Desalination (Brackish and Sea Water)

A Resource Management Strategy of the California Water Plan

California Department of Water Resources

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Acronyms and Abbreviations

µm	micrometer
µmhos/cm	micromhos per centimeter
µS/cm	microsiemens per centimeter
af	acre-feet
af/yr.	acre-feet per year
BARDP	Bay Area Regional Desalination Project
$CaCO_3$	calcium carbonate
CCC	California Coastal Commission
CDPH	California Department of Public Health
CEQA	California Environmental Quality Act
CESA	California Endangered Species Act
CO_2 e	carbon dioxide equivalent
CWA	federal Clean Water Act
CWP	California Water Plan
Desal RMS	Desalination Resource Management Strategy
DFW	California Department of Fish and Wildlife
DWSAP	Drinking Water Source Assessment and Protection Program
EC	electrical conductivity
ED	electrodialysis
EDR	electrodialysis reversal
EPA	U.S. Environmental Protection Agency
ESA	federal Endangered Species Act
FO	forward osmosis
GHG	greenhouse gas
IRWM	integrated regional water management
ISO	California Independent System Operator
kj/kg	kilojoule per kilogram
kWh	kilowatt hour
kWh/af	kilowatt hour per acre-foot
MED	Multi Effect Distillation
mg/L	milligrams per liter
mgd	million gallons per day

MMWD	Marin Municipal Water District
MSF	Multi-Stage Flash evaporation
MUN	municipal
MWh	megawatt hour
NaCl	sodium chloride
NFN	nanofiltration
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
Porter-Cologne Act	Porter-Cologne Water Quality Control Act
Poseidon	Poseidon Water
ppm	parts per million
ppt	parts per thousand
PSU	practical salinity unit
RO	reverse osmosis
RWQCB	regional water quality control board
SARI	Santa Ana Regional Interceptor
SDWA	federal Safe Drinking Water Act
TDS	total dissolved solids
UF	ultrafiltration membranes
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service
UWMP	urban water management plans
VC	vapor compression
WDR	Waste Discharge Requirements

Desalination (Brackish and Sea Water)

Desalination, the removal of salts from saline waters, is one of the few options available to augment California's water supply. California has facilities that desalinate sea water for coastal communities and brackish groundwater for inland water users — many of which have provided high-quality water to their customers for more than 10 years. As water supplies in California become more constrained, many water suppliers with nearby saline water sources are evaluating desalination as a way to provide reliable supply in response to uncertainties relating to future drought and climate change. While desalination is not a viable method for many water suppliers in the state, some not yet engaged in the process could realize significant supply and reliability benefits — even though desalination of both sea water and brackish groundwater comes with financial and environmental challenges. For water suppliers with desalination opportunities, how they implement environmentally sustainable projects is a key issue facing multiple California communities.

Introduction

This resource management strategy report presents the desalination resource management strategy (Desal RMS), which addresses key seawater and groundwater desalination issues and challenges. The resource management strategy report also provides a framework for how California communities and water users can move forward with brackish water and seawater desalination. The Desal RMS:

- Presents water desalination concepts and issues.
- Identifies where desalination is currently occurring and is being considered in California.
- Addresses issues related to a balanced approach to how desalination could support water sustainability in the state.
- Identifies recommendations for water suppliers and agencies to consider when evaluating desalination opportunities.

This resource management strategy report focuses on presenting a strategy for sustainable desalting of surface and subsurface waters of the state for the principal purpose of meeting municipal drinking water demands. It discusses desalination technology, as well as the legal and institutional framework to consider when planning and implementing projects. In addition to other issues, the Desal RMS addresses two special challenges for desalination: costs and environmental impact from water intakes and brine management. Desalinating water for uses other than community water supply, such as large-scale agricultural, industrial, and mining activities, is not addressed in detail in this resource management strategy report but may be discussed briefly within the overall context of desalination technology or implementation of the practice.

Sustainability is a common theme of the California Water Plan (CWP) and an objective in the planning and management of water desalination. As the term is used in this plan, water sustainability is the dynamic state of water use and supply that meets today's needs without compromising the long-term capacity of the natural and human aspects of the water to meet the needs of future generations.

Because of the complexity of desalination and the various ways desalination technologies are implemented in California, the Desal RMS presents brief summaries of key issues. Additional detail about desalination is presented in *California Water Plan Update 2013*, Volume 4, *Reference Guide*.

Salt and Salinity

Many details about water chemistry, drinking water regulations, and the interactions among water bodies are beyond the scope of this resource management strategy report but play a significant role in setting State and regional water quality and supply objectives and implementing a desalination strategy. Basic concepts and terms regarding salts and salinity of water are discussed below.

Salts occur naturally in the environment, but human activity often increases salinity in water and soil. Because of the negative impacts of salinity on human use or the water environment, salinity management is a critical resource management strategy. See the resource management strategy report, *Salt and Salinity Management*, for additional information on this issue.

Definition of Desalination

Desalination is the removal of salts from water to produce a water of lesser salinity than the source water. Other terms that are interchangeable with desalination include seawater or saline water conversion, desalting, demineralization, and desalinization. For consistency, “desalination” will be used in this resource management strategy report.

Desalination can be used to reduce salinity in many sources of water. The term source water is used to identify the body of water from which water is taken for beneficial purposes. Source water for desalination can include surface water, groundwater, and municipal wastewater. Desalinated water can be used for potable uses, such as municipal drinking water, or non-potable applications, such as agricultural irrigation or industrial processes. The focus of this resource management strategy report is on desalination of surface water or groundwater for potable uses.

Description of Salts and Their Origin

The presence of certain impurities (e.g., minerals, elements, and chemical compounds) in water, especially at higher concentrations, can affect the aesthetics and use of water. For example:

- Halite, the mineral commonly known as table salt or sodium chloride ($NaCl$), readily dissolves in water into ionic forms and is found objectionable to human taste even at low levels.
- Sodium (Na) can affect soil properties and thus damage crops.
- Calcium carbonate (the chemical compound $CaCO_3$) deposits on household fixtures and industrial equipment, causing damage or increasing maintenance.

When solid substances mix with water or other liquids, they may separate (dissolve) into two parts called ions, one with a positive charge (such as sodium or calcium) and one with a negative charge (such as chloride or bicarbonate). This form of a dissolved solid is termed an ionic substance. The majority of dissolved solids in raw and finished municipal water supply sources, fresh or saline, are ionic inorganic substances, such as calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, chloride, bromide, and nitrate. These dissolved ionic elements or compounds are known collectively as “salt.”

The principal source of salt in the oceans and brackish waters is from the land. The salts are leached out a bit at a time as water flows over and through the land during each hydrological cycle. Over the millennia, the oceans, seas, and other saline bodies of water have become salty through the interaction of fresh water with rocks containing minerals, such as the sodium chloride compound. After water evaporates from the surface of a saline water body, the salt is left behind, further increasing the salinity. The oceans have developed a noticeably salty taste. The ocean and some inland low-lying bodies of water without drainage accumulate salts, and thus are called “salt sinks.” Salt sinks have traditionally not been used for municipal water supplies in California.

Salinity Measurements

The saltiness of water is referred to as its salinity. *Salinity* is generally defined as the amount of salt dissolved in a given unit volume of water. It is variously measured in units of electrical conductivity (EC), total dissolved solids (TDS), practical salinity units (PSU), or other units depending on the scientific discipline of the person doing the measuring and the purpose of the study or monitoring program.

The unit of measure most often used for TDS is milligrams per liter, or mg/L. Since one liter of pure water weighs one million milligrams at a referenced temperature, TDS is expressed as parts per million (ppm); parts per thousand (ppt); as well as the percentage of salinity. The generally accepted value for salinity of open sea water is a TDS of 35,000 milligrams per liter (mg/L) or ppm, also expressed as 35 ppt TDS or 3.5 percent salinity (3.5 percent salt). TDS is one of the bases for federal and State standards for how much dissolved material is in a water supply.

While TDS is often the measurement of salinity, it should be understood that the TDS measurement includes other dissolved chemicals besides salts, including such metals as copper and iron and such elements as boron. Also, sodium chloride is often the most common salt with the highest concentration in water and is most frequently equated with salinity. However, many other dissolved salts in ionic form are found in natural waters.

There are a number of ways to measure saltiness in water or soil, each having its role in various sciences (e.g., oceanography, hydrology, geology). The most frequently applied metrics are shown in Table 1.

Degrees of Salinity

There is no fixed delineation between “fresh” and “brackish” water; for this resource management strategy report, a TDS concentration value of 1000 mg/L, or 0.1 percent salinity, is used as the dividing line, which is consistent with many references.

The term *brackish* generally refers to water that has more salinity than fresh water but less than sea water. There also is no rigid delineation between brackish water and sea water; however, 30,000 mg/L, or 3 percent salinity, is used for the purposes of this resource management strategy report to make a general delineation between brackish and sea water.

The average salinity of ocean water is generally taken to be 35,000 mg/L TDS, or 3.5 percent, with a range of 30,000 mg/L to 50,000 mg/L. Inland seas can fall within this range, such as the Salton Sea with a rising salinity currently near 44,000 mg/L TDS. A few inlands seas can exceed this range, such as the

Table 1 Measurements of Salinity

Salinity Metric	Common Units	Comment
Electrical conductivity (EC)	µS/cm	EC is a measure of the concentration of dissolved ions in water, and is reported in µmhos/cm (micromhos per centimeter) or µS/cm (microsiemens per centimeter). A µmho is equivalent to a µS. EC may also be called specific conductance or specific conductivity of a solution.
Total dissolved solids (TDS)	mg/L or ppm	TDS is a measure of the all the dissolved substances in water and its units are milligrams per liter (mg/L) of solution.
Practical salinity units (PSU)	Unit-less	PSU is approximately equivalent to salinity expressed as parts per thousand (e.g., salt per 1,000 g of solution). Seawater is about 35 PSU. Its actual measurement is a complex procedure. Oceanographers are likely to use PSUs, which is why it is mentioned here.

Great Salt Lake or the Dead Sea. For the purposes of this resource management strategy report, “sea water” or “seawater” as a salinity descriptor means a TDS between 30,000 and 50,000 mg/L.

The term *brine* is a general term having different meanings in industry, water management, and even household cooking. Depending on how the term is used, brine may have a salinity as low as 1,000 mg/L TDS or as high as the saturation point of salts in water, when the salinity reaches about 280,000 mg/L and the brine has the consistency of slurry of liquid and salt particles. In many food preserving processes, brines are concocted of varying salinity to achieve a specific purpose. Brine may refer to any naturally occurring water with a salinity level higher than sea water. Natural brines, like those found under the Salton Sea and other geothermally active locations, are usually hot with salinities that are much higher than sea water. The Salton Sea natural brines are approximately 280,000 mg/L TDS or eight times that of average surface sea water. Another meaning of *brine*, which is adopted for this Desal-RMS, is the saline reject water from a desalination process. Reject water, that is, brine, from a desalination facility using reverse osmosis technology may have concentrations as low as 4,000 mg/L TDS, such as in the case of desalting brackish groundwater, to 70,000 mg/L in the case of seawater desalination.

Describing a water body by using the terms “fresh,” “brackish,” or “sea” characterizes the degree of salinity or freshness of the source water, depending on the context. Table 2 provides salinity ranges for these common terms as they are used in this resource management strategy report.

Fresh, brackish, and sea are qualitative terms that do not necessarily specify an origin or the exact environment from which a water withdrawal is made. The common inference is that the term “brackish” refers to groundwater, and “sea” refers to surface water from the ocean. Nonetheless, water characterized by the terms fresh, brackish, or sea may be withdrawn from surface or subsurface locations. Because “brackish water” and “sea water” do not refer to locations but are best applied as descriptors of degrees of salinity, brackish water does not necessarily refer to subsurface water (groundwater), and sea water does not necessarily refer to open or surface water, in discussions concerning desalination or saline waters. The subtitle of this resource management strategy report denotes “Brackish and Sea Water” as the two main types of saline water requiring desalination, regardless of whether their origin is underground or on the surface.

Table 2 Degrees of Salinity

General Water Term	Relative Salinity, mg/L TDS
Fresh	Less than 1,000[a]
Brackish	1,000 to 30,000
Sea	30,000 to 50,000
Hypersaline	Greater than 50,000 or that is found in the sea
Natural brine	Greater than 50,000 to slurries[b]
Discharge brine	1,000 to slurries[c]

Notes:

mg/L = milligrams per liter, NaCl = sodium chloride, ppm = parts per million, TDS = total dissolved solids

[a] Based on community drinking water standards. Salinity target values for municipal drinking water systems using desalination technologies are typically less than 500 ppm TDS.

[b] Also, brines or “salines” naturally derived from groundwater are 100,000 ppm or greater. TDS, NaCl-saturated solutions are approx. 260,000 ppm in concentration.

[c] Discharge brine concentrations vary widely and depend on technologies employed and processes used to discharge brine as a final waste stream to the environment. The concentration of reject water from a desalination facility may be referred to as “brine” but may only be 4,000 mg/L TDS in concentration.

