BRINE/CONCENTRATE MANAGEMENT STRATEGIES FOR SOUTHERN CALIFORNIA

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Abstract

The U.S. Bureau of Reclamation (Reclamation) has assisted southern California in the planning and development of water recycling projects since 1991 when the Secretary of the Interior announced the Water Recycling Initiative for southern California. This support has been for both project specific and regional planning activities.

In 2000, Reclamation and twelve cost sharing partners began the Southern California Water Recycling Projects Initiative (Initiative), which is a multiyear planning study. This study was established to assist local agencies in their recycled water planning for specific projects as well as addressing regional issues that may influence water recycling in southern California. One of the main objectives of the regional component is to assess and analyze potential future brine/concentrate management issues at a regional level. This issue is of particular concern to agencies in southern California that produce recycled water because of the potential salinity increases in water supplies and increasing discharge regulations.

This paper will discuss in detail the analysis, results, and information accumulated to date as part of the Initiative project including examining how to address future brine/concentrate issues such as:

- How much projected future brine/concentrate flows can be expected in the region?
- What are the applicable technologies?
- What are the regulations and other implementation barriers facing the technologies or brine/concentrate management strategies?

At a regional level, agencies are growing more aware of the limitations that the production and disposal of brine/concentrate can place on the future of recycled water projects. The Initiative project was developed to assist in assessing and analyzing these issues. As part of the Initiative analysis, projections were made for brine/concentrate flow production, increased salinity in water supplies, limitations to effluent discharges, impacts due to conservation, and changes in regulations. These potential impacts were analyzed to determine the impacts on water recycling and will be used in the next phase of this study to evaluate potential regional solutions to managing brine/concentrate and salinity so that the impacts to recycled water are minimized.

One of the major components of the Initiative analysis was an in-depth review of applicable technologies for treating and/or disposing of projected brine/concentrate flows. Disposal options and related technologies evaluated under the Initiative Study were grouped into the following categories:

- Liquid disposal
- Incineration disposal option
- Landfill disposal option
- Crystallization
- Liquid concentrating/volume reducing
- Zero Liquid Discharge

Projected Future Brine/Concentrate Flows in the Region

Brine/concentrate is produced as a result of advanced treatment of water required to reduce the concentration of a constituent of concern. In southern California this constituent is most often salinity. Salinity in water, including raw water, wastewater, and recycled water, is most commonly reduced using treatment methods that produce a waste flow (i.e., brine/concentrate). Brine/concentrate can be produced from recycled water treatment, impaired groundwater sources, drinking water from a high salinity source such as seawater, specific water quality needed by industry, and/or effluent treatment to meet discharge requirements. In addition, salinity changes in the source water used in the southern California region could impact the amounts of brine/concentrate produced in the future.

To evaluate potential issues associated with effluent discharge and brine/concentrate management, three scenarios were developed based upon future recycled water use to project the volume of brine/concentrate that could be produced. These scenarios were based upon data collected as part of the Southern California Comprehensive Water Reclamation and Reuse Study and refined as part of the Initiative study. The scenarios used in this analysis have the following assumptions:

- Moderate Scenario – This scenario is based on a moderate increase in effluent discharges and flows in brine/concentrate pipelines, a moderate expansion level of recycled water use, desalters and desalination facilities that will be online by 2010, existing imported water supply sources, and existing water conservation levels. In addition, the maximum recycled water contribution factor for groundwater recharged is assumed to be 100 percent.

- Maximum Scenario – This scenario is a maximum or long-term increase of effluent discharges and flows in brine/concentrate pipelines, aggressive expansion of recycled water use, implementation of planned and proposed desalters and desalination facilities, full allotment of imported water supply sources with existing water quality, and existing water conservation levels. In addition, the maximum recycled water contribution factor for groundwater recharged is assumed to be 100 percent.

