Desal in the West: *Opportunities and Challenges*

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What is the next cost-effective and sustainable source of fresh water? Planners in areas experiencing exponential growth must answer this question while also considering the quality of potential source waters, as water quality determines the treatment technology needed and ultimately the sustainability of the supply. Coastal communities of the United States are looking to the ocean for a drought-proof source of water, while interior regions are focusing increasingly on reclaimed water or brackish groundwater. Ultimately, these new water sources have one thing in common: salt.

As sources of fresh water for potable use are being depleted, water quality also is declining. In surface water sources in the Southwest, total dissolved solids (TDS) have increased, exacerbated by drought conditions (see sidebar below). Groundwater sources previously thought unusable due to salinity levels are now being reconsidered. But ultimately there is a limit to the amount of salinity that can be tolerated before the water must be treated.

Membrane Technology

The technology most often considered for brackish water desalting (for waters with TDS less than 10,000 milligrams per liter [mg/l]) and desalination (for waters with TDS of greater than 10,000 mg/l) is reverse osmosis (RO). RO uses a transport model known as solution-diffusion, whereby each component (water and salts) in a pressurized solution passes over a nonporous, homogeneous, semi-permeable membrane surface layer and then diffuses through to the product side. The flow of water and the flow of salt through the membrane are independent of each other, with water moving more rapidly through the membrane than salt. In a typical application, the process is run as a cross-flow, where the feed flow is pressurized, fresh water permeates across the membrane, and a concentrated salt solution or RO concentrate carries away the salt ions (see figure at right).

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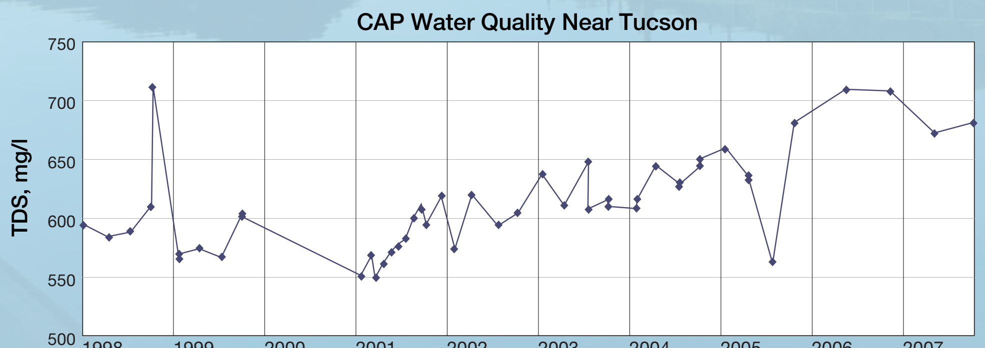
This RO process can produce very low-salinity water. For example, the TDS of RO-treated groundwater in Goodyear, Arizona, typically reduces from 2,000 mg/l to 50 to 100 mg/l.

Reverse osmosis was first commercialized in the late 1960s, with industrial applications beginning in the 1970s. The use of membranes for water reclamation was introduced at the Orange County Water District (OCWD) in 1976. In the 1980s, changes in membrane material from cellulose acetate to polyamide composite nanofiltration (NF) and RO membranes allowed the development of modern low-pressure and high-salt-rejection membranes. These advances have

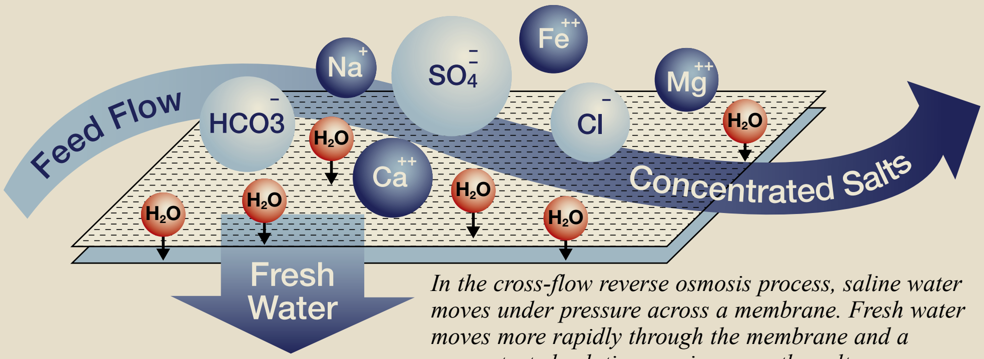
From 1998 to 2007, the total dissolved solids (TDS) concentration in Central Arizona Project water near Tucson increased by approximately 100 milligrams per liter. This translates to 1.1 million pounds more salt imported each year into Arizona.



improved sodium chloride rejection rates for brackish water of less than 2,000 mg/l TDS from about 95 to 98 percent to a current rate of 99.0 to 99.7 percent, at pressures reduced from 300 to 450 pounds per square inch (psi) to 150 to 250 psi.

