a forced-circulation crystallizer. Since this arrangement of evaporation equipment is typically the most economical, it was selected for use as one ZLD alternative for RO concentrate treatment.

Vertical Tube Falling Film Brine Concentrator

High TDS and saturation of low solubility scaling salts such as calcium sulfate ($CaSO_4$) and silica (SiO_2) limit the percentage of water which can be recovered in a conventional evaporator system. The brine concentrator uses a unique process called seeded slurry evaporation to overcome the limitation imposed on conventional evaporators by the saturation limits of low solubility scaling compounds. The seeded slurry process involves establishing and maintaining a slurry of calcium sulfate seed crystals in the circulating brine in the evaporator. With careful thermal and mechanical design, the $CaSO_4$ and SiO_2 can precipitate preferentially on the recirculating seed crystals instead of on the tubes. The ultimate concentration achievable in the brine concentrator is limited by the boiling point elevation of the brine, the relative concentrations of sulfate and chloride (e.g. the double salt, $CaSO_4 \cdot Na_2SO_4$, [glauberite] does not form), and the solubility of the sodium salts. The brine discharged from the brine concentrator is further concentrated in the crystallizer.

Total product water recovery across the concentrator is between 95 and 99 percent. For purposes of the conceptual design, a recovery of 95 percent was assumed. The condensate can be delivered as distillate water, make-up water, or blended with RO product water. The brine is concentrated to approximately 17 percent total solids in the brine concentrator.

A schematic of a falling film brine concentrator in combination with a forced-circulation crystallizer is presented in Figure 6.

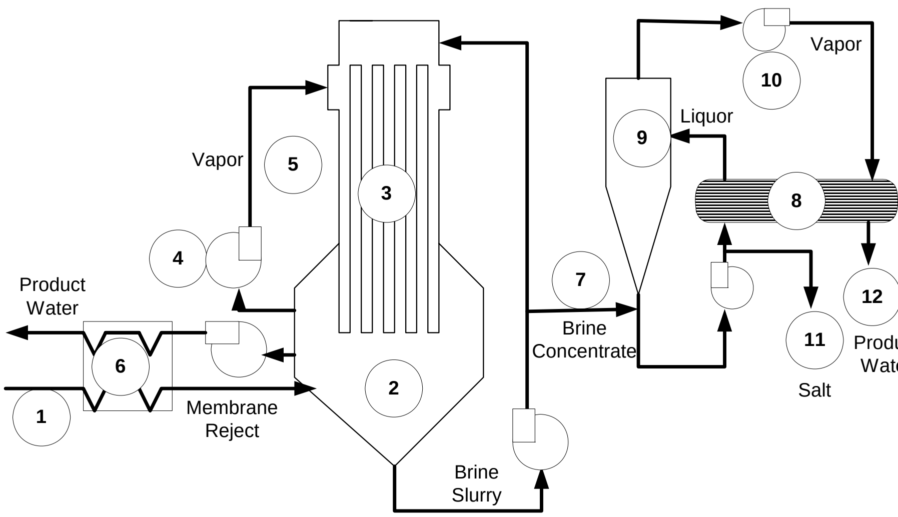

FIGURE 6
SCHEMATIC OF A BRINE CONCENTRATOR FOLLOWED BY A CRYSTALLIZER

Brine Crystallizer

The crystallizer is a forced circulation type evaporator, which is specially designed to precipitate, grow, and handle crystals in the concentrate as water is continuously evaporated. Recirculated concentrate is pumped through the forced circulation heat exchanger where it is heated above its normal boiling temperature with steam. It requires 250-300 kWh of power per 1,000 gallons of crystallizer feed. Boiling of the concentrate in the heat exchanger is suppressed due to sufficient static head. The heated concentrate then enters a flash tank operating at a slightly lower pressure, causing flash evaporation of water and crystallization of salts in the brine. High recirculation rates are used to keep the velocity on the heated surface high, avoiding the formation of scale on the heat transfer surface, and increasing heat transfer efficiency. The slurry produced in the crystallizer is dewatered in the belt filter and the liquid portion is returned to the crystallizer for further concentration. When the salt cake accumulates on the belt filter to a predetermined level, an automatic sequence is initiated which advances the belt and dumps the salt cake into a hopper for disposal.

Due to the highly specialized nature of mechanical evaporation equipment, the suppliers of this equipment were contacted for guidance regarding the specific sizing and materials of construction for a given application. The major suppliers of this equipment are AquaTech International, Swenson Process Equipment, Inc., and GE Ionics through their subsidiary, Resource Conservation Company.