- Extreme-Case Scenario - This scenario focuses on estimating the amount of brine/concentrate produced if regulation changes are aggressive requiring the implementation of advanced treatment processes. Two conditions are developed under this scenario. In condition 1, this includes only the advanced treatment of inland WWTP discharges. In condition 2, this includes advanced treatment for all imported water supply sources and all WWTP flows. Analysis of condition 1 provides an opportunity to illustrate how regulation changes for inland discharges could impact production of brine/concentrate. Analysis of condition 2 will be limited due to the uncertainties in the projections; however, the projections for this condition are intended to illustrate the wide range or variability of the projections for brine/concentrate levels in southern California.

Table 1 provides a summary of the brine/concentrate projections developed in this analysis for southern California. These projections show a range of potential brine/concentrate production from moderate (43.7 mgd), to maximum (285.3 mgd without seawater desalination and 365.1 mgd with seawater desalination), to the extreme case 1 scenario (358.5 mgd without seawater desalination and 438.3 mgd with seawater desalination), to the extreme case condition 2 scenario (approximately 2,011.8 mgd including seawater desalination).

Figure 1 illustrates graphically the location of existing and potential future brine/concentrate management facilities in southern California. These facilities include 86 pipelines, 113 wastewater treatment plants, 32 groundwater desalters, 9 seawater desalination facilities, and 9 major groundwater basins (with 91 sub-basins). In the next phase of the Initiative, these facilities will be analyzed in conjunction with the projections, as part of the potential options to meet the brine/concentrate management needs in the future.

TABLE 1: SUMMARY OF PROJECTED BRINE/CONCENTRATE FLOW GENERATION

Brine/Concentrate Generating Processes	**Moderate Scenario**	**Maximum Scenario**	**Extreme-Case Scenario**	
			Condition 1 - Inland Discharged Wastewater Flows	**Condition 2 - All Wastewater Flows**
	Brine/Concentrate Generation (mgd)[1,3]	**Brine/Concentrate Generation (mgd)[1,4]**	**Brine/Concentrate Generation (mgd)[1,5]**	**Brine/Concentrate Generation (mgd)[1,5]**
Inland Empire Region Total	6.5	124.0	185.6	185.6
Wastewater Discharges with Water Conservation	0.4	69.8	131.4	131.4
Groundwater Desalters	6.1	54.2	54.2	54.2
Los Angeles Region Total	10.3	55.6	104.7	271.3
Wastewater Discharges with Water Conservation	5.0	47.6	96.7	263.3
Groundwater Desalters	5.3	8.0	8.0	8.0
No. Orange Co. Region Total	24.7	60.2	30.0	132.0
Wastewater Discharges with Water Conservation	24.7	60.2	30.0	132.0
Groundwater Desalters	0.0	0.0	0.0	0.0
So. Orange Co. Region Total	0.7	11.9	7.4	19.7
Wastewater Discharges with Water Conservation	0.2	4.7	0.2	12.5
Groundwater Desalters	0.5	7.2	7.2	7.2
San Diego Region Total	1.5	25.6	18.3	83.1
Wastewater Discharges with Water Conservation	0.1	16.9	9.6	74.4
Groundwater Desalters	1.4	8.7	8.7	8.7
Ventura Region Total	0.0	8.0	12.5	19.3
Wastewater Discharges with Water Conservation	0.0	5.0	9.5	16.3
Groundwater Desalters	0.0	3.0	3.0	3.0
Total Wastewater Discharges and Groundwater Desalters	**43.7**	**285.3**	358.5	**711.0**
Other Brine/Concentrate Sources				
Seawater Desalination	0.0	79.8	79.8	79.8
Imported Water	0.0	0.0	0.0	1,221.0
Total All Sources	**43.7**	**365.1**	438.3	**2,011.8**

Notes:
[1] Twenty percent of the advanced treatment flow is assumed to be brine/concentrate reject flow.
[2]Brine/concentrate projections for wastewater discharges account for increased groundwater water recharge (GWR) contribution to 100 percent and include effects of industrial users brine/concentrate generation.
[3]Wastewater discharges under this scenario are based upon current recycled water usage and advanced treatment available in region (i.e., 160.2 mgd).
[4]Wastewater discharges under this scenario are based upon assumption that all recycled water undergoes advanced treatment (i.e., 1,290.8 mgd).
[5]Wastewater discharges under this scenario are based upon assumption that all effluent will be treated using advanced processes (i.e., condition 1 is 1,632.3 mgd and condition 2 is 3,705.1 mgd).

