Desalination

Photo caption. Desalination plant.

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Chapter 9. Desalination

Desalination comprises various water treatment processes for the removal of salt from water for beneficial use. Desalination is used to treat seawater as well as brackish water (water with a salinity that exceeds normally acceptable standards for municipal, domestic, and irrigation uses, but less than that of seawater). Desalination technologies are also used to treat polluted and impaired waters and as an advanced treatment of wastewater to produce high quality recycled water. In California, the principal method for desalination is reverse osmosis (RO). This process can be used to remove salt as well as specific contaminants in water such as trihalomethane precursors, volatile organic carbons, nitrates and pathogens.

Only desalination for municipal purposes, that is, desalination used by public and private water agencies, is considered in the following discussion. Desalination used within an industrial and commercial manufacturing process is not considered since those applications of desalting generally involve treating fresh water to a higher standard than potable water to meet a specific need. For the purposes of this chapter, desalination plant capacity is expressed in terms of the fresh or potable water production capacity of the plant. Total costs are given in dollars per acre-foot of fresh potable water produced.

Desalination in California

Desalination began in California in 1965. The past ten years has seen a rapid rise in installed capacity. This is primarily due to dramatic improvements in membrane technology and the increasing cost of conventional water supply delivery. As of 2009, there were 26 desalting plants operating in California that provide water for urban use. The total capacity of these plants is approximately 84,000 acre-feet per year (AFY). These include 20 groundwater and six seawater desalination plants.

The California Legislature has recognized the future importance of seawater and brackish water desalination through legislation. In 2002, the Legislature approved Assembly Bill (AB) 2717, which asked the Department of Water Resources (DWR) to convene the California Water Desalination Task Force (Task Force) to look into potential opportunities and impediments for using seawater and brackish water desalination, and to examine what role, if any, the State should play in furthering the use of desalination technology.

The Task Force completed its mission after about six months of deliberations and in October 2003 DWR submitted a final report to the Legislature as required by the legislation. The report containing the Task Force findings and recommendations was prepared with significant input from its membership of twenty-seven organizations. It also draws upon the experience of many agencies, experts, and different stakeholders, and provides advice and guidance to those planning desalination plants (DWR, 2003).

"Include desalination, where economically and environmentally appropriate, as an element of a balanced water supply portfolio, which also includes conservation and water recycling to the maximum extent practicable."

From: Water desalination - findings and recommendations *(DWR, 2003). General recommendation # 2, p. 7*

Box 9-1 Acronyms and Abbreviations

AB	California State Assembly bill
AF	acre-foot
AFY	acre-feet per year
Cal Am	California American Water Co.
CO_2 eq	carbon dioxide equivalents
CPUC	California Public Utilities Commission
CWA	federal Clean Water Act
DWR	Department of Water Resources
EIR	environmental impact review
GHG	greenhouse gas
IRWM	integrated regional water management
kWh/AF	kilowatt hours per acre-foot
mgd	million-gallon-per-day
mw	megawatt
MWD	Metropolitan Water District of Southern California
NPDES	National Pollutant Discharge Elimination System
Prop.	ballot proposition
RFP	Request for Proposal
RO	reverse osmosis
SDP	Seawater Desalination Program
SWP	State Water Project
State Water Board	State Water Resources Control Board
SWRO	seawater reverse osmosis
Task Force	California Water Desalination Task Force
TDS	total dissolved solids

Drawing on the work of the California Water Desalination Task Force, and within the framework of providing assistance to California agencies pursuing desalination, DWR developed a California Desalination Planning Handbook in 2008, in collaboration with the California State University, Sacramento Center for Collaborative Policy (DWR, 2008). This handbook is an important resource for project proponents and communities. It provides a planning framework for developing, where appropriate, economically and environmentally acceptable desalination facilities in California. The planning process outlined in the handbook is intended to identify and address siting, regulatory, technical, environmental and other issues, which should be considered in determining whether and how to proceed with a desalination project.