The primary obstacle in implementing mechanical evaporation for the disposal of RO concentrate is the size and complexity of the equipment. For example, a falling film brine concentrator for a 160,000 gallon-per-day (gpd) concentrate stream is approximately 75 feet in height. In addition, evaporators and crystallizers are relatively complex to operate and energy intensive compared to other ZLD methods. Reliance on mechanical compressors results in lower reliability than other ZLD methods that are less mechanically intensive.

Permit requirements for operation of volume reduction process equipment for membrane concentrate disposal are similar to other wastewater treatment processes. Implementation of a mechanical evaporator could require a variance due to the aesthetic impacts of the tower profile on the surrounding vistas.

Conceptual Design Scenarios and Cost Estimation for Mechanical Evaporation and Crystallizer

Because of the high capital and operating cost of mechanical evaporator/brine crystallizer treatment, the most cost effective means of utilizing these technologies for concentrate management for the BBARWA AWT is to first reduce the RO concentrate flow with one the volume reduction processes described above. For purposes of this study, VSEP was selected as a volume reduction technology. The design flow for this scenario was 24,000 gpd. O&M costs for mechanical evaporation equipment are highly dependent on the power usage of the large vapor compressors used in the process. The brine concentrator requires 70 to 90 kWh of power per 1,000 gallons of brine concentrator feed and the crystallizer requires 250-300 kWh of power per 1,000 gallons of crystallizer feed. In this evaluation, a power cost of $0.13/KWh was used. A small increase in power costs can dramatically increase the cost to treat a specified volume of membrane concentrate. Landfill costs are also incurred for ultimate disposal of the salt residue. Table 7 summarizes capital and O&M costs for a typical ZLD system (mechanical evaporation with crystallizer). The cost estimate for equipment is based on CH2M HILL's previous experience on similar size projects.

TABLE 7
Estimated Costs for Concentrate Management Using VSEP, Mechanical Evaporation and Brine Crystallizer

Parameter	VSEP	Mechanical Evaporation	Crystallizer	VSEP, Mechanical Evaporation and Crystallizer
Capital Cost, $	2,087,000	1,825,000	350,000	4,262,000
O&M Cost, $/year	279,000	306,000	123,000	708,000

Evaporation Ponds

Evaporation ponds rely on solar energy to evaporate water from the RO concentrate stream, leaving behind precipitated salts which are ultimately landfilled. Evaporation ponds are most effective in arid and semi-arid climates having high net evaporation rates. High net evaporation rates decrease the pond area required because evaporation occurs in less time. One major advantage of evaporation ponds is that the practicality of using evaporation ponds is not limited by RO concentrate quality.

In the most common case, RO concentrate is conveyed to the evaporation ponds where it is spread out over a large area and allowed to evaporate. For evaporation ponds systems, multiple ponds are constructed to allow for some ponds to be taken offline for periodic maintenance. Periodic maintenance includes allowing the evaporation pond to set idle to firm the consistency of the precipitated salts, cleaning the ponds by removing and transporting the precipitated salts to a landfill, and inspecting the protective lining system.

Factors affecting the feasibility of implementing evaporation ponds for RO concentrate disposal include membrane concentrate flow rate, geographical location, and site location. The RO concentrate flow rate is the primary factor affecting the area required for the evaporation ponds. The greater the flow of RO concentrate, the larger the area required for 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 lower TDS water. A general guideline is to apply a factor of 0.7 to the evaporation rates. This reduces the evaporation rate by 30 percent to account for the lower evaporation rate of the concentrate solution.

The most significant issue associated with implementation of evaporation ponds in the Lucerne Valley is how to convey RO concentrate flow from the BBARWA Facility to the Lucerne Valley site. Currently, permitting and constructing of a new pipeline to the Lucerne Valley would be difficult because the pipeline crosses the San Bernardino National Forest. However, there is enough capacity in the existing discharge pipeline to install a smaller pipeline within it without impacting the ability to discharge flows.

Evaporation ponds must be lined to prevent seepage into the groundwater, or the ponds would be considered a Class V injection well. Permitting an evaporation pond as a Class V injection well would be extremely difficult. To permit a Class V injection well, the project proponent has to show that all constituents in the water are at lower concentrations than those found in the native groundwater. However, installing a double liner with leachate collection system should remove the Class V requirements.