Figure 1 - Brine/Concentrate Management Facilities in Southern California

Southern California Water Recycling Projects Initiative

0 15,000 30,000 60,000 Meters

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WWTP Discharges

- Planned Desalter
- Proposed Seawater Desalination Plant
- Existing Desalter
- Land Discharge
- Stream Discharge
- Ocean Discharge
- Recycled Water Only
- Other

Pipelines

- Existing Land Discharge
- Existing Stream Discharge
- Existing Ocean Outfall
- Planned or Potential Ocean Outfall
- Existing Brine/Concentrate
- Planned or Potential Brine/Concentrate

Major Groundwater Basins

- Bunker Hill Basins
- Chino Basins
- Orange County Basins
- Riverside Basins
- San Diego Basins
- San Fernando Valley Basin
- San Gabriel Basins
- Ventura County Groundwater Basins
- West Coast Basins

Features

- Highways
- Rivers
- Water Bodies

Note: Proposed desalter locations are approximate

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In future analyses in this study, only the moderate, maximum, and extreme case condition 1 scenario will be considered. The extreme case condition 2 scenario was developed to provide a bookend value for the potential range of the problem under an assumed extreme regulatory condition and therefore will not be included in future analysis. These conditions are not expected to occur for all the potential brine/concentrate generation sources. In addition, the future analysis of brine/concentrate management will consider only those flows that will be of primary impact to wastewater discharging. These flows include both groundwater desalination and WWTP generated brine/concentrate flows. Because seawater desalination is not expected to generate brine flows that would directly impact wastewater brine flows/pipelines, seawater desalination brine will not be considered in the future analysis. However, as these discharges could add to the overall impact to the marine environment, these values have been computed and are shown in Table 1.

Applicable Technologies

There are a number of methods available for disposal or reduction of wastewater effluent or brine/concentrate flows. In this study, the disposal/reduction methods were divided into six categories: liquid concentrating/volume reducing, crystallization, zero liquid discharge, liquid disposal, incineration, and landfill. The liquid concentrating and crystallization processes can be used in different combinations to achieve the desired result of a solid salt product for disposal, referred to as Zero Liquid Discharge. The crystallization processes alone require disposal of the dry salts, typically to a landfill, and thus will require transport. The liquid disposal processes, such as surface water discharge, ocean discharge, and deep well injection, exist as stand-alone processes that most commonly consist of a single-step disposal method.

For this study, the specific technologies explored under each category were as follows:

- Liquid disposal
    - Downstream discharge (disposal to brineline or sewer pipeline that discharges to a downstream WWTP)
    - Ocean Discharge
    - Deep well injection
- Incineration disposal option
- Landfill disposal option
- Liquid concentrating and volume reducing
    - Electrodialysis/electrodialysis reversal (ED/EDR)
    - Vibratory shear enhanced processing membrane system (VSEP)
    - Precipitative softening (PS)/RO
    - Mechanical Evaporation
    - Enhanced Membrane Systems
    - Natural treatment systems (NTS, wetlands)
- Crystallization
    - Evaporation ponds/misters
    - Forced circulation crystallizer (FCC)
- Zero Liquid Discharge
    - Conventional Zero Liquid Discharge
    - Enhanced Membrane and Thermal System Zero Liquid Discharge

As part of the Initiative study, these technologies were identified and evaluated to assess their applicability for use in reducing and/or removing of brine/concentrate flows. From this evaluation, it can be concluded that there are a number of disposal/reduction methods that may be viable for effluent discharge and brine/concentrate disposal. Table 2 provides a list of the disposal/reduction technologies evaluated in the study along with the key issues associated with each one. The regulatory requirements associated with these treatment technologies that include either single-disposal methods, such as deep well injection or pipeline conveyance to the Pacific Ocean, or a combination of treatments that first reduce the volume of concentrate then dry the remainder to a salt via evaporation or crystallization are discussed in the following section.