In November 2002, California voters passed Prop. 50, the Water Security, Clean Drinking Water, Coastal and Beach Protection Act of 2002. Chapter 6(a) of that proposition authorized $50 million in grants for brackish water and ocean water desalting projects. The grant program aimed to assist local public agencies with the

development of new local potable water supplies through the construction of feasible brackish water and ocean water desalination projects and advancement of water desalination technology and its use by means of feasibility studies, research and development, and pilot and demonstration projects. Two cycles of funding under this grant program were conducted during 2005 and 2006, competitively awarding the available desalination grants to 48 projects including 7 construction projects, 14 research and development projects, 15 pilots and demonstrations, and 12 feasibility studies.

Other California legislation emphasizing the importance of water desalination included AB 314 (2003), which declared that it is the policy of the State that desalination projects developed by or for public water entities be given the same opportunities for State assistance and funding as other water supply and reliability projects.

Groundwater desalting plants are generally designed to reclaim groundwater of impaired use and are located in urban areas from the San Francisco Bay Area to San Diego. While these plants are generally less than 5 millions of gallons per day (mgd) (5,600 AFY) in capacity, several plants are projected to increase in size to 15-20 mgd (16,800-22,400 AFY). Currently there are seven new groundwater desalting plants and nine plant expansions in the design and construction phase or the planned and projected phase, for a total of about 88,000 AFY in new capacity.

The operational seawater desalination plants in California total about 1.7 mgd (1,900 AFY) in capacity. There are three seawater desalting plants (Sand City, Ocean View Plaza and Carlsbad) with a combined capacity of about 51,000 AFY in the design and construction phase at this time. An additional 13 plants with a combined capacity of 257,000 AFY of capacity are in various stages of planning. Several seawater desalting pilot plants have begun operation, have completed operation or are being designed as part of desalting feasibility studies.

Several regional plans contemplate desalination as an integral component of the water resources portfolio along with water recycling and increased water use efficiency. Moreover, as a resource management strategy, desalination must be evaluated by the integrated regional water management (IRWM) planning region as a method to meet their water resource management goals and objectives of the region. In an IRWM region where desalination has been determined to be an active strategy within its water resource management portfolio (to further the goals of the plan), opportunities for funding for desalination projects may be available through IRWM grants.

From San Francisco Bay to San Diego, there are numerous studies investigating the feasibility of desalting seawater:

- **Northern California.** In the San Francisco Bay Area, agencies are jointly funding planning studies for one or more desalination plants with a maximum capacity of approximately 71,000 AFY. Following completion of the initial feasibility studies, a pilot study was conducted in eastern Contra Costa County near Pittsburg, California. In Marin County, the Marin Municipal Water District is studying the

feasibility of constructing a 16,800 AFY seawater plant. Pilot plant operations have been completed to determine pretreatment and operating parameters for a full scale plant.