Sources of Water for Desalination in California

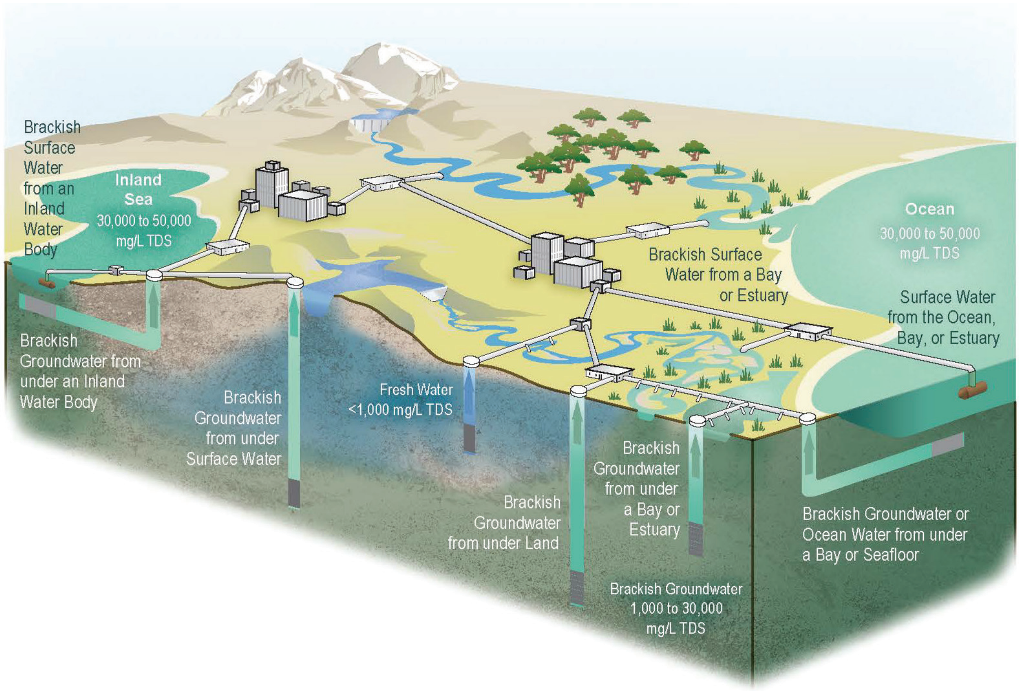
Various water sources are suitable for municipal drinking-water supply using desalination. Although desalination and other technologies are used to treat municipal wastewater for reuse, that topic is not covered in this resource management strategy report.

Typically, raw water sources must meet basic municipal water supply development criteria for quality and quantity. Municipal source waters should be capable of providing an adequate and sustainable amount of water for an intended beneficial use. Potential sources include oceans, bays, rivers, lakes, and groundwater aquifers. The determination of the safe yield from a water body is necessary for desalination as well as many other types of water supply projects. The ocean and other saline open-water environments afford the greatest safe yield potential for desalination water supply projects in California.

Typical water source types used for municipal water supplies throughout California, including those requiring desalting to provide fresh drinking water, together with a typical treatment facility, are shown in Figure 1.

As a general rule most water sources with a TDS concentration higher than 1,000 mg/L are termed brackish and will need desalination treatment or blending with fresher water to meet municipal drinking water quality criteria.

Figure 1 **Basic Municipal Drinking Water Facility and Source Waters in California**



A possible source of saline water is found in subsurface regions deeper than 3,000 feet below ground surface. Such water is not normally associated with the development of municipal drinking water in California, but may be discovered during oil and gas exploration and development. The California Department of Water Resources (DWR) has not compiled information or made assessments with regard to water found at depth and how it might be utilized to meet municipal water demands in the state. This topic is not addressed but may be further explored in future CWP updates.

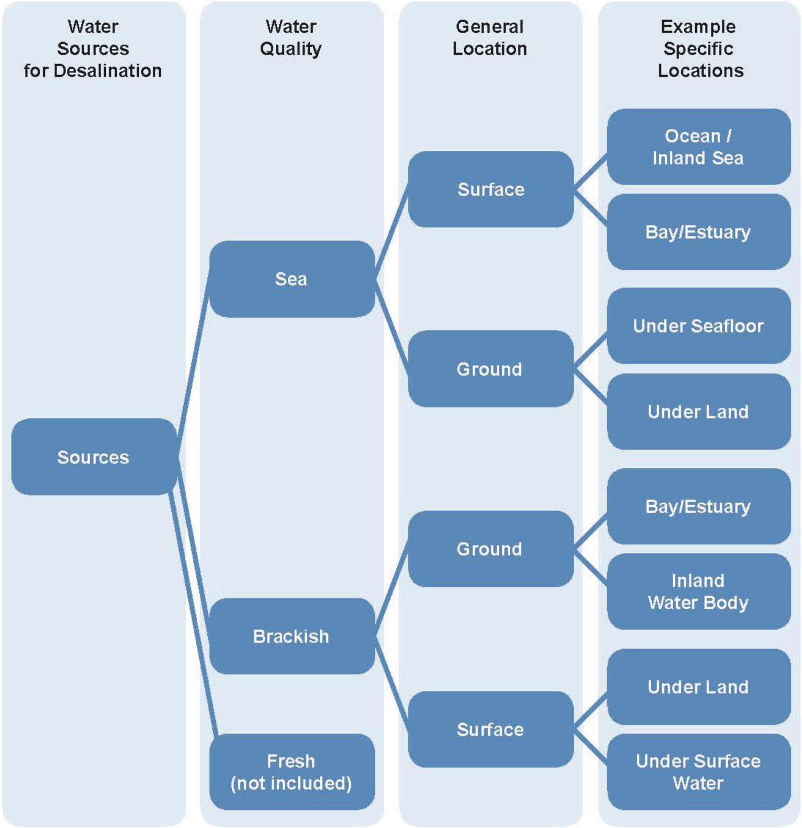
Source Water Classifications

Differences between sources of water suitable for desalination affect cost, environmental impacts, greenhouse gas (GHG) emissions, and other feasibility factors. It is important to classify water by source and quality for clarity of discussion of related issues. In the scheme shown in Figure 2, source waters are divided between two general salinity levels — sea and brackish — as defined in Table 2. While fresh water sources exist, as shown in Figure 2, for the purposes of this resource management strategy report no further classification or discussion of fresh water will be made.

The next level of classification is the general source location of surface or subsurface (underground). More specific surface-location characterizations are the ocean, bays, estuaries, and inland surface water bodies, such as the Salton Sea, major salt marshes, or other salt sinks.

In the discussion of any specific project or in the reporting of data, it is important to avoid ambiguity by using precise characterizations.

Figure 2 **Classification of Saline Water Sources**



Subsurface Water

Subsurface water sources are groundwater aquifers, but depending on their location they may be an indirect conduit for extracting saline surface water for desalination. Currently the most common source of water for desalination in California is brackish groundwater located inland from the ocean. The sources of salinity in the groundwater may be natural or caused by human activity. Natural sources may be salts dissolved from the minerals in the aquifer or salts picked up as water percolated from the land surface down to the aquifer.

The primary human-derived source of salts in groundwater is agricultural irrigation. Salts in irrigation water are left behind by the plants and tend to concentrate and migrate to groundwater. Animal wastes from dairies and feed lots can also be significant sources of salts. Landscape irrigation may contribute, as well.

Groundwater wells located adjacent to or underneath surface waters, in particular the ocean, are a way to extract saline surface waters when the groundwater is directly connected to and readily replenished by surface water. This is called groundwater under the influence of surface water.

There can be advantages to extracting brackish or sea water from a surface water indirectly through wells. Sand adjacent to or underneath the seafloor can serve as a filter to reduce water treatment costs and reduce impacts on fish and other aquatic life living in open water.

When saline surface water is extracted for desalination indirectly through wells, it is important to classify this separately from open-water intakes. As discussed later in this resource management strategy report, the environmental effects can be significantly different between surface and subsurface water intakes, even if the source water is ultimately the same. This is why the classification system shown in Figure 2 distinguishes between groundwater under the land versus under a surface water body. Subsurface water under surface water is intended to mean groundwater under the direct influence of the surface water. Reporting the results of ocean water desalination is often achieved by combining data from open-water intakes and subsurface water intakes, and yet there are significant differences between intake types worth clarifying.

Surface Water

The ocean and connected bays have the potential to be major sources of surface waters for purposes of desalination in California. This supply alternative is unique in that ocean water does not depend on the hydrologic cycle and can be treated to produce fresh water reliably, even during the more frequent and longer droughts projected to be caused by climate change (Committee on Advancing Desalination Technology 2008). Because of the vast volume of water in the oceans, ocean and other saline open-water environments afford the greatest safe-yield potential for desalination water-supply projects in California.

At the same time, the sea provides vast resources beyond just a source of water supply. Sea water contains an array of nutrients supporting plankton blooms and is the broth for much of the marine environment's food web. The marine waterscape contains forests of kelps where young and mature fish and seals dwell along with crabs, snails, and other species of mammals, fish, and invertebrates.

The ocean is a composite of many smaller ecosystems of limited ranges that support marine life adapted to these ecosystems. Although the vastness of the oceans leads some to describe them as "inexhaustible," the term should be used with caution. The sustainable extraction of sea water for desalination to meet municipal freshwater demand depends on safeguarding the seawater environment. Various forms of pollution and the effects of climate change increasingly put the marine environment and the life within it in jeopardy, making them anything but "inexhaustible."

While 35,000 ppm TDS is the average salinity of open-ocean water, scientists know that salinity naturally varies throughout the open oceans and seas. Some marine life depends on a narrow range of salinity fluctuations. Marine biologists are trying to understand just how sensitive certain marine environments, such as the benthic regions on the ocean floor, are to changes in salinity levels. Since the discharge of brine could affect salinity levels, this could increase the mortality of the marine life, an undesirable effect.

Desalination as a Water Treatment Technology

Introduction

Desalination, as previously defined, is the removal of salts from water to provide a water of lesser salinity than the source water. Salt is but one of many contaminants found in source water used for municipal drinking water. There are many types of processes that use various water treatment technologies to remove these contaminants. Some desalination technologies can be arrayed and operated on skid-mounted or self-contained mobile units that can be deployed during disaster relief, thereby increasing preparedness and decreasing vulnerabilities associated with insufficient drinking water. More information may be found on drinking water treatment in California in *California Water Plan Update 2013*, Volume 3, Chapter 15, "Drinking Water Treatment and Distribution."

Aside from the treatment technology to remove the salts, a desalination project must include other elements to convey and additionally treat the source water and to deliver the finished water to customers. Figure 3 depicts key elements of a desalination system, as will be discussed later in this section.

Not every element depicted in Figure 3 is necessary for all desalination systems. The "Pretreatment," "Post Treatment," "Blending," "Solids Disposal," and "Concentrate" elements do not occur in all desalination systems, while "Raw Water," "Intakes," "Desalination," "Finished Water," and "Distribution" are part of every full-scale desalination system. "Raw Water" and "Distribution" in this schematic emphasize where the water comes from and where it ends up, elements that in every desalination system affect feasibility, design, and environmental impacts.

Other common terms may be used when discussing treatment processes. *Component* is widely used instead of "element" in many textbooks*; product water* and permeate may be used instead of "finished water"; *feedwater* and *influent* are often used instead of "raw water."

This section will (1) provide an overview of the types of desalination technologies available and under research, (2) give some detail on the desalination technology known as reverse osmosis (RO), and (3) present the various elements of a municipal drinking water system that uses the RO technology for desalination.

Overview of Types of Desalination Technologies

There is a wide range of processes, technologies, and methods used to achieve a desired level of salt removal in water. This overview provides general information on both established and new or emerging desalination technologies.

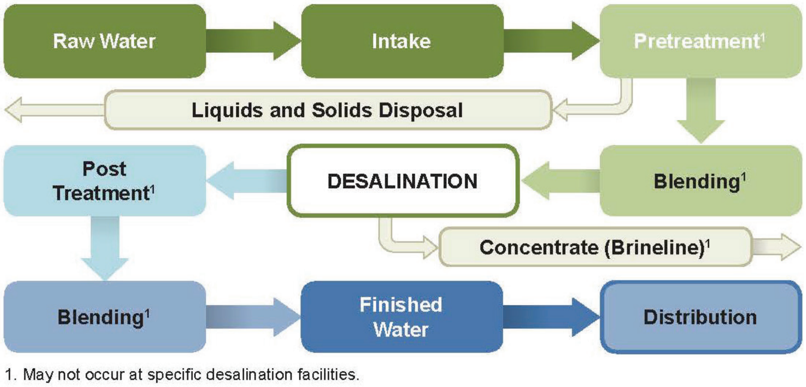
Table 3 provides a list of desalination technologies and their general application. It is convenient to place desalination technologies or processes into three main categories: (1) thermal, (2) membrane separation, and (3) all others.

Thermal Distillation Processes

The oldest desalination process is distillation, which has been used for more than 2,000 years. Thermal desalination processes render safe and reliable water from almost any raw water source, including fresh water, brackish water, and seawater sources. Most large-scale thermal distillation facilities are coupled with power plants that use steam turbines to generate electricity. Waste heat from the cooling of the power generation system can be used in the distillation process to reap benefits of a "cogeneration" approach to produce drinking water and electric power in the same complex. No municipal drinking water in California is produced with a thermal distillation process. Many of the large-scale facilities that use thermal processes at the municipal or industrial level are in Middle Eastern countries.

Two of the most widely used thermal processes for seawater desalination are Multi-Stage Flash evaporation (MSF) and Multi Effect Distillation (MED). The processes deliver water of exceptionally

Figure 3 **General Desalination System Schematic**



high purity (less than 25 mg/L TDS) and have been successfully operated in very large sizes. Among the disadvantages are the high capital cost and the requirement for a large input of heat.

At least one new thermal process concept has been proposed for possible use in California that claims to eliminate disposing of brine wastewater back to the environment, operates with higher efficiencies than other distillation processes, and management of solid waste includes recovering useful mineral products for industry (U.S. Patent 8,946,787).