TABLE 2: KEY ISSUES ASSOCIATED WITH DISPOSAL/REDUCTION ALTERNATIVES

Brine/Concentrate Disposal Method	Key Issues to be Addressed
Liquid Disposal	
Ocean and Downstream Discharge (Including disposal via brineline or sewer to downstream WWTP with an outfall)	Availability of Discharge Facilities with Capacity
	Environmental/Habitat Issues
	Regulatory Requirements/Permits
	Type of Treatment Available
Deep Well Injection	Land Availability/Seismic Activity
	Geologic/Geohydrologic Conditions
	Membrane Brine/Concentrate Compatibility
	Public Perception/Acceptance
	Regulatory Requirements/Permits
	Potential to Use Abandoned or Active Oil Wells
Other Disposal Methods	
Incineration	Transportation and Landfill Costs
	State or Form of waste (liquid, solid)
	Packaging of Waste
	Composition of Waste (most applicable to organic wastes)
	Industrial Waste Classification
Landfill	Transportation and Landfill Costs
	State or Form of waste (liquid, solid)
	Industrial Waste Classification
Crystallization	
Evaporation Ponds/Misters	Land Availability/Climate Applicability
	Construction and Maintenance Requirements
	"Salt Drift"
	Potential Groundwater Infiltration
	Disposal of Crystal/Particulate Residue
	Aesthetic Issues
	Habitat Issues
Forced Circulation Crystallizer	Complexity of Equipment
	Mechanically Intensive
	Energy/Power Requirements

TABLE 2: KEY ISSUES ASSOCIATED WITH DISPOSAL/REDUCTION ALTERNATIVES

Brine/Concentrate Disposal Method	Key Issues to be Addressed
Liquid Concentrating and Volume Reducing	
Natural Treatment System	Land Availability/Space Requirements/Climate Applicability Potential Groundwater Contamination Membrane Brine/Concentrate Quality (TDS, Nitrogen, Silica, etc.) Additional Treatment Required Downstream for Untreated Brine/Concentrate Selection of Appropriate Vegetation/Plant Species Habitat/ Toxicity Issues
Electrodialysis Reversal	Costs Associated with Antiscalants and Cleaning Chemicals Energy/Power Requirements Variable Transmissivity of the Membrane
VSEP Membrane System	Costs Associated with Antiscalants and Cleaning Chemicals Membrane Replacement Costs Energy/Power Requirements
Precipitative Softening/Reverse Osmosis	Containment of Runoff & Infiltration from Sludge Management Processes Lime and Lime Sludge Handling Regulatory Requirements/Permits
Mechanical Evaporation - (Vertical Tube Falling Film)	Complexity of Equipment/Mechanically Intensive Site Specific Sizing and Materials Required Cost Intensive (Capital and O&M) Height of System Energy/Power Requirements
HERO Membrane System	New Process Requiring Extensive Pilot Testing Mechanical/Solar Evaporation Required for Brine/Concentrate Lower Quality Product Water

Table 3 provides a list of the advantages and disadvantages for the identified disposal/reduction technologies. These technologies and disposal options were evaluated for a number of key criteria:

- Proven Technology
- Sensitivity to Feed Water Quality
- Recoverable Product Water
- Sustainability
- Ease of Implementation
- Staffing Requirements
- Capital Costs
- Operation and Maintenance Costs
- Site Requirements
- Aesthetics
- Noise
- Air Quality
- Odor
- Wildlife Impacts
- Discharge Regulatory Considerations
- Land Disposal of Residuals

Because of differences in location, wastewater plant operating conditions, and proximity and access to existing brinelines, a definitive conclusion as to which disposal/reduction mechanisms are more suitable for the existing regional needs is difficult to reach. Therefore, the evaluations will be used as a basis to look for solutions to this long-term issue based upon local (sub-regional and treatment plant specific) conditions and criteria. This work is currently being conducted as part of the current phase of the Initiative study and is expected to be completed in mid-2004.