Another major concern with installation of evaporation ponds is the control of habitat including water fowl. Large evaporation ponds are attractive to many birds. In some cases, high concentrations of selenium in evaporation ponds have caused birth defects in waterfowl. However, waterfowl control can be successfully accomplished by broadcasting the sound of the fowl's natural predators over a loud-speaker system. This type of control is in use at fruit orchards across the country and has been proven to be quite effective.

The required area for evaporation ponds in the Valley would be approximately 140 acres, if no volume reduction occurred prior to the evaporation ponds, based on an average annual pan evaporation rate of 46.6 inches per year. Implementation of such a large pond area is neither feasible nor economically attractive. A hybrid method, incorporating volume reduction technologies (e.g. VSEP, EMS, mechanical evaporation), should be used to reduce the evaporation pond area.

A more attractive and cost-feasible option is to use a portion of the 450 acres of land that BBARWA owns in the Lucerne Valley to site the evaporation ponds. A major advantage to constructing evaporation ponds in the Lucerne Valley is the higher evaporation rates than those observed in the Valley.

In addition to economic factors, the BBARWA Board could also use the following factors to evaluate the best concentrate management alternative:

- Ability to use capacity within existing Lucerne Valley discharge pipelines to convey flow
- BBARWA's future expansion plan at the WWTP (the minimum area requirement for a wetland will be 12.2 acres, if the wetlands are constructed at BBARWA)
- Issues associated with public perception and regulatory acceptance

Evaporation Pond Conceptual Design and Cost Scenarios for Lucerne Valley

Six different concentrate management alternatives using evaporation ponds located in the Lucerne Valley were costed:

- Alternative 1(LV-EP1): All RO concentrate (160,000 gpd) is conveyed to the Lucerne Valley for evaporation pond application, requiring installation of a 2.5 inches PVC pipeline within the existing effluent pipeline and a small pump station to convey the concentrate to the Valley. The length of the pipeline is approximately 19.5 miles or 110,000 feet.
- Alternative 2 (LV-EP 2): All RO concentrate flow is first treated using a three stage EDR to reduce the flow to approximately 34,000 gpd, with this flow then sent to the Lucerne Valley for evaporation. This alternative requires installation of a 1.5 inches PVC or HDPE pipe line and a small pump station.
- Alternative 3 (LV-EP 3): All RO concentrate flow is first treated using VSEP to reduce the flow to 24,000 gpd, with this flow conveyed to the Lucerne Valley for evaporation pond application. This scenario requires installation of a 1.5 inches PVC or HDPE pipe line and a small pump station.
- Alternative 4 (LV-EP 4): 32,000 gpd of RO concentrate is blended with wastewater effluent with the remainder treated by VSEP, resulting in a final concentrate flow of 19,200 gpd, which is conveyed to evaporation ponds in the Lucerne Valley. This scenario requires installation of a 1.5 inches PVC or HDPE pipe line and a small pump station.
- Alternative 5 (LV-EP 5): All RO concentrate flow is treated by EMS, reducing the flow to 16,000 gpd, which is conveyed to evaporation ponds in Lucerne Valley. This scenario requires installation of a 1.5 inches PVC or HDPE pipe line and a small pump station.
- Alternative 6 (LV-EP 6): All RO concentrate flow is processed by VSEP, mechanical evaporation to a flow of 1,200 gpd, which conveyed to the Lucerne Valley for evaporation pond application. A small pump station and a 1.5 inches PVC pipeline are required.

Table 8 presents estimated costs for concentrate management alternatives using evaporation ponds located in the Lucerne Valley.

TABLE 8
Estimated Costs for Lucerne Valley Based Evaporation Pond Concentrate Management Alternatives

Parameter	Design Scenario 1 (LV EP 1)	Design Scenario 2 (LV EP 2)	Design Scenario 3 (LV EP 3)	Design Scenario 4 (LV EP 4)	Design Scenario 5 (LV EP 5)	Design Scenario 6 (LV EP 6)
Design Flow, gpd	160,000	34,000	24,000	19,200	16,000	1,200
Evaporation Pond Surface Area, acres	69.4	16.4	11.3	9.8	8.3	1.2
Capital Cost, $	9,566,000	2,296,000	1,659,000	1,389,000	1,182,000	214,000
O&M Cost, $/year	246,000	153,000	147,000	133,000	143,000	138,000