- **Central California.** In the Monterey Bay area, the State Water Resources Control Board (State Water Board) has mandated a 10,730 AFY reduction in groundwater pumping from beneath the Carmel River. To replace this water and provide for water needs outside of the Monterey Peninsula, there are several competing proposals to construct regional seawater desalination facilities. Both of the proposals are for plants of about 22,400 AFY in capacity. Pilot testing by California American Water Co. (Cal Am) at Moss Landing is ongoing and a final environmental impact review (EIR) has been released for consideration by the California Public Utilities Commission (CPUC).
- **The City of Santa Cruz and the Soquel Creek Water District** have completed operation of a pilot plant and are now evaluating results to determine the feasibility of a 2.5 to 5.0 million-gallon-per-day (mgd) seawater plant to be shared by the two agencies.
- **Southern California.** In November 2001 the Metropolitan Water District of Southern California (MWD) issued a Request for Proposal (RFP) under its Seawater Desalination Program (SDP). The objective was 150,000 AFY of sustained production. Through a competitive process, selected projects will be eligible for financial assistance up to $250 per acre-foot. Currently, five projects are under consideration that, if constructed, could produce about 166,000 AFY. The status of these five projects is shown below. In addition, other projects outside of the SDP are also being considered (e.g., the San Diego County Water Authority is investigating the feasibility of a 56,000 AFY (that could be expanded to 168,000 AFY) seawater desalting facility at Camp Pendleton.
    - **Carlsbad.** A 50 mgd plant located adjacent to the Encina Power Station is under construction by Poseidon Resources. All of the required permits have been approved. The production capacity of the plant is fully subscribed.
    - **Huntington Beach.** A 50 mgd plant located adjacent to the AES power plant is planned for construction by Poseidon Resources. The EIR certified by city which has approved a Condition Use Permit. A Coastal Development Permit has been approved by the City and is pending before the Coastal Commission. An National Pollutant Discharge Elimination System (NPDES) permit has been received from the Regional Water Quality Control Board and the California Department of Public Health has given conceptual approval of a Drinking Water Permit. Additional permits are in process.
    - **Dana Point.** A 20 mgd plant is proposed by the Municipal Water District of Orange County. A feasibility study is underway that includes testing a seawater well intake and a possible seawater reverse osmosis (SWRO) pilot test project.
    - **Long Beach.** A 9 mgd plant is proposed to use a unique two-staged nanofiltration membrane process design. Pilot testing has been underway since 2001 and alternative intake and discharge methods are being studied with a Prop. 50 grant.

- **West Basin.** A 20 mgd plant is proposed by West Basin MWD. Pilot testing has been underway since 2002. A 0.1 mgd demonstration plant using, in part, a Prop. 50 grant has completed the permitting process.

Potential Benefits of Desalination

In times of water scarcity and an ever-growing demand for fresh water due to population growth, and given current climate trends, water resources will become even more unevenly distributed as water-scarce regions experience more frequent and prolonged droughts. Desalination can be a reliable water supply alternative and a part of the solution for meeting current and future water needs. Conventional water sources are often limited by overdraft, depletion, pollution, and environmental requirements. Furthermore, traditional water supply management methods such as surface water storage, groundwater extraction, and inter-basin water transfer may not be sufficient to meet increasing water demand.

Desalination, when adopted as part of a diversified water supply portfolio, can offer several benefits including:

- Increase in water supply
- Reclamation and beneficial use of impaired waters
- Increased water supply reliability during drought periods
- Decreased need for imported water by developing a local supply source
- Diversification and increased reliability and operational flexibility of water supply sources
- Improved potable water quality
- Protection of public health
- Facilitate more recycling and reuse, given the lower salinity of the source

The primary benefit of desalting is to increase California's water supply. Seawater desalting creates a new water supply by tapping the significant supply of feedwater from the Pacific Ocean. In addition to seawater desalting, desalination technologies can be used to produce potable water from brackish waters and impaired waters. Many surface and groundwater sources are brackish—having high salinity levels—which can be naturally occurring due to the soil type and aquifer lithology or induced by man-made activities such as farming and overdraft of coastal aquifers causing seawater intrusion. Desalination was also proven to treat to very high levels of purity other water that may have low salinity but is impaired by high levels of specific contaminants such as nitrate. Accordingly, desalination in water resources planning is a unique tool serving both water supply augmentation and water quality improvement strategies.

Table 9-1 shows the number and capacity of groundwater and seawater desalting plants in operation, design and construction, and planned or projected for construction as of 2008. While not all of these are likely to be constructed, it is assumed that they, or an equivalent number, will be operational by 2025.

Table 9-1 Desalting in California for new water supply

Feedwater Source	Plants in operation		Plants in design and construction[2]		Plants planned[3] or projected[4]	
	No. of plants	Annual capacity[1]	No. of plants	Annual capacity[1]	No. of plants	Annual capacity[1]
Groundwater	20	82,200	4	30,000	3	57,300
Seawater	6	1,700	3	50,800	13	257,000
Total	26	83,900	7	80,800	16	314,300
Cumulative			33	164,700	49	479,000

1. Capacity in AFY, assuming 10% downtime. No. of Plants is the number of new plants. Capacity includes existing plant expansions.