General Membrane Separation

Membranes exist in nature and technological advances are mimicking the separation of salts found in the natural processes in three important desalting processes: forward osmosis (FO), RO, and electrodialysis (ED). A membrane for this purpose is a thin, film-like material that separates two fluids. It is semi-permeable, allowing some particles or chemicals to pass through, but not others. The objective is to allow water molecules to pass through the pores in the membrane and prevent the passage of other substances. In reality, what is filtered out depends on the size of the pores and the type of material used for a membrane. There are several types of membrane separation processes, but the most common processes used for desalination in the water industry are electrodialysis and reverse osmosis.

Considerable research has been invested in graphene, which is described as a one-atom thick layer of graphite. It holds potential as a desalination membrane with greatly reduced energy requirements. This would revolutionize the feasibility of desalination, but the practical application of graphene remains elusive.

Electrodialysis and Electrodialysis Reversal

ED and electrodialysis reversal (EDR) processes require membranes designed for the specific salts they will remove, in particular, membranes that will pass only positive or negative ions. Both ED and ERD use an electrical force to move salt ions through membranes, leaving behind desalinated water. The EDR and ED processes are similar except EDR periodically switches the electrical flow direction (reversal), which decreases fouling (when debris collects on the membranes) and scaling (when dissolved minerals are

Table 3 List of Desalination and Associated Technologies

Technology	Brief Description
THERMAL DISTILLATION	
Multi-Stage Flash Evaporation (MSF)	The thermal process by which distillation principles are employed through chambers at slightly different atmospheric pressures to flash liquid water into vapor and immediately condense the vapor in adjacent chambers as product water for use.
Multi Effect Distillation (MED)	The thermal process by which distillation principles are employed through pipes rather than chambers as in MSF. Once evaporation has occurred, water vapor is condensed within tubes (pipes) rather than chambers.
Vapor Compression (VC)	The thermal evaporative process where vapor from the evaporator is mechanically compressed and the heat from the compression activity is used to evaporate additional feedwater. VC is capable of achieving zero-liquid waste discharge requirements, even with very high salt concentrations in the feedwater.
MEMBRANE SEPARATION	
Electrodialysis (ED)	This technology uses an electrochemical separation process in which ions are transferred through specially designed ion-exchange membranes by the application of electrical current, leaving desalinated water as the product.
Electrodialysis Reversal (EDR)	This technology uses the same electrochemical principles as electrodialysis, except EDR periodically switches the electrical current flow direction (reversal), which decreases fouling and scaling of the elements.
Reverse Osmosis (RO)	RO uses pressure to force water across a semi-permeable membrane from the saline water side to the desalinated product water side, leaving the salts and other impurities behind as brine reject.
Forward Osmosis (FO)	FO is a two-part process. In the first part, a semi-permeable membrane separates the saline feedwater from an artificial “draw” solution of higher salinity. Water is drawn across the membrane out of the saline feedwater and into the draw solution. In the second part, the water is separated from the draw solution, leaving desalted water and regenerated chemicals reusable for new draw solution.
Nanofiltration (NF)	This type of membrane will not remove salt ions but does remove other substances with very small particle sizes. Pores are near to or smaller than 0.001 micrometer (µm). NF may be used in pretreatment stages to RO systems to prevent fouling of the RO membrane.
Ultrafiltration Membranes (UF)	This type of membrane will not remove salt ions but is used to remove larger particles and high-weight dissolved organic compounds, bacteria, and some viruses. Pore sizes range of 0.002 to 0.1 µm. UF may be used in pretreatment stages to RO systems.
Microfiltration Membranes	This type of membrane will not remove salt and is used to reduce turbidity and remove suspended particles, algae, and bacteria. MF membranes operate at lower pressures than the other types of membranes and have pore sizes ranging between 0.03 to 10 µm.
OTHER TECHNOLOGIES	
Ion Exchange	Ion exchange involves the selective removal of charged inorganic species from water by use of an ion-specific resin designed for the feedwater. The surface of the ion exchange resin contains charged functional groups that hold ionic species by electrostatic attraction. As water passes by the resin, charged ions on the resin surface are exchanged for the contaminant species in the water. When all of the resin’s available exchange sites have been replaced with ions from the feedwater, the resin is exhausted and must be regenerated or replaced. This process may not reduce TDS but is suitable to soften water and remove specific undesirable chemicals.

Technology	Brief Description
OTHER TECHNOLOGIES	
Captive Deionization	Capacitive deionization is an electrosorption process whereby ions are removed from water by use of an electrical current to force flow. The saline feed flows through electrodes comprised of materials such as carbon-based aerogels. Salt Ions are separated in the process and fresh water is developed. This technology is likely suitable for brackish waters, not sea water.
Freeze Desalination	This process relies on thermodynamic properties of water when changing from liquid to solid state (freezing). Ice crystals form as salt water freezes and the salt is expelled in the process. The process requires further innovation to perfect the process of salt separation (washing) from the frozen fresh water without remixing of the salt occurring. Freezing of water at atmospheric conditions requires generally far less energy input (334 kilojoule per kilogram [kj/kg]) than evaporation (334 to 2,326 kj/kg), making this a still-promising technology.

Source: Committee on Advancing Desalination Technology 2008

deposited on the membranes). EDR and ED are used most often used to treat brackish waters, not sea water.

Osmosis (Forward and Reverse)

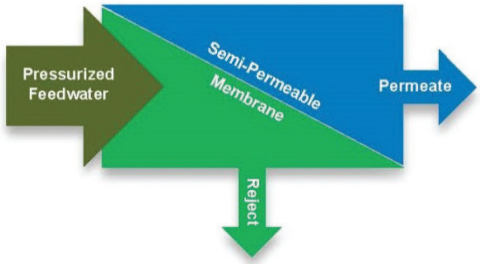
If two bodies of water with different salinity are separated by a semi-permeable membrane, water will naturally migrate through the membrane from the solution of low salinity to the solution of higher salinity. This process is called *osmosis*.

If the objective is to remove water from the higher salinity solution to provide fresh water, the natural flow of water across a membrane can be reversed by applying pressure on the high- salinity side. This process is called reverse osmosis as illustrated in Figure 4. The brackish or seawater feedwater is pumped against a semi-permeable membrane and the water molecules will migrate from the high-salinity side to low-salinity side. Depending on the salinity of the feedwater, this process may need to be repeated until the permeate leaving the low-salinity side is of freshwater quality suitable for drinking. The excess salts left behind, the *reject*, also called concentrate or brine, must be disposed of or processed, as explained in the “Concentrate Management” section below.

RO processes that use membranes are the most effective commercially available processes for salt removal today, but no membranes result in absolutely pure water. The removal of particles and dissolved chemicals from water can be accomplished through a variety of filtration technologies, while the size of the pores or passages determines the size of particles and chemicals that can pass through. Filters using sand or other granular material are a common technique for removing large particles from water, particularly during drinking- water and wastewater treatment. Filters using membranes with increasingly smaller pores are microfiltration, ultrafiltration, nanofiltration, and reverse or forward osmosis. Examples of the kinds of particles and chemicals removed by filtration techniques are shown in Figure 5. Brief descriptions of the various membranes are presented in Table 3. For the purpose of removing chemicals via desalination, the focus is on reverse or forward osmosis.

RO membranes typically come in the form of rolls called cartridges. The membrane sheets are sandwiched between spacers to allow feedwater to enter one side of the membrane and permeate water to pass through and leave the other side. The salts are left behind on the feedwater side of the membrane

Figure 4 **Basic Reverse Osmosis Schematic**



and build up in concentration, becoming brine. An assembly of RO cartridges looks like the photograph on the title page of this resource management strategy report.

In general, an energy input is required to use membrane separation. High pressures are needed to get water molecules to pass through the membrane at fast enough rates for functional municipal- scale applications and to overcome the inherent properties of the membrane. The amount of energy required generally increases as the particle size decreases and salt concentrations increase. The energy needed for RO treatment of brackish water is much less than for seawater treatment. Energy is a major factor in desalination, especially seawater desalination, and is discussed further in the "Major Implementation Issues" section of this resource management strategy report.

Experimentation is taking place on a two-part process called forward osmosis for drinking water applications, which takes advantage of the natural tendency of water to flow from low salinity to high salinity solutions across a semi-permeable membrane. Brackish or seawater feedwater is placed on one side of the membrane and an artificial solution of higher salinity, called the draw solution, is placed on the other side of the membrane. The water molecules are drawn out of the feedwater through the membrane, rather than pumped, leaving behind the undesirable salts in the brackish or seawater feedwater.

A secondary step is needed to separate water from the draw solution, which is artificially high in salinity. The chemicals used for the draw solution are especially chosen to be easily separated from the water to leave behind fresh water and the chemicals that can be reused. Heating is one method of separating water from the draw solution. The expected results of testing of forward osmosis are lower costs and energy use. Two forward osmosis plants using proprietary technology of Modern Water PLC operate in Gibraltar and Oman.

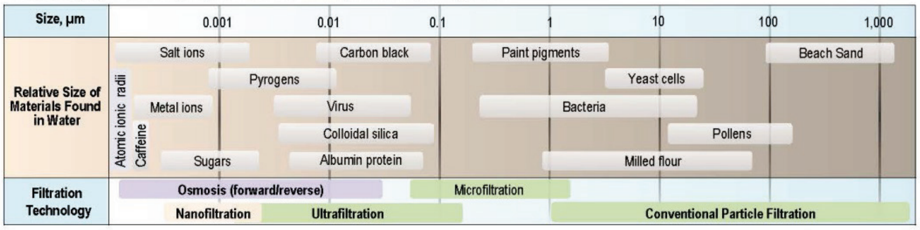
Among the various membrane separation technologies listed in Table 3, RO has matured rapidly over the last few decades and has become the process of choice for many desalination projects. In the United States, it has become the most economic process and is now widely utilized in the Southeast, Southwest, and West to provide an alternate source of supply derived from saline surface and groundwater. Because of its current prevalent position in the desalination arena in California, RO will be the focus of further discussion of desalination in this resource management strategy report.

Basic Elements of a Desalination System

Each element of a desalination system, as shown in Figure 3, is discussed in this section. The differences among systems that use surface sources (mainly sea water) and subsurface sources (brackish groundwater or groundwater under the direct influence of surface sea water) will be described. Figure 3 is a simplified

Figure 5 Filtration Spectrum for Desalination

Simplified scale for illustration purposes.
1 micrometer (µm) = a unit of length equal to 1×10^{-6} meter. It is equivalent to 10,000 angstroms.



schematic of a desalination system. Some systems omit one or more of these elements, arrange the elements in a different sequence, or combine various elements into a single component to create a desalination system.

Raw Water

The raw water element is the source water for desalination, also referred to as feedwater. Encompassed in this element is not only the water itself but also the geophysical characteristics of the environment containing the water. The raw water characteristics affect the capability of a particular location to serve as a water source, the design of facilities to accomplish water extraction, and the protection needed for the environment and the raw water for long-term sustainability.

The typical raw water factors for surface water intakes that must be considered include oceanographic conditions, limnology of fresh water bodies, hydrogeology, episodic water quality changes, benthic topography, pollution, and adverse impacts on aquatic species. A surface water source supports an aquatic ecology that is especially susceptible to damage caused by water intakes. Design features can minimize those effects, as described in the next section, but mitigation measures may be needed to compensate for unavoidable impacts. More settleable (undissolved) solids are generally found in surface waters than in groundwater.

Typical raw water factors to consider for subsurface water intakes include water quality, long- term sustainable withdrawals (safe yield), interaction with surface water, and seawater intrusion impacts. Subsurface intakes, under the ocean floor or at inland near-shore locations, can be a means of using sea water while avoiding surface water intake effects on aquatic organisms. However, they can also cause seawater intrusion into, or depletion of, inland freshwater aquifers.

Intake

The uncertainties in many raw water environments regarding life cycles, food webs, and degrees of abundance or safe yield levels necessary to achieve water sustainability are reasons for an extra level of caution when implementing a water supply project, especially for the open-water intakes. The interface (intake element) between the raw water environment and the municipal water system delivering drinking water plays a crucial role in determining the water supply project’s ongoing adverse impacts on the natural habitat.

The intake element consists of the entrance structure where raw water is withdrawn from the source and a pipeline used to route the water to the desalination facility; also, pumps might be used to lift and move the water. As previously mentioned, desalination intakes generally fall into two major categories — surface intakes located above the floor of the source water body, such as the ocean, and subsurface intakes located beneath the floor of a water body or below dry land.

It is common to include a pretreatment element, a screen (see Figure 6), at the water intake to reduce any adverse impact on aquatic organisms (e.g., larvae sucked through the screen) and avoid taking in undesirable suspended debris or, in the case of groundwater wells, sand or other particles. Discussion of intakes will focus on those associated screens and other devices used to extract water from the environment.

For surface water intakes, also called open intakes, using conventional screen designs causes impingement and entrainment (IE) of organisms. An example of an open seawater intake is shown in Figure 6. *Impingement* occurs when organisms sufficiently large to avoid going through the intake screens are trapped against the screens by the force of the flowing source water. *Entrainment* occurs when aquatic organisms enter the intake. Impingement typically involves adult organisms (e.g., fish, crabs) that are large enough to actually be retained by the intake screens, while entrainment mainly affects aquatic species small enough to pass through the particular aperture size of intake screen. Entrained living organisms are typically not returned to the environmental alive, but instead are destroyed through the intake and pretreatment processes and routed to and combined with the brine waste stream or solid-waste disposal process.

