Several US cities are turning to brackish groundwater and municipal wastewater to supplement their dwindling drinking water supplies. Desalination is a reliable technique for producing potable water but can be limited by a lack of suitable concentrate-disposal options and land area. New technologies offer approaches for heightened recovery and evaporation to meet these challenges.

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**Enhancing Water Recovery Sustainably**

Desalination use is growing rapidly with the marked improvement of the technology’s efficiency during the last decade. By 2010, a total of 324 US municipal desalination plants with a capacity of 25,000 gpd or larger had been built. High-recovery desalination methods such as zero discharge desalination (ZDD) and concentrate enhanced recovery reverse osmosis (CERRO) offer substantially higher potable water yield, typically achieving 95–98 percent recovery, from brackish water supplies.

Because the recovery is higher, the concentrate from these processes contains much higher dissolved solid levels (albeit with lower flows). Moreover, incorporating evaporation ponds, if they’re cost-effective, could improve water and residual salt recovery for a more sustainable operation. A review of the advantages and disadvantages of these enhanced recovery and evaporation processes in terms of technical and economic feasibility follows.

**CONCENTRATE MANAGEMENT**

Managing concentrate solutions produced by desalination processes grows increasingly difficult. Factors include:

- the increasing size of plants, as larger plants have larger volumes requiring disposal;
- the increasing number of plants in a region, which increases salt loading;
- increased discharge regulation, which makes disposal more difficult;
- increased public concern with environmental issues, which affects the permitting process; and
- increased siting of desalination plants in semiarid regions, which may have more limited conventional disposal options.

In some cases, installing evaporation ponds can double the capital cost of a desalination plant. Other factors affecting concentrate management cost may include outfall construction and operation, land, storage and conveyance systems, and concentrate pretreatment before disposal as applicable.

![Figure 1. Simplified ZDD Flow Diagram](image)

**ZDD** takes advantage of the relatively high solubility in sodium and chloride salts. The EDM acts as a kidney to remove troublesome salts (i.e., calcium and sulfate) from NF/RO concentrate. Useful salts, including NaCl for the process, can be recovered from the EDM concentrate.
Methods for dealing with desalination-generated concentrate include discharge to surface waters and wastewater treatment plants; deep well injection; land disposal; evaporation ponds; and zero-liquid discharge (ZLD), which typically includes the use of mechanical/thermal evaporation.

Of these methods, surface disposal is most frequently used, but its implementation is restricted by waste volume and salinity. Land and surface disposal can lead to soil or aquifer contamination from the highly saline concentrate. Consequently, concentrate is usually diluted with secondary wastewater effluent or even potable water before application. At inland locations, surface waters that wouldn’t be significantly impaired by the addition of brine are generally unavailable. Deep well injection is commonly implemented for larger plants, but geological conditions aren’t always appropriate for this solution.

Evaporation ponds are appropriate for desalination plants with small concentrate flows and in arid regions with high evaporation rates. The main drawbacks of evaporation ponds are the large area required and increasing efficiency with pond area, increased risk of groundwater contamination with increased pond area, and expense of double lining to prevent pond leakage.

**HIGH-RECOVERY DESALINATION**

ZLD usually involves additional brine concentration to reduce the concentrate’s volume before using an evaporative method to approach dryness. The removed water can be recycled to the process, increasing the overall recovery. The remaining reduced-volume waste is a dry or semidry solid that should be disposed of properly; if the solids contain hazardous materials, a special landfill is required for waste disposal.

ZLD is usually the least cost-effective concentrate disposal method, because it generally requires multistep, energy-intensive processes such as enhanced concentration, crystallization, and dewatering. ZLD has been most intensively used in the power industry, where waste heat is abundant and regulations severely limit effluent discharge.

ZLD capital costs (i.e., the combination of brine concentrators and crystallizers) of about $15–$50/gal of daily capacity are typical, with unit costs varying with system capacity. Energy consumption ranges from about 60–90 kW•h/kgal for brine concentrators and 180–250 kW•h/kgal for crystallizers.

**ZDD AND CERRO**

More affordable, sustainable methods of high-recovery desalination are needed to minimize salt buildup in surface water or saline aquifers used for injection. Enhanced-recovery desalination approaches such as ZDD and CERRO have been shown to provide substantially higher recovery than brackish water reverse osmosis (BWRO) alone. ZDD was demonstrated at pilot scales in New Mexico, Colorado, Texas, Florida, and California by The University of Texas at El Paso (UTEP) and other researchers. CERRO was evaluated at El Paso Water Utilities’ Kay Bailey Hutchison Desalination plant (KBH) and at the Brackish groundwater National Desalination Research Facility (BGNDRF) in Alamogordo, N.M. These high-recovery techniques produce much more concentrated waste streams, which may eliminate deep well injection and surface water disposal as concentrate management strategies for the liquid residuals.