2. Design & Construction—Construction underway or preparation of plans and specifications has begun for new plants or plant expansions.

3. Planned—Planning studies underway for new plants or plant expansions.

4. Projected—Projected new plants or plant expansions.

Sources: Water desalination - findings and recommendations (DWR, 2003), news reports, technical papers, Prop. 50 grant submissions, and Worldwide Desalting Plants Inventory series by the International Desalination Association (Global Water Intelligence, 2006).

Desalting groundwater allows groundwater of impaired quality to be adequately treated for potable use. Approximately 88,000 AFY of additional capacity is under construction or planned. Groundwater desalting may or may not be a new water supply depending upon the water portfolio or balance in the area or region where it occurs. It is, however, providing water from a source that is not currently being used for beneficial purposes.

Desalination can serve as an emergency water supply option. Desalinated water produced by mobile water desalination units can provide emergency potable water supply for towns and communities during droughts or in response to an abrupt disruption of their water supplies. Mobile water desalination units are water treatment units—generally, Reverse Osmosis mobile desalination units—that can be truck-mounted or air-lifted, enabling the provision of short-term emergency water supply as well as supplemental supply for drought-stricken or disaster areas. These units can provide a flexible solution to water shortages as they can be quickly and easily deployed. Unlike permanent desalination plants, temporary mobile units can be commissioned, installed and put into production in a short period of time. They can also be quickly and easily decommissioned or moved to other locations should emergency or drought conditions ease. Please see the Mobile Desalination Units article in the Volume 4 Reference Guide under the Drought topic.

Potential Costs of Desalination

Technological advances in desalination have in the last 20+ years significantly reduced the cost of desalinated water to levels that are comparable, and in some instances competitive, with other alternatives for acquiring new water supplies. Prop. 50 grant

funding cycles in 2005 and again in 2006 are funding a number of research and development programs directly related to desalting in California. Membrane technologies in the form of reverse osmosis (RO) have the most significant improvement. Continuing improvements in system design, membrane technology and energy efficiency and recovery have helped increase efficiency and reduce costs and energy demand. The RO process has been proven to produce high quality drinking water throughout the world for decades.

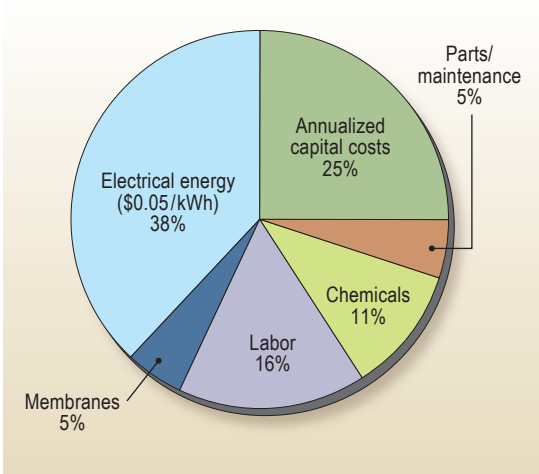
The estimated capital cost to achieve about 300,000 AFY in increased seawater desalting capacity is about $1.5-$2.0 billion. Table 9-2 shows the range in total unit water cost that can be expected from plants desalting groundwater (or brackish), wastewater, and seawater. These costs are based on the expected lifetime of the plant (20-30 years).

The cost of desalination depends on numerous factors that are often project-specific. A cost breakdown for a typical seawater RO desalination plant is shown in Figure 9-1. When planning desalination projects, it is important that cost estimates take into account the costs of concentrate management and intake systems, including environmental and permitting costs in addition to process costs (i.e., costs of pre-treatment, post-treatment, and main desalting process).