Constructed Wetlands

Constructed wetlands are an established technology for the polishing and treatment of wastewater effluent, but have not been widely used as a method of RO concentrate disposal. Recent pilot testing conducted by the City of Oxnard (2003a, 2003b and 2004) indicates that brackish marshes can be constructed to significantly reduce concentrate volume through evapotranpiration. These studies also showed that chemical constituents of concern found in the membrane concentrate can be reduced to levels safe for wetlands biota, thereby providing valuable habitat as an additional benefit. For brine/concentrate applications, a constructed wetland can consist of high-salt-tolerant plant species that can be used to remove or concentrate constituents in the root zone of the plant or in sediments while allowing evapotranspiration to reduce the volume of flow. The advantages and disadvantages of wetlands are somewhat similar to those of evaporation ponds. The major benefits of constructed wetlands over evaporation ponds are:

- Aesthetically more attractive than evaporation ponds
- Provide further treatment
- Typically requires less surface area than evaporation ponds due to improved evapotranspiration rates
- Less accumulated material for landfill disposal due to plant uptake

The only disadvantage of constructed wetlands when compared with evaporation pond is that no demonstration projects have been implemented for a constructed wetland that operates in a zero liquid discharge mode using a high TDS input water. Therefore, a pilot demonstration is required prior to implementation of a ZLD constructed wetland.

As with evaporation ponds, groundwater will be protected through use of a double synthetic liner, and surface water discharges will be prevented by evapotranspiration of the concentrate.

The use of constructed wetlands is regulated by both federal and state laws, and in some instances, by local ordinances. By law, a minimum of secondary treatment must be provided prior to any discharge to natural wetlands. For permitting purposes, constructed wetlands that are considered to be a part of treatment process and have outflow require an NPDES permit at the point of discharge to a surface water. The proposed wetland, however, will be designed as zero liquid discharge system, so no new NPDES permit is required.

Wetland Conceptual Design Scenarios for Big Bear Valley

Similar to the analysis that was performed for the evaporation ponds, the cost of constructed wetlands located in the Lucerne Valley are significantly less than in BBARWA because the higher evapotranspiration rates that occur at the lower elevation and higher air temperatures. Consequently, only costs for constructed wetlands sited in the Lucerne Valley and used concentrate management are presented herein.

Constructed Wetlands Based Concentrate Management Alternatives

Five alternatives were developed for wetland implementation in the Lucerne Valley, they are:

Alternative 1 (LV-CW 1): All RO concentrate from the ATF (160,000 gpd) is conveyed to the Lucerne Valley via 2.5 inch pipeline and a small pump station for wetlands application.

Alternative 2 (LV-CW 2): RO concentrate flow to 34,000 gpd by EDR. The resultant flow of approximately 34,000 gpd is conveyed to the Lucerne Valley via 1.5 inches pipe-line and a small pump station for wetlands application.

Alternative 3 (LV-CW 3): RO concentrate flow is reduced to 24,000 gpd by VSEP, with the resultant flow conveyed to the Lucerne Valley via 1.5 inches pipe line and a small pump station for wetlands application.

Alternative 4 (LV-CW 4): 32,000 gpd of RO concentrate is blended with wastewater effluent and the remainder is treated by VSEP, resulting in 19,000 gpd of VSEP concentrate conveyed to the Lucerne Valley via 1.5 inches pipe line and a small pump station for wetlands application.

Alternative 5 (LV-CW 5): RO concentrate flow is reduced to 16,000 gpd using EMS, with the resultant flow conveyed to the Lucerne Valley via 1.5 inches pipe line and a small pump station for wetlands application.

Table 9 presents estimated costs for alternatives using constructed wetlands located in the Lucerne Valley for concentrate management.

TABLE 9
Costs for Lucerne Valley Based Constructed Wetlands Alternatives

Parameters	Conceptual Design Scenario 1 (LV CW1)	Conceptual Design Scenario 2 (LV CW2)	Conceptual Design Scenario 3 (LV CW3)	Conceptual Design Scenario 4 (LV CW 4)	Conceptual Design Scenario 5 (LV WDS 5)
Design Flow, gpd	160,000	34,000	24,000	19,200	16,000
Wetland Surface Area, acres	51.7	11.6	8.2	6.7	5.6
Capital Cost, $	9,626,000	2,190,000	1,557,000	1,280,000	1,074,000
O&M Cost, $/year	469,000	161,000	139,000	130,000	126,000

Summary of the Results and Discussion

A major advantage to constructing evaporation ponds in the Lucerne Valley is the higher evaporation rates than those observed in Big Bear Valley. Constructing evaporation ponds or wetlands in Lucerne Valley also offer following advantages:

Minimizes public perception issues (i.e., mosquito, vector issues)
Leaves space in WWTP for future plant expansion (the minimum area requirement for a wetland will be 12.2 acres, if the wetlands are constructed at BBARWA)

This evaluation assumes that evaporation and wetlands facilities will be constructed in Lucerne Valley. Table 10 summarizes costs for each of the concentrate management alternatives. LCC analysis indicates that VSEP is the best volume reduction technology; however, it should be coupled with either evaporation ponds or wetlands to achieve the lowest estimated cost.