**Zero Discharge Desalination.** ZDD technology was demonstrated at the Alamogordo facility with a blend of two wells simulating the city’s brackish raw water source, called the “Snake Tank” wells. ZDD is best suited for desalinating brackish groundwater that has high levels of calcium sulfate like the BGNDRF and Snake Tank wells’ groundwater. This is because calcium sulfate will limit desalination recovery to 70–75 percent. Only about 2 percent of the initial volume of brackish water remains in the ZDD concentrate streams.

ZDD produces drinking water and useful salts from brackish water and typically comprises a primary—RO or nanofiltration (NF)—desalination system followed by electrodialysis metathesis (EDM), as shown in Figure 1. This arrangement allows the EDM to remove troublesome constituents such as calcium sulfate and boost the desalination recovery from 75 percent to 98 percent.

The EDM operates similarly to an electrodialysis system in that alternating cation- and anion-exchange membranes comprise the “stack.” The applied voltage is the driving force for ion removal from the EDM feed stream. This voltage causes cations to move toward the cathode and anions toward the anode. Cations are able to pass through the cation-exchange membrane but are blocked by the anion-exchange membrane. Similarly,
Desalination

**Figure 2. Simplified CERRO Diagram**
CERRO takes advantage of the relatively slow kinetics of scale formation. A batch of water is desalinated with all of the concentrate returning to a feed tank. After a period of time, the feed tank is drained and a new batch restarted.

![CERRO Diagram](image)

Anions are able to pass through the anion-exchange membrane but are blocked by the cation-exchange membrane. Conventional electrodialysis systems have a single diluting stream and a single concentrating stream. EDM differs in that it has two diluting streams, EDM feed and NaCl, and two distinct concentrate streams. The cations removed from the EDM feed combine with Cl– ions from the NaCl to produce a concentrate stream of mixed Cl– salts. The anions removed from the EDM feed combine with Na+ ions to produce a concentrate stream of mixed Na salts. Useful (and saleable) by-products such as gypsum, magnesium hydroxide, and sodium chloride (recycled in ZDD) can be recovered from these concentrate streams.

**Concentrate Enhanced Recovery Reverse Osmosis.** CERRO uses batch treatment to achieve high recovery of water from RO concentrates saturated with silica or calcium sulfate. The CERRO process typically uses seawater RO membranes and short cycle times to mitigate silica and other scale formation. Silica scale formation can be irreversible in RO; however, the kinetics are slow. The CERRO process is a semicontinuous batch process in which batch size and run time are designed to take advantage of the slow silica scale formation.

As shown in Figure 2, concentrate is fed to the RO system at constant pressure, and permeate is collected in a second tank, during which the CERRO concentrate is returned to the feed tank until the batch is completed. At this point, the feed tank is drained and refilled with the next batch of concentrate. CERRO was evaluated at the El Paso KBH plant in 2010 and was able to recover 85–95 percent of the concentrate, increasing the overall desalination recovery to at least 97 percent.

Several CERRO configurations were evaluated by UTEP, including the use of a single stage, multiple stages, and various antiscalant dosages and membranes. Recently, El Paso Water Utilities was awarded a WaterSmart Water and Energy Efficiency grant to install CERRO on existing wellhead RO systems.

**Enhanced Evaporation**
The Texas Commission on Environmental Quality has proposed a general permit for evaporation ponds to treat liquid residuals from treatment plants. Once approved and finalized, the process for permitting evaporation basins in Texas will be much quicker (days and weeks versus months).

Although evaporation ponds are a promising and sustainable concentrate management approach, evaluations consistently show these to be largely infeasible because of high land area requirements and associated costs.

Evaporating water into the atmosphere could be a sustainable method for reducing concentrate volume if the land area used for evaporation ponds could be reduced to a cost-effective size. Recent proprietary technology, wind-aided intensified evaporation (WAIV), has the potential to reduce evaporation pond size to one-tenth the size of typical systems using current design methodology.

The technology entails increasing the evaporative capacity per footprint area by closely packing vertically mounted and wetted surfaces and exposing them to the dry winds of the semiarid region. This technique exploits wind energy to maximize water evaporation from the brine using minimal external energy and land area while improving the feasibility of generating mineral by-products and reusing them.

In short, many states are experiencing population growth and droughts. As a result, an increasing number of cities are using brackish water sources in inland areas and considering desalination and direct potable reuse. Research on high-recovery processes such as ZDD and CERRO will continue to play a valuable role in developing more sustainable operations that recover more water and generate less waste.

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