In the 1990s, membranes for municipal water, wastewater, and water reclamation applications became more prevalent, and RO plant size increased from an average treatment capacity of 1 million gallons per day (mgd) to the 5 to 20 mgd range by the end of the decade. OCWD began planning the design and construction of their now-operational 70-mgd Groundwater Replenishment System, treating wastewater for indirect potable reuse with microfiltration and RO. Until the late 1990s, Florida and California led the nation for the number of brackish water and wastewater applications treated by RO; since that time, other areas of the country have implemented RO on a large scale, as with the 12-mgd Scottsdale Water Campus in Arizona and a 29-mgd facility now operating in El Paso, Texas (see page 28).

Seawater desalination with membranes has gained real acceptance as a viable technology for producing municipal water supplies in the United States in the last five years. The first large-scale municipal desalination facility recently came online in Tampa Bay, Florida. California's 12 planned desalination facilities are projected to supply over eight percent of the state's total water demand by 2020.



In the cross-flow reverse osmosis process, saline water moves under pressure across a membrane. Fresh water moves more rapidly through the membrane and a concentrated solution carries away the salt.

The Energy Cost of Desalination

The cost of desalination is high compared to other water supply and treatment approaches due to higher energy consumption and operations and maintenance costs. Historically, cost has impeded the use of desalination, but recent technological advancements such as high-efficiency pumps, energy-recovery devices, and higher-productivity membranes are now making desalination more viable.

The table below left compares power consumption for treating various waters. For California, the energy cost of importing and treating water is not much less than the cost of seawater desalination, and the latter option gives population centers more control of their water source. However, as energy costs continue to rise, desalination of both brackish water and seawater will always have a higher cost because it is the most energy-intensive. For example, the absolute minimum potential energy for treating seawater desalination of Pacific Ocean water is considered to be in the range of 6 to 7 kilowatt-hours per 1,000 gallons.

Waste Stream Challenges

The most notable challenge for RO technology is coping with the waste stream or concentrate generated by the process. As water is removed, the salts are concentrated and eventually discharged from the treatment process. For typical brackish water applications, 75 to 85 percent of the water is recovered and the remaining water is discharged as a concentrated waste stream. This waste stream translates directly into lost water, but also is the most costly stream to treat as a percentage of the overall project. Municipal agencies must balance the loss of resource against treatment costs. In many brackish water RO projects, concentrate waste streams have a TDS of less than 10,000 mg/l. This is still considered a viable water to treat, yet constituents such as barium sulfate or silica may be present in the water in concentrations above saturation, prohibiting higher recovery. Cities such as Phoenix and Tucson that are just beginning to consider desalination are investigating ways to treat the raw water or concentrate to allow for higher water recovery and more concentrated waste streams, with reduced disposal volume.

The six major discharge options for concentrate waste streams are shown in the table below, along with their comparative prevalence based on the number of facilities in the United States.

It is clear from the high percentage of facilities that discharge to sewer or to surface waters that these alternatives are the most cost-effective, especially when impacts to wastewater treatment plants and infrastructure are not considered. As discharge options are reduced

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Water Supply	Process Energy Consumption kWh/1,000 gallons (kWh/acre-feet)
Local surface water	0.6 to 1.25 (195 to 407)
Colorado River water delivered to AZ customers (untreated)	1.23 to 1.57 (400 to 500)
Colorado River water delivered to CA customers (untreated)	9.2 to 10.7 (3,000 to 3,500)
Water reclamation	2.0 to 4.5 (650 to 1,467)
Brackish water desalination	2.6 to 4.6 (850 – 1,500)
Desalination of Pacific Ocean (without delivery power)	10 to 12 (3,200 to 4,000)