Despite several attractive futures of wetlands (i.e., aesthetically attractive, less area requirement and providing further treatment) the use of a constructed wetlands operating in a zero liquid discharge mode using a high TDS input water has not been demonstrated. Therefore, the ZLD wetland process should be extensively pilot or demonstration tested prior to full-scale implementation to confirm feasibility and cost and to develop project-specific design and operational criteria.

Coupling wetland and evaporation ponds, where treated water in wetlands is periodically applied to evaporation ponds, may be the best option because wetlands reduce selenium, nitrate, and organic concentrations while providing habitat and mitigating water quality concerns.

Implementing wastewater effluent mixing (i.e., bypassing approximately 32,000 gpd RO reject around VSEP and blending VSEP permeate, bypassed flow, and secondary treated wastewater effluent) is another effective strategy to reduce the LCC of the alternatives. According to Table XX, effluent mixing coupled with VSEP and wetlands/evaporation ponds is the best alternative for RO concentrate management. The least attractive alternative based on LCC is treated entire RO flow via a constructed wetland (LV CW1).

TABLE 10
Capital, O&M, and 20-year Life Cycle Costs for Lucerne Valley Concentrate Treatment and Disposal Options

Conceptual Design Alternative	Process Description	Capital Cost	Annual O&M Cost	Life Cycle Cost
LV EP1	Evaporation Pond Only Flow Conveyance + Evaporation Pond	$13,106,000	$342,000	$18,613,000
LV EP2	EDR+ Flow Conveyance + Evaporation Pond	$7,002,000	$506,000	$15,149,000
LV EP3	VSEP + Flow Conveyance + Evaporation Pond	$6,169,000	$491,000	**$14,075,000**
LV EP4	Effluent Mixing + VSEP +Flow Conveyance + Evaporation Ponds	$6,199,000	$450,000	**$13,444,000**
LV EP5	Mechanical Evaporation + Flow Conveyance + Evaporation Ponds	$6,335,000	$648,000	$16,768,000
LV EP6	EMS+ Flow Conveyance + Evaporation Pond	$9,206,000	$514,000	$17,482,000
LV CW1	Flow Conveyance + Wetlands	$13,166,000	$565,000	$22,263,000
LV CW2	EDR + Flow Conveyance + Wetlands	$6,896,000	$514,000	$15,172,000
LV CW3	VSEP+ Flow Conveyance + Wetlands	$6,067,000	$483,000	**$13,844,000**
LV CW4	Effluent Mixing + VSEP + Flow Conveyance + Wetlands	$5,820,000	$433,000	**$12,792,000**
LV CW5	EMS + Flow Conveyance + Wetlands	$9,098,000	$501,000	$17,165,000

Acknowledgments

The authors would like to thank to Michelle Chapman, Research Manager and Katherine Benko, Project Engineer, at United State Bureau of Reclamation for providing the RO pilot unit and assistance with unit start-up and data monitoring; and Pete Carboy and Traver Crabtrey, sales manager and application engineer at New Logic Research, respectively for providing and operating pilot VSEP unit. The authors would also like to thank Joe Hanford, Bob Sellards and Nikki Orabuena of BBARWA for their endless support during pilot testing.

References

CH2M HILL. 2003 a. *Membrane Concentrate Pilot Wetlands Research Plan.* Prepared for the City of Oxnard Water Division.

CH2M HILL. 2003 b. *Additional Testing for the Membrane Concentrate Pilot Wetlands Project Report.* Prepared for the City of Oxnard Water Division.

CH2M HILL. 2004. *Membrane Concentrate Pilot Wetlands Project Report.* Prepared for the City of Oxnard Water Division.

CH2M HILL. 2006. *Southern California Water Recycling Projects Initiative. Water Quality Technical Memorandum No. 4 Regional Approaches to Brine/Concentrate Management*. Prepared for United States Bureau of Reclamation