Table 9-2 Total unit water costs of desalting

Type of desalting plant	Total water cost ($ per acre-foot)
Groundwater	$500-900
Wastewater	$500-2,000
Seawater	$1,000-2,500

Figure 9-1 Cost breakdown for seawater reverse osmosis desalination



Assumes a 20-year capital payback period, a plant capacity of 25 mgd, a nominal interest rate of 6%, and an electricity rate of $0.05/kWh

Major Issues Facing Desalination

Desalination has historically been prohibitively expensive. Improvements in technology and the rising cost of conventional water supplies have made desalination competitive with imported water and recycled municipal wastewater in a number of cases. As a result of the improved economics of desalination, other issues have increased in relative importance to cost, namely, environmental impacts and associated permitting (particularly for coastal plants).

Cost and Affordability. The cost will be influenced by the type of feedwater, the available concentrate disposal options, the proximity to distribution systems, and the availability and cost of power. The higher costs of desalting may, in some cases, be offset by the benefits of increased water supply reliability and/or the environmental benefits from substituting desalination for a water supply with higher environmental costs (e.g. Carmel River, Monterey Bay area). When comparing the cost and impacts of desalination as a water supply option, it is important to compare it to the development of other new water supply options.

Environmental Impact and Permitting. Brackish water desalination plants have fairly routine environmental and permitting requirements with the exception of the problematic issue of concentrate disposal in inland locations. Coastal desalination plants face much greater scrutiny. With a location within the coastal zone, and with the need for water intakes and outfalls, there are many reviewing agencies, organizations, and permitting requirements.

Seawater Intakes. A primary concern associated with coastal desalination plants is the impact of feed water intake on aquatic life. Surface intakes of seawater result in impingement and entrainment of marine organisms. This impact can be avoided by adopting subterranean intakes (e.g., beach wells and under ocean bed intakes) wherever feasible. Existing seawater intakes for power plant cooling have been approved or are proposed as the source of supply for several of the currently proposed plants. Other projects are currently studying or testing alternative seawater intake designs. It is worth noting here that the State Water Board is in the process of developing a statewide Water Quality Control Policy based on federal Clean Water Act (CWA) Section 316(b) regulations related to the use of coastal and estuarine waters for power plant cooling. However, given that desalination plants co-located with power plants typically draw water off of the system after thermal exchange, the State Water Board's released scoping documents consider that the subject is outside of the scope of CWA section 316(b) and would be more appropriately addressed under existing water quality control plans and policies. A stand-alone desalination facility will be required to apply for an NPDES permit to discharge waste brine.

Carbon Footprint. Given the energy intensity of advanced water treatment processes used to separate salts from water, energy consumption represents a major portion of the direct operation and maintenance expenses of a desalination plant. Energy efficiency will therefore be a key factor in assessing the viability of using desalination as a water supply option in California. Furthermore, efforts to reduce desalination energy use will significantly contribute toward the reduction of greenhouse gas (GHG) emissions from the many proposed desalination projects in California.

The carbon footprint of a desalination plant is mainly a translation of its energy consumption. The associated GHG emissions will be measured by the indirect CO2 emissions from the electricity used by the plant. In instances where desalinated water is displacing other water supplies currently in use with their own GHG emissions (e.g., imported water), the net carbon footprint of desalination should be counted as the incremental GHG emissions beyond the current emissions baseline.

The average energy consumption of currently operational RO desalination facilities is estimated at about 1,800 kilowatt hours per acre-foot (kWh/AF) for brackish water and about 4,000 kWh/AF for seawater desalination. Using a conservative estimate of GHG emissions of 400 grams of carbon dioxide equivalents (CO2 eq) per kWh (assuming electricity is generated from natural gas, this number climbs up to 900 grams of CO2 eq /kWh for electricity generated from coal), the GHG emissions associated with an

RO desalination plant operations are estimated to be 720 kilograms of CO2 eq /AF of desalinated brackish water and 1,600 kilograms of CO2 eq /AF of desalinated seawater.