Intake systems may require on-going maintenance, including underwater activities, excavation, dredging, embedment, pipe laying, and anchoring. Intake system maintenance and construction impacts might be minimized by sharing intakes with other facilities, such as power plants, or using existing infrastructure no longer needed for its original use. Modification of existing infrastructure, whether or not it is used for its original purpose, may provide the best benefits and minimize adverse impacts.

Pretreatment

Desalination treatment technologies, especially RO facilities, require a feedwater that meets certain minimum water quality parameters to avoid damage, corrosion, membrane fouling (clogging), impaired performance, or excessive maintenance procedures. Raw water often needs to be conditioned through pretreatment processes to improve water quality before the actual desalination occurs. Intake screens, as previously discussed, are often recognized as the first pretreatment component to prevent debris, weeds, algae, fish, shells, and to the extent feasible other aquatic life and aquatic food sources. Together, the intake and additional pretreatment components remove settleable and suspended particles and entrained organisms, as well as further condition the raw water to enable efficient and effective desalting. Figure 5, "Filtration Spectrum for Desalination," shows typical sizes and types of particles, molecules, and organisms along with filtration technologies used to remove them.

Certain source waters are subject to contamination by natural toxins generated by algal blooms (red tides); wastewater discharges (point and non-point); oil and hydrocarbon residues or spills; urban runoff; and agricultural pollution, such as animal wastes, fertilizers and pesticides. This contamination may necessitate robust pretreatment processes to ensure treatment reliability and safety. In the case of RO, pretreatment membranes often require disinfection, use of biocide, and/or use of other chemical additives

Figure 6 **Open-Water Intake Element**

Pre-Installation (60" Length by 13" Diameter)

Continuous Slot Style Screen (Wedgewire, 2 mm slot size)

Raw Water Environment (Ocean, 41" Length by 13" Diameter)

Source: Dianne Gatza, West Basin Municipal Water District

to control biological growth, scaling, and corrosion effects. Pretreatment may include other membranes or filtration equipment, such as microfiltration, to improve the efficiency of RO.

Subsurface intakes are a form of pretreatment — the filtering effect on water flowing through sediments in the ground before reaching the intake screen of a subsurface well. Such in-situ filtration removes most of the solids, including food and marine life normally found in surface waters. Subsurface intakes may also be insulated from algal blooms, direct pollution, and other natural or human-generated, system disrupting factors. To avoid IE effects on aquatic life, subsurface intakes from wells under the ocean floor can be used if the right geologic conditions exist.

Figure 7 shows a simple drawing of a vertical groundwater well with an intake screen and surrounding engineered gravel-pack envelope to reduce finer particles from migrating through the screen apertures and into the feedwater flowing to the treatment components. The location of the well or intake and the elevation of the screen are important to control the type of water being pumped. Several situations with regard to wells are illustrated in Figure 7, with a comparison to an open-water intake. A well in a transition zone could variously take both fresh water and brackish or sea water from the aquifer, creating vulnerability to brackish or seawater intrusion into the freshwater zone. There are several types of subsurface intakes, including groundwater wells (vertical and slant orientations), beach well galleries, and other configurations.

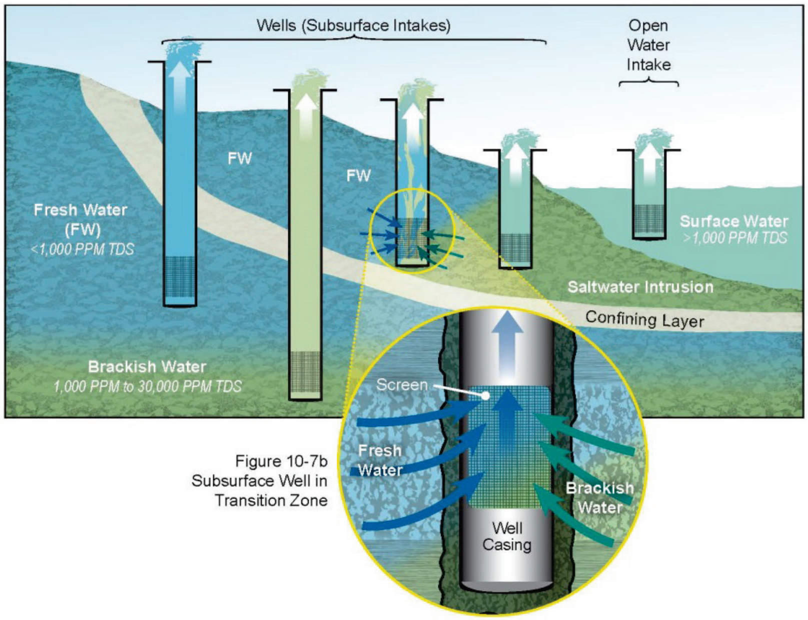
Blending

Blending may occur before or after the desalination treatment element. The water used for blending may be another raw water source or potable fresh water. The purposes for blending include improving either the desalination operation or the aesthetics of the finished water for customer acceptance.

Desalination

The function of the desalination treatment element is the removal of salts and other contaminants not removed in previous treatment processes. It is the core of a desalination system. RO is the most common desalination technology for producing potable water in California. This element also includes pumps to force water through the RO membrane and energy recovery devices. Because of the high pressure needed

Figure 7 Cross-Section of Wells and Typical Engineered Gravel Pack



Notes: PPM = parts per million, TDS = total dissolved solids

for RO, desalination treatment is the most energy-intensive element of a desalination system, even with energy recovery devices.

Post Treatment

Permeate water leaving the RO process can be acidic and has little hardness (mineral content). It can be corrosive to pipes and have an unnatural taste and feel. Post treatment may include the addition of chemicals to produce acceptable water from the consumer perspective — some hardness is desirable. Blending with another source of water is another way of adjusting the quality of water for desirable drinking water. Post treatment includes providing the necessary disinfection and other treatments to produce finished water.

Finished Water

The finished water element designates the end product of the treatment elements involved in a desalination facility. At this stage, the water may be distributed to customers. If the water meets all requirements, it will be considered safe and reliable for drinking purposes.

Distribution

The distribution element consists of the facilities needed to convey the finished water to the consumer. The facilities are pipelines, pumps, and storage tanks. Most communities considering desalination already have a water distribution system to deliver their existing sources of water. When a new desalination treatment plant is constructed, a pipeline is needed to connect the desalination treatment facility to the existing distribution system. If the source of brackish or sea water is far from the existing distribution system, the connecting pipeline and associated pumps or tanks, often called conveyance or transmission facilities, could be expensive. If the existing distribution system is not designed to receive a large, new flow of water, modifications may be necessary.

Solids and Liquid Waste Disposal

Most, if not all, solids are removed during the pretreatment stage of the desalination process. Typically, surface waters, such as open-ocean supplies, will contain more settleable solids than subsurface water supplies. Surface waters are more susceptible to water quality variation owing to weather, the seasons, or other events, such as La Niña and El Niño, which may require increased costs in operation and more solids removal. Solids include debris, organic particles (e.g., plants or animals), or inorganic particles (e.g., sand). The amount of solids to be removed and the inherent fluctuations in solids of a source water may influence overall intake design and affect feasibility of the plant or particular components. After removal of excess water these solids can often be hauled to a landfill as solid waste.

There are liquid waste streams that may be generated during normal operation and maintenance, such as cleaning screens or equipment and backwashing filters or the desalting membranes. The resulting liquid waste may vary in salt concentration, from raw-water to product-water quality. The liquid waste may contain small suspended particles or cleaning solutions. This liquid waste may be mixed with the brine waste or handled separately, such as when discharging to a municipal wastewater collection system.

Concentrate Management

Concentrate is defined as the resulting byproduct from the various separation processes used in desalination. The terms reject, brine, and wastewater are commonly used to refer to the concentrate generated and managed at desalination facilities. The term brine is commonly used in place of concentrate, as in brine management. Depending on the source water, desalting technologies, and the process configurations employed, the concentrate will be of a specific character that must be dealt with as a product or a waste.

There are several methods to manage and dispose of brine. The salinity of brine is greater from seawater desalination than from brackish water desalination. The quality of the brine and the location of the desalination facility affect the available management options. The main options are waste discharge to a surface water (especially into the ocean), discharge into a dedicated brine line (combined with other saline wastes for possible further treatment and disposal), subsurface discharge by injection into a deep well-aquifer, land application by irrigation, solar evaporation ponds, and thermal evaporation to produce solids suitable for landfill disposal. While brine is usually managed as a waste, the characteristics of the brine may make it suitable for processing into usable byproducts. If brine is managed by a process that reclaims the salt and other byproducts, it is said to be a *zero-discharge process*.

Concentrate management is an important issue discussed later in this resource management strategy report.

Desalination in California

Desalinated water currently is one of California's lowest volume drinking-water supplies. For most California water suppliers, desalination is neither practical because of a lack of suitable saline source water nor is it economically feasible because more cost-effective water supply alternatives are available. However, desalination is being considered more frequently as water supplies become constrained, more local supplies are sought to augment imported water, and desalination technologies improve and become more cost-effective. Additionally, with submittal of their 2010 urban water management plans (UWMPs) and the State integrated regional water management (IRWM) funding program plans, California water suppliers are now required to evaluate desalination as a method to meet their water resource management goals and objectives.

Some of these evaluations have become high-profile and contentious, but they have resulted in very important water supply reliability and sustainability discussions, as well as concrete steps to plan, design, and construct desalination projects.

History of Desalination in California

Water agencies began considering desalination in California in the late 1950s. The first major facilities involving desalination came on line in the 1960s, primarily to support cooling processes at power plants, such as Pacific Gas and Electric Company's Morro Bay and Moss Landing facilities. Since then, desalinated sea water has been successfully integrated into industrial and non-potable uses at multiple coastal sites.

In the 1960s, it was envisioned that desalination could play an increasing role in California's water supply and power generation needs. In the 1960 transmittal letter for DWR Bulletin 93, titled "Saline Water Demineralization and Nuclear Energy in The California Water Plan," DWR Director Harvey O. Banks wrote to Governor Edmund G. Brown and members of the Legislature of the State of California:

> Although no saline water demineralization technique yet developed can compete with the costs of large scale development of natural sources of water in California, it is probable that saline water conversion plants will have a definite place in the water program. The Department of Water Resources will continue to take a definite and continuing interest in those areas of research and development that may have promise of eventually producing low cost converted water.

Desalination technologies were extensively tested in California in the late 1950s and early 1960s to address water supply issues. Experiments and pilots testing of different technologies and projects were conducted using both ocean and underground source water (California Department of Water Resources 1960, 1963).

Data collected on water desalination in California for 2006 and 2009 are shown in Tables 4 and 5. These data are for projects whose primary purpose is salt removal for potable use. Desalination technology for pollutant removal, as in wastewater treatment, or for industrial water use, is not included.

Brackish Groundwater

Coalinga was the site of the first operational brackish groundwater desalination facility in California. It operated from 1959 to the early 1960s, reducing groundwater salinity from 2,100- 2,400 to under 500 mg/L (California Department of Water Resources 1963). This Coalinga site now receives surface water from the U.S. Bureau of Reclamation (USBR).

In the 1970s and 1980s, DWR tested the feasibility of desalinating agricultural drain water to address San Joaquin Valley drainage issues. RO testing facilities were constructed in Firebaugh and Los Banos. These projects assessed biofouling issues and implementation requirements.

Table 4 Summary of California Desalting, 2006

Feedwater Source	In Operation		In Design and Construction		Planned	
	No. of Plants	Annual Capacity	No. of Plants	Annual Capacity	No. of Plants	Annual Capacity
Groundwater	14	46,200	5	31,000	8	56,300
Seawater	4	1,150	1	250	9	187,100
Total	**18**	**47,350**	**6**	**31,350**	**17**	**243,400**
Cumulative	**-**	**-**	**24**	**78,700**	**41**	**322,100**

Notes:

Capacity in acre-feet per year.

Data courtesy of California Department of Water Resources Exhibit-H1, California Perspective on Desalination Meeting, Jeanine Jones, May 24, 2006.

Ultimately, because of agricultural drainage issues identified at Kesterson Reservoir, the project was discontinued in 1989. DWR continues to be involved with efforts to reduce salt accumulation in soil and aquifers throughout the state by investigating desalination technologies for agricultural tail water. Tail water, or specifically drainage water from irrigated lands, may be put to beneficial use through desalination. For more information about desalination and other advanced treatment related to agricultural practices and water use, visit http://www.water.ca.gov/drainage/.

During and after the severe drought of the early 1990s, water agencies launched large-scale conservation and water recycling programs and began to consider additional local resources, including desalination. Rapid advances in RO membrane efficiency, energy recovery technology, and innovative process designs also occurred during the 1990s. Several communities constructed brackish groundwater desalination facilities in the 1990s. An example is the City of Tustin, which completed its groundwater desalter in 1989. Over a dozen other facilities were constructed and began operation by the end of the decade. These facilities were primarily located in the near- coastal and inland areas of the greater Los Angeles area.

Data for groundwater desalination projects in 2006 and 2009 are shown in Tables 4 and 5. Capacities of operational facilities were tracked, but actual production amounts were not. The source water for these groundwater projects is assumed to be of brackish water quality.

Sea Water

There are approximately 1,100 miles of coastline in California, making sources of saline waters accessible in many locations. The first ocean desalination facility in California was constructed in San Diego in 1962, but intake issues involving kelp and sea grass caused operational challenges. The U.S. Navy also began early California desalination operations and research at Port Hueneme (California Department of Water Resources 1963).