TABLE 3: ADVANTAGES/DISADVANTAGES OF DISPOSAL/REDUCTION ALTERNATIVES

Disposal Alternative	Advantages	Disadvantages
Liquid Disposal		
Surface Water Discharge (Ocean and Downstream Discharges)	Treatment of brine/concentrate not required prior to disposal for nontoxics No additional permits required if continue to meet existing NPDES permit Environmentally acceptable alternative Proven technology for brine/concentrate disposal	Costs associated with transporting brine/concentrate are variable Ocean outfall of brine/concentrate may become unacceptable to regulators and/or public in the future Brine/concentrate must meet discharge requirements set by downstream treatment operator Disposal pipeline may be necessary
Deep Well Injection	Treatment of brine/concentrate not required prior to disposal Proven environmentally safe Mature technology – a number of successful installations for RO brine/concentrate disposal worldwide Small footprint requirement Minimal aesthetic impact (noise, odor, insect or waterfowl attraction) Simple to design and operate Potential to use abandoned or active oil wells, which eliminates drilling costs	Expensive well construction due to industrial waste classification of RO brine/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/concentrate flows Monitor well must be drilled in addition to disposal well Potential for well plugging by organics and nutrients Must comply with regulations protecting USDW
Other Disposal Methods		
Incineration	Proven track record Reduces amount of material required for landfill	Costs vary widely based on state or form of material High transportation costs Industrial waste classification of brine/concentrate limits incineration facilities Disposing waste in landfill is still required
Landfill	Proven track record Transfers responsibility for waste No additional processes required	Loss of a valuable resource – water, if direct disposal to landfill is practiced. Costs vary widely based on state or form of material High transportation costs especially when direct disposal to landfill is practiced. Industrial waste classification of brine/concentrate limits incineration facilities

TABLE 3: ADVANTAGES/DISADVANTAGES OF DISPOSAL/REDUCTION ALTERNATIVES

Disposal Alternative	Advantages	Disadvantages
Liquid Concentrating and Volume Reducing		
Natural Treatment System	Proven technology for treatment of wastewater with high organic loading Potential for agricultural source of revenue 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 Treatment system may require liner and monitor system to prevent infiltration into groundwater Alternative form of water required during the months when recharge system is not operating Vegetation not very effective at removing sodium, chloride, and sulfates Limited experience in using NTS to treat brine/concentrate Limited agricultural crops available for TDS values greater than 4,000 mg/L Additional disposal mechanism required
Electrodialysis Reversal	Mature technology - many EDR plants in service throughout the world Small site footprint Least costly of the membrane based liquid concentrating alternatives Highly automated for ease of operation	Degree of concentration of RO brine/concentrate is less than other membrane-based concentrating alternatives TDS level in EDR product is higher than from other concentrating alternatives. Additional treatment of the EDR product by RO will be required for artificial surface recharge Alternative methods of disposal of the product may be required EDR membranes are susceptible to fouling from wastewater organics in RO brine/concentrate No past experience of EDR for treating secondary effluent RO brine/concentrate Large energy demands Additional disposal mechanism required
VSEP Membrane System	Capable of operating at high recovery without chemical treatment Small site footprint Highly automated for ease of operation No permitting needed for this application	Limited installations Complex mechanical mechanisms - may increase O&M costs No past experience for treatment of effluent–derived RO brine/concentrate High capital and operating cost Additional crystallization step required for final disposal