Measures to help reduce the carbon footprint of desalination plants include efficiencies through energy recovery devices, high efficiency pumps, variable frequency drives, low-energy with improved salt rejection membranes, the use of renewable energy sources, and carbon offset plans. A recent demonstration led by the non-profit Affordable Desalination Collaboration (a consortium of industry-leading companies, municipal and government agencies) showed that by using state-of-the-art energy recovery technology and high efficiency pumps and membranes, the energy required for seawater desalination can be substantially reduced to the range of 2,000—2,500 kWh/AF.

Growth-inducing Impacts. The availability of water has been a substantial limitation on development in a number of locations, primarily coastal communities. Since seawater desalination on the coast is now a more affordable option in comparison to the past, the lack of water may no longer be as strong a constraint on coastal development. However, such a concern is not restricted to desalination and would also be associated with any other new water supply option.

Concentrate Discharge. Desalination plants of any type produce a salt concentrate that must be discharged. The quantity and salinity of that discharge varies with the type of desalting plant and its operation. Brackish water plants in California discharge their concentrate to municipal wastewater treatment systems where they are treated and blended with effluent prior to discharge. For brackish water plants, this type of discharge is likely to continue. Inland desalting plants without a discharge to the ocean may be limited by the type of discharge options available. Seawater desalination produces a concentrate approximately twice as salty as seawater. In addition, residuals of other treatment chemicals may also be in the concentrate. Some plants currently being planned will use existing power plant or wastewater plant outfall systems to take advantage of dilution and mixing prior to discharge. The availability of power plant cooling systems to dilute the concentrate prior to discharge to the ocean will also be affected by the future of coastal power plants as discussed in the prior section. On the other hand, co-locating concentrate discharge with wastewater effluent outfall might have some environmental benefits to the extent that the concentrate from the desalination plant would increase the salinity of the wastewater effluent to levels that are comparable or closer to that of seawater.

Energy Use. Desalination's primary operation cost is for power. A 50 mgd seawater plant (approximately 50,000 AFY, assuming operating 90% of the time) would require about 33 megawatts (MW) of power. Forecasted seawater desalination of about 300,000 AFY would require about 198 MW of power. The reduction in unit energy use has been among the most dramatic improvements in recent years due to improvement in energy recovery systems. Additional improvements in energy use are expected.

Generally, the variance in energy requirements of RO desalination is a direct function of the salinity of the feedwater source (total dissolved solids (TDS)). As a result, given

similar operating conditions and plant parameters, brackish water desalination is usually less energy intensive, and hence less costly, than seawater desalination.

Even though desalination is energy intensive, other conventional water supply options might in some instances be as energy intensive. At a given point of use, energy intensity of a water supply is the total amount of energy required for its extraction, treatment and conveyance. Energy required for pumping and transporting water over long distances may be higher than that needed to desalinate local saline waters. Delivering State Water Project (SWP) water to Southern California requires a significant amount of energy to convey and to pump over the Tehachapi Mountains. Due to continuing reductions in energy use, the energy needed at the end of the SWP pipe reaches levels that in some instances become, comparable to the amount of energy needed to desalinate seawater.

Recommendations to Facilitate Desalination in California

1. Desalination should be considered, where economically and environmentally appropriate, as an element of a balanced water supply portfolio, which also includes conservation and water recycling to the maximum extent practicable.

2. Desalination projects developed by or for public water entities should be given the same opportunities for State assistance and funding as other water supply and reliability projects.

3. Where appropriate, desalination must be considered by an integrated regional water management planning region in developing a strategy to meet the water resource management goals and objectives of the region.

4. Ensure adequate funding to further develop emerging technologies to advance and refine desalination processes, feedwater intake and concentrate management technologies, energy efficiencies, and the use of alternative and renewable energies.

5. Provide technical assistance and funding, when available, to local agencies exploring desalination to help with the implementation of their desalination programs.

6. Provide guidance on permitting requirements to help agencies pursuing desalination overcome the complex regulatory processes. There is a need for a State clearinghouse to serve as an information source and facilitator for desalination projects, particularly for seawater desalination.

7. Project sponsors should ensure adequate planning to include a collaborative process which engages key stakeholders and the general public, as well as permitting agencies.

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