Table 5 Summary of California Desalting, 2009

Feedwater Source	In Operation		In Design and Construction		Planned	
	No. of Plants	Annual Capacity	No. of Plants	Annual Capacity	No. of Plants	Annual Capacity
Groundwater	20	82,200	4	31,000	3	57,300
Seawater	6	1,700	3	250	13	257,000
Total	**26**	**83,900**	**7**	**31,350**	**16**	**314,300**
Cumulative	**-**	**-**	**33**	**78,700**	**49**	**479,000**

Source: California Department of Water Resources

Notes:

Capacity in acre-feet per year.

In the 1970s and 1980s, several communities completed potable water desalination facilities, but for various reasons, each of those projects operated only briefly. Decommissioned or non- operational facilities are or were in San Simeon and Santa Barbara. Marina Coast Water District has a standby desalination facility. Reasons cited for ceasing desalination include operational expense and challenges, availability of less expensive supply, and end-of-drought conditions.

In addition to Morro Bay and Moss Landing, desalination for power plant operation was implemented in 1960 at Southern California Edison Mandalay steam station (now Reliant Energy Mandalay), in Ventura County and later at the Contra Costa Power Plant on the San Joaquin River in Contra Costa County (California Department of Water Resources 1963).

By the late 1990s, the costs of seawater desalination became competitive with alternative new supplies in some areas. To evaluate its potential, water agencies conducted numerous feasibility studies and several pilot projects. The pilot projects — miniature desalination plants used to develop design parameters — included research into alternative treatment processes, baseline environmental conditions, innovative seawater intakes, public outreach, and other pre- construction issues. Many of these studies were partially funded through State and federal grants. The pilot projects represent a significant investment in the future of desalination in California.

Data for seawater desalination projects in 2006 and 2009 are shown in Tables 5 and 6. Actual production data for those years were not reported. All of the operational projects extracted water either directly from the ocean or from groundwater wells adjacent to the ocean. The salinity of the water from these wells was probably brackish rather than seawater quality.

Table 6 **Summary of California Desalting, 2013**

General Source Water Designation	In Operation			In Design and Construction		Proposed	
	No. of Plants	2010 Production	Annual Capacity	No. of Plants	Annual Capacity	No. of Plants	Annual Capacity
Brackish groundwater	23	79,812	139,627	3	9,050	17	74,629
Brackish surface water	0	0	0	0	0	1	22,403
Ocean water	3	130	562	1	56,007	15	381,791
Total	**26**	**79,942**	**140,189**	**4**	**65,057**	**33**	**478.823**
Cumulative	**-**	**-**		**30**	**205,246**	**63**	**684,069**

Note: Production and capacity in acre-feet per year.

Current Desalinated Water Use in California

Water desalination projects currently active as of 2013 in California and their status are shown in Table 6. The locations of these projects are shown in Figure 8. Actual production of the desalinated water is provided for 2010. These data are for projects with the primary purpose of salt removal for potable use.

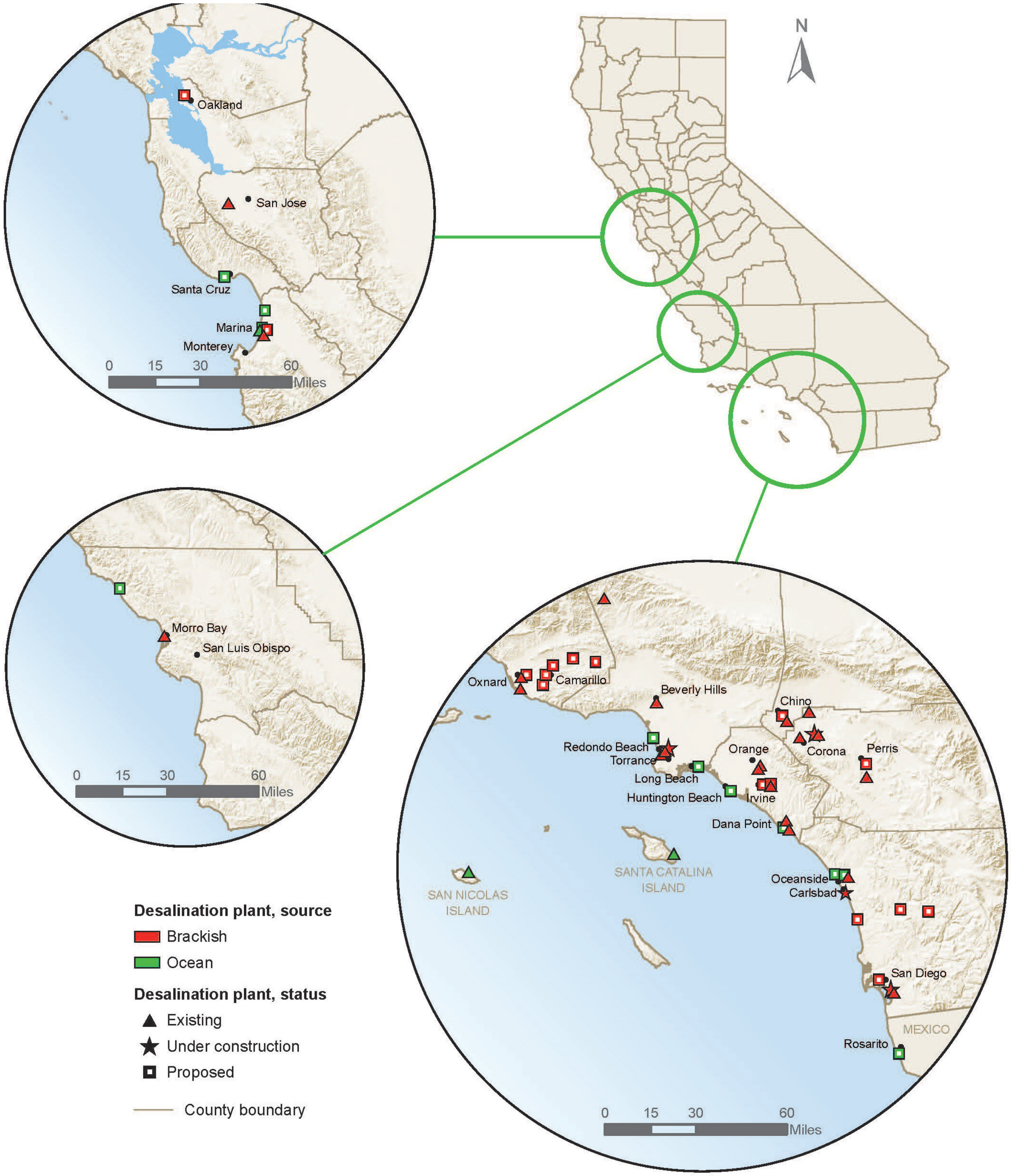
Projects classified as proposed are in some stage of planning, from conceptual to final feasibility, and the time frame for implementation may be as much as a few decades away. Pilot studies may be taking place for proposed projects. For greater precision, “ocean water” as a water source replaces “sea water” found in previous reporting. Ocean water includes subsurface intakes of groundwater recharged primarily by the ocean. The brackish surface water project in planning would take water from the San Francisco Bay.

Current Brackish Groundwater Desalination

Groundwater desalting plants are generally designed to reclaim groundwater of impaired quality and are located in urban areas, from the San Francisco Bay Area to San Diego. Currently, there are at least 23 operating groundwater desalting plants, 22 of which are located in Southern California and one plant in the San Francisco Bay Area. Plant capacities range from 0.2 to 15 million gallons per day (mgd) (226-16,800 acre-feet per year [af/yr.]).

The source groundwater quality ranges significantly, depending on the project. The primary constituent typically targeted for removal by these projects is TDS, but nitrate removal may also be an objective. One of the key constraints for groundwater desalination is brine disposal. Existing facilities are located either near a brackish or saline water body or near a brine disposal line, such as the Inland Empire Brine Line (also known as the Santa Ana Regional Interceptor [SARI]). Waste in the SARI line is treated with other wastewater and discharged into the ocean. These regional interceptors enable sustainable disposal of brine

Figure 8 **California Municipal Desalination Facilities**



wastes. Several additional lines are planned for Southern California, and constructing them will be a key component of the expansion of brackish groundwater desalination.

As it now stands and as groundwater desalination expands in the future, groundwater overdraft issues will be an integral consideration. At this time, the majority of groundwater desalination occurs in basins with some degree of groundwater management or adjudication. This enables groundwater desalination to be strongly linked to other groundwater uses and recharge activities, IRWM, and local supply.

Current Seawater Desalination

Current seawater desalination reported in this section is limited to those municipal water-supply facilities in operation or in construction in the state. There are three active desalination facilities providing municipal water. These are relatively small systems at Santa Catalina Island (Avalon), San Nicolas Island (U.S. Navy Air Strip), and Marina (Fort Ord) with a combined annual capacity of 562 acre-feet (af). Only the Santa Catalina Island Desalination Facility reported production for year 2010 (128 af). Because of operating expenses, potable seawater desalination facilities often operate intermittently and may represent emergency and standby sources of water. An example is the Marina Desalination Facility, which is in operational-standby/emergency status with no reported production for 2010. There are two existing but inactive seawater desalination facilities at Morro Bay and Santa Barbara. The Morro Bay Desalination Facility houses two treatment trains, one for sea water and another for brackish groundwater. The Morro Bay Seawater Unit was listed as inactive for 2010, but the brackish groundwater treatment unit was and continues to be active. In the past, the Sand City Desalination Facility in Monterey County was listed as a seawater facility but now is listed with existing brackish groundwater facilities, based on system design.

There is currently one seawater desalination facility under construction by Poseidon Water (Poseidon) at Carlsbad. The Carlsbad Seawater Desalination Facility is designed to deliver 50 mgd (56,007 af/yr.) and is being constructed and operated as a public-private partnership. When completed, the Carlsbad facility will be the largest ocean-water desalination plant in the Western Hemisphere. The San Diego County Water Authority has a 30-year water purchase agreement with Poseidon. Poseidon will own and operate the plant. San Diego has the option to buy the plant after 10 years and to take ownership after 30 years, at essentially no cost. Poseidon has also designed and started to construct a 10-mile pipeline to deliver the desalinated ocean water; the pipeline will be publicly owned and operated. Deliveries are scheduled to begin in 2016. More about the project may be found at http://carlsbaddesal.com.

Future Desalination in California

There are approximately 17 proposed brackish groundwater plants, including existing plant expansions scheduled to occur before 2030. Most of these proposed facilities are at the final feasibility phase or in advance planning and design. Proposed brackish groundwater facilities have the potential to increase municipal water supplies in California by an estimated 74,600 af/yr. (66.6 mgd).

There is one active brackish surface water facility, the Bay Area Regional Desalination Project (BARDP), being planned in the San Francisco Bay Area with a reported potential design capacity of 22,403 af/yr. (20 mgd). The Marin Municipal Water District (MMWD) has planned a desalination project that could use brackish surface water; however, the MMWD has placed a hold on any further implementation of the project as of the end of 2013, so it is considered inactive and not included in the proposed project data.

Fifteen ocean desalination projects are under consideration with an estimated potential capacity of 382,000 af/yr. (341.0 mgd). There are two seawater desalination projects included in the planning that would be located in Mexico, where desalinated water would cross the border into California just west of San Ysidro. The projects involve raw water intakes and desalting works in the Mexican city of Rosarito Beach, pipelines crossing into the United States, and final treatment of the desalted ocean water in California to meet the State's drinking water standards. Each plant has a potential capacity of 50 mgd (56,007 af/yr.).

Many sources of data were compiled to assess the current status of desalination projects. Many projects previously reported as proposed or even in operation were found to be currently inactive or no longer proposed. It cannot be assumed that current proposed projects will be or even could be implemented by any given date. UWMPs required for major water suppliers were an important source for evaluating current project status. In some cases, lead agencies were contacted to gain better status information on proposed and existing facilities.

Legal and Regulatory Framework of Desalination in California

Water supply projects utilizing desalination technologies are subject to State statutes and regulations, as well as local laws. Over 20 permitting authorities have been identified for the planning, management, and operation of desalination facilities.

Planning and Management of Water Resources

A general policy framework for desalination in California was set forth in 1965 in the Cobey- Porter Saline Water Conversion Law (Water Code Sections 12946-12949.6). The people of the state have a primary interest in development of economical desalination processes that could:

- Eliminate the necessity for additional facilities to transport water over long distances, or supplement the services provided by long-distance facilities.
- Provide a direct and easily managed water supply to assist in meeting the growing water requirements of the state.

DWR is directed to find economic and efficient methods of desalination so that desalted water (e.g., drinking or other water) may be made available to help meet the growing water requirements of the state.

Protecting Water Quality

The brackish water and seawater environments are important to preserve and protect. Utilizing desalination techniques requires compliance with State and federal laws governing water quality.

The federal Clean Water Act (CWA) established a permit system known as the National Pollutant Discharge Elimination System (NPDES) to regulate point sources of discharges into navigable waters of the United States.

The Porter-Cologne Water Quality Control Act (Porter-Cologne Act) is California's comprehensive water quality control law and is a complete regulatory program designed to protect water quality and beneficial uses of the state's water. This act requires the adoption of water quality control plans by the State Water Resources Control Board (SWRCB) and the state's nine regional water quality control boards (RWQCBs) for watersheds within their regions. These plans designate beneficial uses for each surface water and groundwater body within the state, water quality objectives to protect these uses, and implementation measures.