Energy consumption based on water supply

Concentrate Disposal Option	Disposal in U.S. (%)
Discharge to surface water	45
Discharge to sewer	42
Deep well injection	9
Evaporation ponds	2
Spray irrigation	2
Zero liquid discharge	<1

Concentrate disposal options

Photo: Central Arizona Project

Deep Well Injection, continued from page 29

Well Construction and Testing

The second and third injection wells were constructed in late 2006 and early 2007, and completed to Class I standards. The wells are 3,720 feet and 4,030 feet deep, and include 8.5-inch-diameter open-hole completions in the injection zone (below 2,900 feet). During test pumping of each of the wells, drawdown data were collected in the two non-pumping wells to provide estimates of aquifer transmissivity; these data were used to update the subsurface geologic model. Based on the results of the testing program, it was concluded that any two of the wells could be used to inject 3 mgd of concentrate. Initial operational plans, therefore, included developing a rotational schedule to operate two wells over an 8-hour period. Thus, each well would be operational for 16 hours and at rest for 8 hours.

At the completion of testing, each well was video-logged to assess the nature and size of the fractures in the injection zone. Numerous fractures over the entire thickness of the injection zone were observed, many of which were nearly an inch wide. The number and size of the fractures, coupled with the open-hole completion, reduced concerns regarding the potential for mineral precipitation.

As part of the overall project, surface facilities (tanks, pipes, valves, communications systems) were constructed at each injection well site. The sites are remote with no commercial power readily available; an evaluation determined that their modest power requirements (about 7.5 kilowatt-hours per day) could best be met by a solar power system with propane generator backup.

Testing of the wells began in May 2007 and initially involved injecting fresh Hueco Bolson groundwater in order to develop baseline well-performance data without concern of mineral precipitation. At the beginning of plant operations, the concentrate was diluted, but dilution was gradually reduced and finally eliminated, with no observable change in well performance related to injection rate and groundwater level buildup. During these tests, the concentrate received no pH adjustment. Although the tests were short-term and the initial operation has been only a few months, it appears that mineral precipitation is not significant with respect to well performance. Monitoring efforts during operation include continuous recording of injection rate and depth to groundwater in each well and monthly water quality analyses of the injected concentrate.

Costs

Overall desalination construction costs were about $91 million. Of that, concentrate disposal was about $19 million, including construction of the pipeline, surface facilities, and wells. Annual operating costs for the entire project are projected to be $4.8 million, of which $200,000 is expected for concentrate disposal. Assuming 80 percent operation at capacity, produced water costs are expected to be about $534 per acre-foot, of which $49 per acre-foot is related to concentrate disposal.

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by regulatory constraints, available space, environmental impacts, or other limitations, the cost of the disposal increases dramatically as technology is added to treat the waste stream.

Some technologies, such as Turbomisters, Wind Aided Intensified Evaporation (WAIV), and Solar Bees augment evaporation and reduce land area requirements, but the water is not recovered and costs for energy, equipment, and maintenance are higher. Even more advanced are Zero Liquid Discharge (ZLD) technologies which use both thermal and nonthermal processes to recover more of the water, leaving a solid waste for disposal.

Research is being conducted on intermediate chemical treatment (lime precipitation and ion exchange) to allow for further membrane treatment and water recovery with seawater RO or vibratory shear enhanced processing (V-SEP). Beyond the membrane alternatives are the most expensive thermal evaporation and crystallization processes.

The ZLD alternative is used least, as it has the greatest energy and operating costs. Yet these alternatives allow for the best option for recovering lost water resources and have the greatest potential for innovative treatment solutions. A significant amount of research is being conducted in this area in Arizona, El Paso, and other regions facing similar water shortage and disposal challenges.

Looking Ahead

As communities struggle to find new economically viable and sustainable sources of fresh water, they will face the inevitable question, "How do we remove the salt?" The answer will rely on technologies such as reverse osmosis. RO can remove impurities from the water and, as history has proved, will continue to become more efficient. Recent advances in large-diameter technologies and membrane chemistry will lower capital costs for facilities, leading to improved water quality at lower cost. A complete answer must also address the concentrated waste streams generated by the process, especially for inland facilities. Significant opportunities exist for research and development of innovative and cost-effective approaches to treatment and waste handling.

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Resources

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