TABLE 3: ADVANTAGES/DISADVANTAGES OF DISPOSAL/REDUCTION ALTERNATIVES

Disposal Alternative	Advantages	Disadvantages
Liquid Concentrating and Volume Reducing		
Precipitative Softening/ Reverse Osmosis	Two proven technologies - many installations with RO following lime softening Removal of hardness and operation at high pH (increased silica solubility) allows for high recovery operation of the RO system No permitting needed for this application	Large site footprint High chemical usage due to level of hardness and alkalinity in RO brine/concentrate Handling of lime can be difficult and labor intensive Many support facilities required (chemical facility and dewatering) High sludge management costs Additional disposal mechanism required
Vertical Tube Falling Film	Proven technology for concentration of brine/concentrate solutions Small site footprint No permitting needed for this application	High capital and O&M costs Operational costs susceptible to large variations based on energy costs Mechanically complex Aesthetically unpleasing (height) Additional disposal mechanism required Requires pilot testing for application
HERO Membrane System	Uses combination of mature technologies - ion exchange and RO History of industrial installations for concentration of brine/concentrate solutions high in silica Product water, when blended with RO permeate, may by suitable for recharge Small site footprint No additional permits required	High capital and O&M costs Additional disposal mechanism required May require the use of a precipitative softening process instead of ion exchange Complex process control (IX, pH adjustment, RO system)
Crystallization		
Evaporation Pond/Mister	History of installations for concentration of brine/concentrate solutions Inherently simple technology Low capital costs (assuming land is available) Low O&M costs Misters are effective and simple to operate and maintain	Large footprint requirement Ponds must be lined to avoid being classified as Class V wells Potential for nuisance odors and noise from misters Can serve as nesting site for waterfowl Salt drifting may be problematic Salt must be excavated and removed periodically without compromising pond liners Additional disposal mechanism required
Forced Circulation Crystallizer	History of installations for concentration of brine/concentrate solutions Product water is suitable for recharge Small site footprint	High capital and O&M costs O&M costs susceptible to large fluctuations based on energy costs Mechanically complex Additional disposal mechanism required

Regulations and Other Implementation Barriers

For water recycling to succeed in southern California, regulatory issues related to effluent discharges and brine/concentrate management need to be taken into consideration. As part of the Initiative study existing and potential regulatory concerns or barriers associated with effluent discharge and brine/concentrate disposal in southern California were identified and discussed. In addition, the study outlined when potential regulations could be implemented.

In California, a number of public health, regulatory, and resource agencies have authority to approve of evaluations and permitting of wastewater discharges, brine/concentrate flows, and recycled water use. The number of agencies involved in a given project depends upon the proposed effluent or brine/concentrate disposal option or technology, the location of the project, and the sensitivity of the local ecosystem. These agencies include the California Department of Health Services, the State Water Resources Control Board and Regional Water Quality Control Boards (RWQCBs), California Coastal Commission, U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, and other resource agencies. These agencies are responsible for implementation of several regulations and laws and for the permitting of water recycling projects as well as discharge of wastewaters. Applicability of these agencies to the management of brine/concentrate disposal will depend upon the location, discharge media (land, stream, or ocean), and if additional water is being extracted from the brine/concentrate streamflow for reuse.

The actual applicable plans, policies, and regulations were also researched and evaluated for the potential implication on implementing future brine/concentrate disposal projects. These include the following:

- Federal Clean Water Act
    - Clean Water Act Section 404
    - 303(d) List and Total Maximum Daily Loads (TMDLs)
- California Ocean Plan
- California Water Code
    - Title 22
    - Maximum Contaminant Levels
    - Public Health Goals
    - Action Levels
- Regional Water Quality Control Board Basin Plans
- California Coastal Act
- California Toxics Rule
- State Implementation Plan
- California Environmental Quality Act
- National Pollutant Discharge Elimination System (NPDES)
- Special Status Species Protection
- Clean Air Act
- Resource Conservation and Recovery Act (RCRA)
- Toxic Substance Control Act (TSCA)

For each of the potential brine/concentrate technologies and disposal and/or discharge types, the major regulatory barriers were identified in this study.

Conclusions

Management of the projected brine/concentrate in the future will require long-term planning that agencies in southern California have already initiated. The issues, barriers, and potential solutions associated with brine/concentrate management are complex and expensive. The wide range of potential future brine/concentrate flows make long-term planning difficult and will greatly depend on how future regulations change. Solutions will require utilization of advanced, unproven, and potentially very expensive technologies, as well as meeting ever increasing regulatory conditions. Further research and piloting of these technologies will likely be required in order to ensure the chosen technologies will perform under local conditions and to meet regulatory approvals. The Initiative study is working to further this research on technologies as well as their potential applications towards planning for the long-term management of brine/concentrate flows in southern California.

References

1. *Water Quality Technical Memorandum #3 Effluent Discharge and Brine/Concentrate Management,* Southern California Water Recycling Projects Initiative, U.S. Bureau of Reclamation, August 2004.