The Porter-Cologne Act also establishes a permitting system for waste discharge requirements for point and nonpoint sources of discharges to both surface water and land. The U.S. Environmental Protection Agency (EPA) has delegated authority to the RWCQBs to issue NPDES permits.

These permits are issued in tandem with waste discharge requirements. These permits are required for disposal of brine from desalination facilities. The permits incorporate provisions in the water quality control plans, including protections of the brackish-water and seawater aquatic ecosystems.

Protecting Drinking Water

Safe drinking water depends on protection of the surface and underground sources of water from pollution, as well as maintaining appropriate water treatment to remove harmful chemicals and pathogens before they enter the drinking water supply. The primary agency responsible for regulating drinking water systems is the California Department of Public Health (CDPH). However, the SWRCB and the RWQCBs also have an important role.

The federal Safe Drinking Water Act (SDWA) directed the EPA to set national standards for drinking water quality. It required the EPA to set maximum contaminant levels for a wide variety of constituents. Local water suppliers are required to monitor their water supplies to assure that regulatory standards are not exceeded. The finished water of a municipal desalination facility must meet these standards. Under the SDWA, the State is required to develop a comprehensive Source Water Assessment Program that will identify the areas that are used to supply public drinking water systems, inventory possible contaminating activities, assess water system susceptibility to contamination, and inform the public of the results. This assessment could include surface and subsurface sources for desalination projects.

The CDPH has primary responsibility for implementing the SDWA in California, as well as provisions in State law. In 1999, CDPH issued the Drinking Water Source Assessment and Protection (DWSAP) Program (revised in 2000). The program, primarily voluntary on the part of water agencies, involves their performing source water assessments. As of 2003, between 82 and 97 percent of surface water and groundwater sources were covered by assessments. There is no requirement that these assessments be updated. The implementation measures to protect source waters are a mix of voluntary and mandatory actions by local water and land use planning agencies and the regulatory programs of county health departments, CDPH, SWRCB, and the RWQCBs.

The primary safeguard against pollution of source waters is the RWQCBs, through their permitting systems for discharges and other nonpoint-source control programs. These permits are based on protecting the beneficial uses of water bodies specified in water quality control plans. By default, bodies of surface and groundwater in California are considered suitable or potentially suitable for municipal or domestic water supply and are classified as MUN (municipal) in water quality control plans (SWRCB, Resolution No. 88-63). One of the exceptions is water bodies where the TDS exceeds 3,000 mg/L, because these saline water bodies are not reasonably expected by RWQCBs to supply a public water system. However, RWQCBs are to assure that the beneficial uses of municipal or domestic supply are designated for protection wherever those uses are presently being attained. With a few exceptions, RWQCBs have not designated for protection brackish groundwater or ocean water sources currently being treated with desalination for municipal water supply.

Environmental Laws for Protecting Resources

The California Environmental Quality Act (CEQA) is a California statute passed in 1970 to institute a statewide policy of environmental protection. CEQA directly followed passage of the federal National Environmental Policy Act. CEQA does not directly regulate land uses or other activities. CEQA requires State and local agencies within California to adopt and follow protocols of analysis and public disclosure of environmental impacts of proposed projects and carry out all feasible measures to mitigate those impacts. CEQA makes environmental protection a mandatory part of every California State and local agency's decision-making process.

Applying CEQA requirements equally among water supply alternatives (e.g., fresh, brackish, sea, and recycled water) is essential for determining the best water-supply project to implement.

Protecting Endangered Species and Habitats

There are federal and State laws to protect endangered species of wildlife and their habitats. These laws are encountered with desalination intakes and brine discharges.

Federal Endangered Species Act. The federal Endangered Species Act (ESA) is designed to preserve endangered and threatened species by protecting individuals of the species and their habitat and by implementing measures that promote their recovery. Under the ESA, an *endangered species* is one that is in danger of extinction in all or a significant part of its range, and a *threatened species* is one that is likely to become endangered in the near future. The ESA sets forth a procedure for listing species as threatened or endangered. Final listing decisions are made by U.S. Fish and Wildlife Service (USFWS) or National Marine Fisheries Service (NMFS).

Federal agencies, in consultation with the USFWS or NMFS, must ensure that their actions do not jeopardize the continued existence of the species or habitat critical for the survival of that species. The federal wildlife agencies are required to provide an opinion as to whether the federal action would jeopardize the species. The opinion must include reasonable and prudent alternatives to the action that would avoid jeopardizing the species' existence. Federal actions, including issuance of federal permits, such as the dredge and fill permit required under Section 404 of the CWA, trigger ESA requirements that stipulate the project proponent must demonstrate no feasible alternative exists consistent with the project goals that would not affect listed species. Mitigation is required if impacts on threatened or endangered species cannot be avoided.

The ESA prohibits the "take" of endangered species and threatened species for which protective regulations have been adopted. *Take* is broadly defined to include actions that harm or harass listed species or that cause a significant loss of their habitat. State agencies and private parties are generally required to obtain a permit from the USFWS or NMFS under Section 10(a) of the ESA before carrying out activities that may incidentally result in taking listed species. The permit normally contains conditions to avoid taking listed species and to compensate for habitat adversely affected by the activities.

California Endangered Species Act. The California Endangered Species Act (CESA) is similar to the federal ESA. Listing decisions are made by the California Fish and Game Commission. All State lead agencies are required to consult with the California Department of Fish and Wildlife (DFW) about projects that affect State-listed species. DFW is required to render an opinion as to whether the proposed project jeopardizes a listed species and to offer alternatives to avoid jeopardy. State agencies must adopt reasonable alternatives unless overriding social or economic conditions make such alternatives infeasible. For projects causing incidental take, DFW is required to specify reasonable and prudent measures to minimize take. Any take that results from activities that are carried out in compliance with these measures is not prohibited.

Many California species are both federally listed and State listed. CESA directs DFW to coordinate with the USFWS and NMFS in the consultation process, so that consistent and compatible opinions or findings can be adopted by both federal and State agencies.

Regulatory and Permitting Agencies

Most of the primary agencies that exercise regulatory and permitting authority with regard to water supply facility planning, construction, and operation, and that could exercise authority over construction and operation of desalination facilities in California, are listed in Table 7 along with their primary role. There is a current effort within the State agencies to improve the permitting process of projects along the California coast, and all stakeholders recognize the need to formally adopt a coordinated permitting process.

Regulations for Water Use Efficiency

The State Urban Water Management Planning Act requires urban water suppliers that serve more than 3,000 customers or more than 3,000 af/yr. to prepare and adopt UWMPs. The plans must contain several specified elements, including identifying feasible desalination water supply alternatives. The act requires water suppliers to review and update their plans at least once every five years.

Potential Benefits

Desalination can improve a water supplier’s ability to provide safe and reliable drinking water to its customers. When adopted as part of a diversified resource portfolio, desalination can provide many potential benefits, including:

- Expanding local water supply.
- Improving overall supply reliability by diversifying resource portfolios.
- Providing emergency supplies during drought periods and after extraordinary events.

Expanding Local Water Supplies

For California communities with limited water supplies and viable saline water sources, both brackish groundwater and seawater desalination can provide a local water source. Development of local water resources reduces dependence on imported supplies (e.g., State Water Project or Colorado River water) and vulnerability to water supply reductions that result from drought, climate change, or disruption of imported water. This enables water suppliers to have more confidence in their water supplies, supports water supply reliability and community planning, and reduces the potential for water-related conditions beyond the local suppliers’ control.

Table 7 Regulatory Roles for Municipal Desalination Projects

Organization	Role
FEDERAL	
National Marine Fisheries Service	Provides Endangered Species Act (ESA) Section 7 consultation to address potential incidental take of federally listed species.
National Marine Sanctuaries	Issues Research Permit or Authorization, Education Permit, or Authorization Permit. Reviews other State and federal permits (including U.S. Army Corps of Engineers, RWQCB 401, and NPDES permits) with activities/discharges into waters and wetlands.
U.S. Army Corps of Engineers (USACE)	Issues Clean Water Act Section 404 permit for discharge of dredge/fill into waters of the United States, including wetlands. Issues Rivers and Harbor Section 10 permit for activities, including the placement of structures, affecting navigable waters. Issues permit for survey activities, such as core sampling, seismic exploratory operations, soil surveys, sampling, and historic resources surveys, under Nationwide Permit No. 6, Survey Activities. Issues permit for activities related to the construction or modification of outfall structures and associated intake structures where the effluent is authorized by NPDES under Nationwide Permit No. 7, Outfall Structures and Associated Intake Structures.
U.S. Coast Guard	Provides consultation on Coastal Commission Coastal Development Permit. Provides consultation on USACE Section 10 Permit.
U.S. Environmental Protection Agency	Issues permits for injection wells used for brine disposal by deep well injection
U.S. Fish and Wildlife Service	Provides Endangered Species Act (ESA) Section 7 consultation to address potential incidental take of federally listed species. Provides comments to prevent loss of and damage to wildlife resources under the Fish and Wildlife Coordination Act.
Other Entities	
Federal Energy Regulatory Commission Tribes NOAA	

Organization	Role
STATE	
State Water Resources Control Board, Regional Water Quality Control Board	NPDES, General Permit For Storm Water Discharges Associated With Construction Activity. NPDES Permit in accordance with the Clean Water Act (CWA), Section 402. Water Quality Certification in accordance with CWA Section 401. Waste Discharge Requirements (WDR) per Porter-Cologne Water Quality Control Act.
California State Lands Commission	Issues Land Use Lease (Right-of-Way permit) for right-of-way across State lands.
California Department of Fish and Wildlife (DFW)	Issues Incidental Take Permits where a State-listed candidate, threatened, or endangered species under California ESA may be present in the project area and a State agency is acting as lead agency for CEQA compliance.
California Coastal Commission (CCC)	Issues a Coastal Development Permit within the Coastal Zone, excluding areas where local jurisdictions have approved Local Coastal Plans in place.
California Department of Public Health (CDPH)	Issues a permit to operate a public water system.
California Department of Parks & Recreation Office of Historic Preservation	Consults with project applicant, appropriate land management agencies, and others regarding activities potentially affecting cultural resources, under Section 106 of the National Historic Preservation Act.
California Department of Transportation	Issues Encroachment permits for State roads and highways.
Other Entities	Specific permits or consultations may be required on a project-specific basis.
California Independent System Operator (ISO) California Energy Commission	

Organization	Role
REGIONAL AND LOCAL	
Local Lead Agency	Approves CEQA documentation.
County and City Departments, including but not limited to Planning, Transportation, Public Works, Environmental Health, Building, and various utilities (electrical, gas, solid waste, wastewater, water, and stormwater)	Issue use permits. Issue Coastal Development Permit / Exemption for development within the Coastal Zone where City or County has jurisdiction through Local Coastal Program Consistency. Issue encroachment permits for activities within rights-of-way. Issue grading permits; issue electrical permits; issue erosion control permits; issue building permits; issue right-of-way permits. Issue haul route permits; issue connection permits. Approves hazardous materials management plan. Issues well permits, where jurisdiction is granted.
Air Pollution Control District	Issues permit to construct; issues permit to operate.
Other Entities	
Adjudicated basin watermaster Groundwater management	Adjudicated basin watermaster Groundwater management

Notes:

CEQA = California Environmental Quality Act, ESA = Endangered Species Act, NOAA = National Oceanic and Atmospheric Administration, NPDES = National Pollutant Discharge Elimination System, RWQCB = Regional Water Quality Control Board.

Because desalination makes use of saline water sources that otherwise are unused and unusable, desalinated supplies represent a “new” supply source to the state.

Improving Water Supply Reliability

Improving water supply reliability can be accomplished by having supplies that are consistently available or by having a diverse water supply portfolio, that is, multiple sources from which water can be obtained. A water supplier with a diverse water supply portfolio has more flexibility, particularly when managing how it supplies water to its customers under changing conditions. Changing conditions can include customer demands, available supplies, or environmental or climatic conditions. For example, if surface water supplies are constrained, having groundwater, recycled water, and/or desalinated water available enables water suppliers to look at cost, system conditions, and other factors involved in meeting demands.

Both brackish groundwater and seawater desalinated supplies can be a highly reliable component of a water supply portfolio because they tend to be less influenced by changing conditions than other sources.

Providing Emergency Supply

Some communities have established desalinated water as an emergency supply option. Because desalinated supplies tend to have a higher unit cost than other sources, these water suppliers maintain desalination facilities on a stand-by basis and only operate them when other sources of water are not available. This approach enables water suppliers to maintain a base level of water supply in times of extreme shortage, but it can require higher capital and maintenance costs than other sources. For suppliers in water-constrained regions, this approach can provide needed flexibility and supply. For example, Marina Coast Water District and the City of Morro Bay maintain standby seawater desalination facilities.

Mobile water treatment units, including those capable of desalting sea or other saline waters, can provide emergency potable water supplies for small towns and communities during droughts, emergencies, or unplanned disruption of their primary water supplies. Unlike permanent desalination plants, temporary mobile units can be commissioned, installed, and put into production relatively quickly, provided environmental and other concerns are addressed. They can also be quickly moved or decommissioned, as necessary. A white paper prepared in 2009 by DWR (BenJemaa 2009) on mobile desalination units is available on the DWR's Desalination Web page: http://www.water.ca.gov/desalination/.

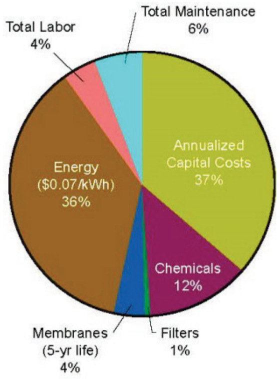
Potential Costs

While technological improvements over time have reduced the cost of desalination, it still remains one of the most expensive options for water supply. Nonetheless, it is typically the case that, in areas where a new water supply is being sought, many of the low-cost alternatives have already been implemented. The costs are rising for new conventional supplies and expanded water conservation and recycling. Desalination offers benefits of reliability during droughts and resiliency during interruptions of other supplies that may offset the higher cost. Within the context of overall water management objectives, desalination is becoming a more feasible alternative despite cost considerations.

Each component of the desalination system shown in the general schematic of Figure 3 has capital and operational costs associated with it. The cost of desalination is especially influenced by the type and salinity of source water, the available concentrate disposal options, the proximity to potable water distribution systems, and the availability and cost of power. The cost of desalination treatment is also influenced by size. The unit cost of construction of a 50 mgd membrane desalination plant may be half the cost of a 1 mgd plant. Combined capital and operating costs of existing groundwater desalters in Southern California range from $600 to $3,000 per acre-foot. Recent estimates for proposed large-scale seawater desalination projects in California range from about $1,600 to $3,000 per acre-foot. Pre construction planning costs, including feasibility evaluations, pilot studies, and environmental monitoring, can also be considerable for seawater desalination. Caution should be exercised when using reported values of costs, including the costs above, because of site-specific variation of costs and the varied assumptions incorporated into reported costs. Often, costs of various system components shown in Figure 3 are not included.

A significant cost of desalination is the cost of energy. This is illustrated in Figure 9, showing the distribution of costs by type of cost for a seawater RO plant with conventional pretreatment. Energy constitutes 36 percent of total capital and operational costs. Much of the research on desalination is focused on technology that can reduce energy needs.

Figure 9 Annual Cost Breakdown in 50 mgd Seawater RO Plant with Conventional Pretreatment



Source: Committee on Advancing Desalination Technology 2008

Notes: kWh = kilowatt hour, mgd = million gallons per day, yr = year

Major Implementation Issues

The major implementation issues associated with desalination as a viable resource management strategy can be placed in the following categories:

- Permitting and Regulatory framework.
- Energy use and sources.
- Climate change.
- Funding.
- Intakes and ocean and freshwater ecosystems.
- Concentrate (brine) management.
- Subsurface extraction.
- Planning and growth.

These implementation issues are discussed in the following sections.

Permitting and Regulatory Framework

Two permitting and regulatory issues have been identified: coordination of permitting and protection of source waters used for municipal drinking water. As described in the "Legal and Regulatory Framework of Desalination in California" section above, there can be over 30 federal, State, and local agencies that have some regulatory or permitting authority over desalination projects. While any single project may not have to encounter all of these, the regulatory process can be formidable and lengthy. A need for coordination among agencies has been identified (California Department of Water Resources 2003).

One effort to improve coordination was the creation of the Seawater Desalination State Interagency Workgroup in 2012. It has been proposed that the State permitting agencies establish an agency priority sequence for permit reviews to improve coordination at the project level.

A key element in the protection of sources of drinking water is the designation of water bodies for this beneficial use in water quality control plans adopted by the RWQCBs and SWRCB. As described in the "Legal and Regulatory Framework of Desalination in California" section, brackish and seawater sources used for municipal drinking water after desalination are not designated for this beneficial use. Desalination is very effective in removing constituents in water that could be harmful to human health; however, desalination does not remove all chemicals, including some chemicals with known health effects. General concern is circulating among water quality management regarding the thousands of manufactured chemicals introduced into the environment, with little or no testing for human or environmental effects. These chemicals are commonly referred to as chemicals of emerging concern. A regulatory strategy has not been developed to prevent potentially harmful chemicals of emerging concern or other chemicals of known health effects from occurring in brackish or seawater sources of drinking water. Source water assessments could be used to identify zones of protection for saline waters used for drinking water, assess the potential contaminant activities, and identify chemicals that desalination cannot be expected to remove. Water quality control plans could designate zones in saline waters for protection as sources of drinking water after desalination and include appropriate regulatory measures, such as water quality objectives or implementation programs, to provide reasonable protection for this use.

Energy Use and Sources

Energy use is a significant factor in water desalination projects for reasons of costs and environmental impacts of energy generation. Each of the elements in a desalination system, as shown in Figure 3, entails energy use, but the most significant energy use is in the treatment process where the salt ions are removed. Generally, the energy requirement of RO desalination is a direct function of the salinity level and the temperature of the feedwater source. Given similar operating conditions and treatment plant parameters, brackish water desalination is usually less energy intensive, and hence less costly, than seawater desalination. Several summary reports on desalination and energy intensity of water supply and treatment systems have been published that report data on the energy intensity of desalination processes. Drawing from an array of studies (Klein 2005; GEI Consultants/Navigant Consulting 2010; Wilkinson 2000; Cooley and Heberger 2013; Cooley and Wilkinson 2012; WateReuse Desalination Committee 2011), it has been determined that energy intensity for seawater desalination ranges between 3,300 kilowatt hour per acre-foot (kWh/af) and 5,900 kWh/af, and for brackish water desalination between 1,000 kWh/AF and 2,700 kWh/AF.

To compare the energy intensity of desalinated water supplies with the energy intensity of other water supplies provided in each regional report, a factor for water treatment would have to be added to the energy intensities of "raw water" provided in the regional reports (see *California Water Plan Update 2013,* Volume 2). The energy of conventional water treatment is typically between 50 kWh/af and 650 kWh/af, depending on the capacity of the treatment plant and the quality of incoming raw water (Cooley and Wilkinson 2012; WateReuse Desalination Committee 2011).

For a seawater desalination RO facility, 28 percent to 50 percent of total annual costs, including annual capital recovery costs, are devoted to energy consumption (WateReuse Desalination Committee 2011). However, improvements in RO membranes and the incorporation of energy recovery devices in treatment facilities have resulted in reduced energy needs for new facilities compared with older projects. While research continues, it is not expected that further major reductions will occur in the near term.

Because of the high energy requirements for desalination, it is especially important to look at the sources of power used to operate plants. Although there has been an overall emphasis on expanding reliance on sustainable/renewable energy sources within California, fossil-fuel- based power plants continue to be a major source of energy, about 62 percent of total in-state electricity generation. Significant improvements in energy generation technology have reduced the environmental impacts associated with energy generation; nonetheless, energy generation (including exploration, extraction, and conversion to electricity) continues to result in significant environmental impacts. Air pollution, including GHGs, groundwater pollution, water use, and despoiling of scenic views and wildlife habitat are major concerns associated with new and existing energy generation. Many of these concerns apply not only to just fossil energy sources, but also to renewable power.

Aside from drawing electricity from a power grid to operate desalination facilities, it has been proposed that renewable energy generation be incorporated directly into such facilities. In some proposals, seawater desalination would take advantage of its proximity to the natural energy within the ocean environment. A commercial-scale wave energy project is being constructed by Carnegie Wave Energy Ltd in Western Australia, to provide hydroelectric power to a naval base. The project is also designed to provide water pressure to a desalination pilot plant (Australian Renewable Energy Agency 2014). In addition, research is being conducted on two concepts funded by the EPA: the microbial desalination fuel cell and desalination with a solar evaporation array.

Climate Change

General

As water resource planners and managers move to develop water supplies, they will need to address potential climate change impacts. Climate change projections include warmer air temperatures, diminishing snowpack, precipitation uncertainty, increased evaporation, prolonged droughts, and sea level rise. These anticipated changes could further reduce water supply in many regions, including those that are already experiencing difficulty meeting current water demands. Climate change impacts will put additional stress on aging freshwater collection, storage, and conveyance infrastructure, thereby reducing the capacity to provide a stable source of drinking water.

DWR projects that the Sierra snowpack will experience a 25-40 percent reduction from its historic average by 2050, limiting the amount of water that can be supplied during the summer and fall months. Prolonged droughts with changes in precipitation and runoff patterns will likely affect communities that rely on surface water deliveries, making them more dependent on groundwater sources. Sea level rise could increase salt water intrusion to coastal freshwater aquifers, resulting in brackish waters that would require treatment to attain drinking water standards. Aside from water availability impacts resulting from climate change, initial estimates of watershed models show that increases in temperature and consequent increases in evapotranspiration will cause a higher water demand. Sea level rise could put at risk facilities at low elevations.

Adaptation

As the impacts of climate change continue to intensify, desalination may become a more attractive adaptive strategy. Desalination provides a water supply that remains robust even during extreme drought periods; desalination capacity will not be affected by rising sea levels, decreased exports from the

Sacramento-San Joaquin Delta, or changes in snowpack runoff. For these reasons, desalination is an adaptation strategy to improve the resiliency and reliability of a region's water supply, even in the face of uncertain future climate conditions. To remain a reliable water source, all municipal drinking water facilities, especially coastal desalination facilities, need to be located away from or protected from rising sea levels and other events that could increase their vulnerability to flooding and erosion.

Mitigation

Because of the higher energy intensity of desalination (when compared to most alternative water supplies), energy use and associated GHG emissions from desalination pose a major concern. While desalination may be used to increase water supplies and provide a climate-resilient and robust water supply, operation of desalination facilities may have associated substantial GHG emissions, depending on the type of energy used to operate them. Some energy sources contribute to existing atmospheric GHG concentrations and lead to larger future climate changes. Potential mitigation opportunities include reduced energy consumption by increasing operational and process efficiencies and coupling or dedicating renewable/sustainable energy sources not generating GHGs to desalination facilities.

The energy factors provided in the "Energy Use and Sources" section of this resource management strategy report can be converted to GHG emissions by using a GHG emission factor for the region or the energy utility that would provide power for desalination. The California region$_2$ (Comprehensive Air Quality Model with Extensions, or CAMX) average GHG emissions rate for electricity is 0.300 metric tons of carbon dioxide equivalent (CO_2 e) per megawa^{2}tt hour (MWh). Emissions rates for specific utilities' service areas and other states can be found at http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html. Looking at specific proposed seawater desalination projects in California, Cooley and Heberger (2013) arrived at an average of 0.39 metrics tons of CO_2 e/MWh.

As previously stated, though desalination is a proven technology, its energy requirements are higher in most cases than levels necessary for importing and treating water or using local groundwater and surface water sources. Brackish water desalination is comparable in energy intensity to recycled and imported water supplies, while seawater desalination is considerably more energy intensive than most other water supply options. As an energy-intensive process, desalination has the potential to counteract the GHG reduction goals of California if fossil-fuel- powered plants are used as a primary energy source. Then again, desalination operations can take measures to optimize efficiency, purchase renewable energy, minimize GHGs on-site, and mitigate for emissions off-site to reduce their overall carbon footprint.

Funding

The California Legislature emphasized the importance of water desalination in 2003 with the passage of Assembly Bill 314, 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 (California Water Code, Section 12947).

Implementation of water desalination involves capital financing to plan, design, and construct facilities and revenue sources to pay for debt service (loan repayment) and operational costs. To advance desalination technology and address implementation issues, financing is also needed for research and special studies.

Capital financing is often through borrowed funds, especially the sale of bonds. Many agencies set aside a part of their annual revenue in a capital reserve fund for future projects. Grants and low-interest loans from State and federal governments are also available at times.

Annual revenues are derived primarily from the sale of water. Other sources include parcel tax assessments and incentive rebates from regional water suppliers. Individual water users may also pay for projects that directly benefit them, such as an industrial facility installing on-site or off- site infrastructure to receive or produce desalinated water.

The following list provides potential sources of financial assistance to local agencies seeking to facilitate the implementation of water desalination.

- **Water Desalination Grant Program**. DWR administers this program funded by Proposition 50, the Water Security, Clean Drinking Water, Coastal and Beach Protection Act of 2002. Chapter 6 of that proposition authorized $50 million in grants for desalination projects. The program assists local public agencies with the development of 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 awarded approximately $46.25 million in grants to 48 projects. Five projects were subsequently cancelled, leaving 43 projects as shown in Table 8. The five construction projects produce approximately 30,000 af/yr. of water. A third round of funding was released in early 2014, awarding approximately $8.7 million from unused grant funds.
- **Integrated Regional Water Management Grant Program.** DWR administers this program funded by Proposition 50 and Proposition 84, which was approved in 2006. The IRWM grants are for water supply and management projects, including desalination, arrived at through a cooperative process with stakeholders to cost-effectively meet the regional goals and objectives. This program has resulted in more than 10 desalination projects. Additional funding will be available from this program.
- **Title XVI: Water Reclamation and Reuse Program**. This federal program (authorized by Title XVI of Public Law 102-575), administered by USBR, funds water projects, which include those reclaiming naturally impaired water, throughout the western United States. This program has funded several desalination projects or studies in California.
- **Other Federal Programs.** Potential funding sources administered by USBR include the Basin Studies program, which could incorporate desalination planning; Advanced Water Treatment Pilot and Demonstration Grants, which aim to encourage pilot and demonstration projects that address technical, economic, and environmental viability of treating and using brackish groundwater, sea water, impaired waters, or otherwise create new water supplies within a specific locale; and the WaterSMART Water and Energy Efficiency Grant Program.

National desalination research and development efforts have been funded through at least nine federal agencies and laboratories, each with their own research objectives and priorities.

The majority of federal desalination research and development funding also comes from congressional earmarks, which limit the ability to develop a stable research program (Committee on Advancing Desalination Technology 2008). National foundations have been active in funding desalination research,

Table 8 Proposition 50 Desalination Funding by DWR

Project Category	Number of Awarded Projects	Awarded Projects Total Cost	Awarded Grant Amount
Construction Projects	5	$92,162,000	$11,700,000
Feasibility Studies	11	$5,059,700	$2,318,793
Pilots and Demonstration Projects	14	$46,434,279	$15,704,793
Research and Development Projects	13	$21,298,077	$8,730,710
Total	**43**	**$164,954,056**	**$38,453,951**

especially the WateReuse Research Foundation and Water Research Foundation. DWR, by using Proposition 50 funds, also has contributed to research efforts.

Financial aid and other funding opportunities are critical to the progression of the desalination strategy at the national, State, regional, and local levels. The recent successful progression of desalination from a cost-prohibitive alternative to the alternative of choice is attributable, in part, to funding contributions from State and federal governments and the foundations.

Intakes and Ocean and Freshwater Ecosystems

A primary concern associated with coastal desalination plants using open-water intakes is the impact of feed-water intake on aquatic life. Surface intakes of sea water result in impingement and entrainment of marine organisms. This impact can be avoided or reduced to insignificant levels by proper design of open water intakes or use of subterranean intakes (e.g., beach wells and under-ocean-bed intakes), wherever feasible. It is important to have a strong regulatory structure to ensure protection of the ocean and other aquatic environments.

Desalination may be a means of protecting freshwater or inland ecosystems by reducing reliance on water extracted from inland zones. Restrictions put in place to protect fish and wildlife within an inland watershed zone may prevent a community from meeting its freshwater supply sources within the affected watershed zone.

In the past, seawater desalination has been able to gain cost efficiency by sharing intake and discharge structures with coastal power plants. This option, however, has been diminished. To reduce the harmful effects power-plant cooling water has on marine and estuarine life by using sea water with surface water intakes, the SWRCB has adopted a policy preventing any new once- through cooling power plants (State Water Resources Control Board 2011).

Concentrate (Brine) Management

The desalination process produces a salty concentrate (brine) that must be properly managed. This brine must be handled in an environmentally safe and sustainable manner in accordance with regulations. The quantity and salinity of the concentrate varies with the type of technologies employed in operating the plant.

The main options for concentrate management are listed in the “Concentrate Management” section, above. The discharge of brine into water bodies poses problems when the salinity of the brine is significantly different from the receiving water. Higher saline brine will tend to sink to the bottom, adversely affecting organisms that reside in the benthic zone, that is, the ecological region of the sediment surface and immediately below the sediment surface. Brine applied on land, either in ponds, landfills, or irrigation sites, can contaminate groundwater if the salts are allowed leach downward.

The adverse effects from discharge of brine into such water bodies as the ocean can be reduced by inducing rapid mixing of the brine with receiving water to reduce its concentration and tendency to sink. Nonetheless, while the plume of brine is suspended before complete mixing, there is a zone within the water that is harmful to fish and other aquatic life. Considerable attention and testing is devoted to brine discharge diffusers to enhance the mixing and minimize the adverse effects on either the benthic zone or the water column.

Percolation of saline water coming from brine applied on land can be prevented through proper design of evaporation ponds or landfills. Irrigating with water that contains brine is not common because it is only practical where the brine is of low concentration, as from brackish water desalination, and of low volume, and when it is applied to salt-tolerant plants.

It is more likely that brackish water plants in California discharge their concentrate to municipal wastewater collection systems where it is subsequently treated and disposed of with other municipal wastewater. For brackish water desalination plants, this type of concentrate management is likely to continue where the wastewater treatment system capacity is adequate. Seawater desalination produces a concentrate approximately twice as salty as sea water. In addition, residuals of other treatment chemicals may be in the concentrate of brackish and sea water. Some plants currently being planned will use existing power-plant or wastewater plant outfall systems to take advantage of dilution and mixing before discharge to the ocean or adjacent water bodies. The option of sharing brine discharge with power-plant cooling water discharges is diminishing as restrictions are placed on power plants. On the other hand, co-locating concentrate discharge with wastewater effluent in ocean outfalls 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 comparable or closer to that of sea water.

Brine discharges from desalination facilities are regulated by the SWRCB through the issuance of a NPDES permit that contains conditions protective of aquatic life. Concentrate management requires integration with other plans adopted by the State, such as the Ocean Plan and Enclosed Bays, Estuaries and Inland Surface Waters Plan. At the time this resource management strategy report was written, these plans did not address the impacts of intakes and brine discharge. However, an amendment of the Ocean Plan to address desalination is expected in 2014, to be followed by an amendment to the Enclosed Bays, Estuaries and Inland Surface Waters Plan.

Subsurface Extraction

When considering a source for water supply, the safe yield of the water body must be determined. While *safe yield* has previously been defined to include only groundwater sources, USBR defines it as the annual quantity of water that can be taken from a supply source over a period of years without depleting the source beyond its ability to be replenished naturally in wet years (U.S. Bureau of Reclamation 2012). Groundwater overdraft, even of brackish water, can have negative consequences. Overdraft can cause land subsidence. Surface water bodies, such as streams or lakes, connected to aquifers might become depleted through the extraction of groundwater, affecting both water rights and aquatic life. When the safe yield of a subsurface water source is limited, it may be best to reserve the water for such emergencies as droughts.

The extraction of saline water for desalination should not cause intrusion of lower quality water, such as sea water or polluted water, into a fresher water source. *Seawater intrusion* is the subsurface flow of sea water into a subsurface water body. The higher density of sea water allows it to flow beneath the fresher water and move inland. Groundwater extraction exacerbates the inland flow by lowering the groundwater level and reducing the overlying pressure, allowing sea water to flow further inland. Because sea water has high salt content, the influx causes a degradation of water quality. This can result in higher water treatment costs or wells being abandoned. Brackish groundwater extraction near the coast could exacerbate seawater intrusion.

Because aquifers are often interconnected to surface water bodies, such as streams or lakes, groundwater extraction affects these surface water sources. The known ecological impacts of groundwater overdraft in California include diminished stream flow and lake levels, damaged vegetation, effects on fish and migratory birds, and land subsidence. The interaction of groundwater with surface water needs to be considered when brackish groundwater is a desalination source.

Planning and Growth

There are many factors to consider before deciding whether to implement a water desalination project. Desalination should be analyzed in comparison with other alternatives that could achieve the same project objectives. In the context of this resource management strategy, obtaining a municipal water supply would be a primary objective. Established feasibility criteria applied in water resources planning are:

- Ability to meet project objectives.
- Technical feasibility.
- Economic justification.
- Financial feasibility.
- Environmental feasibility.
- Institutional feasibility.
- Social impacts.

As with any water resources project, desalination cannot be evaluated on the basis of any single criterion. Water supply alternatives rarely include an outstanding alternative that meets all of a community's vision for the future and the needs and goals to achieve that vision. All alternatives, including desalination, need to be evaluated together by applying the evaluation criteria listed above.

Drawing on the work of the California Water Desalination Task Force, which was convened in 2003, DWR published *the California Desalination Planning Handbook* (California Department of Water Resources 2008). This handbook is a valuable 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 when determining whether and how to proceed with a desalination project.

There are major issues facing desalination, as described in other sections, including cost, environmental impacts, GHG emissions, and growth inducement. A methodical planning process with community involvement is the best way to minimize negative impacts and to weigh these impacts against those of other water supply options and the supply reliability and other benefits of desalination. Even the presence of some unavoidable adverse impacts may be acceptable. The regulations implementing CEQA state the following:

> CEQA requires the decision-making agency to balance, as applicable, the economic, legal, social, technological, or other benefits, including region- wide or statewide environmental benefits, of a proposed project against its unavoidable environmental risks when determining whether to approve the project. If the specific economic, legal, social, technological, or other benefits, including region-wide or statewide environmental benefits, of a proposal project outweigh the unavoidable adverse environmental effects, the adverse environmental effects may be considered 'acceptable'. (California Code of Regulations, Title 14, Division 6, Chapter 3, section 15093[a])

One of the issues has been the assertion that desalination is "growth-inducing." Any water supply or water management alternative, including water conservation, which augments or frees up water supply to accommodate new water demands, has the same potentially growth-inducing impact. A community's vision for population growth and land development ideally should be resolved in a broader context of community planning, such as county general plans, not water supply planning. State CEQA guidelines require that growth-inducing impacts of a proposed project be discussed in environmental documents. Nonetheless, as stated in the guidelines, "It must not be assumed that growth in any area is necessarily beneficial, detrimental, or of little significance to the environment" (California Code of Regulations, Title 14, section 15126.2[d]).

The goal of a water resources planner is to meet the needs of the community for a reliable water supply now and in the future, aligned with how the public envisions future land use and population. Desalination is part of the portfolio of potential supplies that should be considered. An analysis of desalination is required as part of UWMPs to comply with the Urban Water Management Planning Act (California Water Code, Section 10631) and IRWM plans submitted as part of DWR's Integrated Regional Water Management Grant Program.

Recommendations

Desalination of brackish and sea water is a proven technique to augment water supplies in a balanced water supply portfolio. Treatment of brackish groundwater for beneficial use is a common practice in

California, and in some places it approaches conventional treatment status. Small-scale seawater desalination facilities (less than 5 mgd) have been built, but as of 2013 seawater desalination has not become an established method to meet municipal water demands.

Desalination, particularly of sea water, has been a challenge. If desalination is to be an appropriate and successfully implemented component of California's water supply, certain constraints need to be agreed on and certain actions need to be taken in the planning, regulatory, and scientific arenas.

Nevertheless, sea and brackish surface waters constitute potential water supplies in many parts of California, even as they already are throughout the world, and water supply planners in California are increasingly looking to desalination as a means of diversifying water supply portfolios.

Policy

1. The State recognizes that desalination is an important water supply alternative and, where economically, socially and environmentally appropriate, should be part of a balanced water supply portfolio that includes other alternatives, such as conservation and water recycling.
2. Desalination should be implemented in a manner consistent with environmental protection and water sustainability goals. Regulatory agencies should have a strong regulatory framework, with adequate resources to establish technically sound criteria that provide adequate environmental safeguards for water supply projects, including desalination.
3. The State recognizes that desalination requires energy to operate; to mitigate the energy needs where economically and environmentally appropriate, project sponsors and water suppliers are encouraged to consider coupling energy from sustainable sources.

Actions

4. Project sponsors and water suppliers should evaluate the potential for groundwater and surface water desalination as a means of meeting current and future water demands. This evaluation will provide communities across the state with the information they need to make sound choices on water supply options, and where appropriate via science-based decision- making for a sustainable future.
5. When planning a water supply project as part of an IRWM plan prepared in order to acquire State funding, project sponsors and water suppliers shall consider desalination as a strategy to meet the goals and objectives of the region (California Water Code, Section 10530).
6. Desalination should be evaluated using the same well-established planning criteria applied to all water management options, using such feasibility criteria as water supply need within the context of community and regional planning; technical, economic, financial, environmental, and institutional feasibility; social impacts; and climate change. *The California Desalination Planning Handbook*, published by DWR, should be one of the resources used by water supply planners (California Department of Water Resources 2008).
7. Project sponsors and water suppliers should evaluate desalination within the context of integrated water management to better reflect community and regional needs and priorities with respect to water quality protection, water supply, growth management, brine disposal, and economic development. Water management planning should occur within a wider context of community values and visions for the future. Key stakeholders, the general public, and permitting agencies need to be engaged in the planning process.

8. DWR, in collaboration with regulatory agencies, should lead an effort to create a coordinated, streamlined permitting process for desalination projects. Because of the many regulatory agencies involved in desalination of ocean, bay, or estuarine waters, a coordinated framework to streamline permitting approvals without weakening environmental and other protections should be explored. Establishing an appropriate sequencing of approval by the various agencies may be appropriate. The Ocean Protection Council may be an appropriate and a reasonable choice for the role of coordinating regulatory reviews and guiding project sponsors through the regulatory process.
9. Project sponsors and water suppliers should evaluate climate change impacts, primarily with regard to GHG generation from energy consumption, for proposed desalination projects within the context of available water-supply alternatives. Note that desalination should not be precluded solely on the basis of energy consumption, because the allocation of energy to meet water supply needs and reliability may be considered of higher social value to a community than other uses of energy.
10. Desalination projects developed by public agencies, as well as utilities regulated by the California Public Utilities Commission, should have opportunities for State assistance and funding for water supply and reliability projects.
11. Research and investigations should continue to develop new or improved technologies to advance and refine desalination processes, feedwater intake and concentrate management technologies, energy efficiencies, and the use of alternative and renewable energy sources. The State legislature is urged to provide additional funding for desalination research.
12. DWR should be adequately funded to maintain technical expertise and current data on the status of brackish and seawater desalination in California, to support the planning and policy roles of State government and to be an information resource to the public.
13. The SWRCB, in consultation with CDPH and DWR, should develop an effective regulatory framework, via source water assessment plans and water quality control plans, for protection of saline waters for the beneficial use of municipal drinking water after desalination treatment. The framework should provide reasonable protection against chemicals of emerging concern and constituents that are known to be harmful in drinking water and cannot reliably, readily, and feasibly be removed with existing technology, such as that currently employed in RO desalination systems.

Desalination in Resource Management Strategies

The following resource management strategies have additional information related to the use of desalination or issues addressed in these resource management strategy reports:

- *Municipal Recycled Water*.
- *Drinking Water Treatment and Distribution*.
- *Salt and Salinity Management*.
- *Land Use Planning and Management.*

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