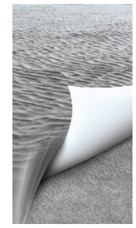

Chapter 4

Environmental Impacts and Mitigation Measures

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INTRODUCTION

The purpose of this chapter is to provide an overview of key environmental impacts of seawater desalination plant construction and operation, and to discuss alternatives for environmental impact minimization and mitigation.

The environmental impacts of seawater desalination plant operations have many similarities to those of conventional water treatment plants. Similar to conventional water treatment facilities, desalination plants have source water intake and waste stream discharge that may impact the aquatic environment in which they are located. In addition, desalination facilities and conventional water treatment plants may use many of the same chemicals for source water conditioning, and therefore, have similar waste streams, apart from salinity, associated with the disposal of the spent conditioning chemicals and the source water solids. Seawater desalination plants, however, use large pumps and motors that have potential to be larger sources of noise pollution than similarly sized conventional plants. These pumps also consume relatively large amounts of electricity and therefore, may have direct and indirect impacts on air quality and greenhouse gas emissions.

Despite many of the similarities of their environmental impacts, desalination plants have several distinctive differences as compared to conventional water treatment plants: (1) they use approximately 1.5 to 2.5 times more source water to produce the same amount of fresh water; (2) they generate a discharge with elevated salinity, which typically has

1.5 to 2 times higher TDS concentration than that of the source seawater; and (3) they use five to ten times more electricity for treatment of the same volume of freshwater.

The environmental impact of desalination plant operations should be assessed in the context of the environmental impacts of water supply alternatives that may be used instead of desalination. Desalination projects are typically driven by the limited availability of alternative lower-cost water supply resources, such as groundwater or fresh surface water (rivers, lakes, etc.). However, environmental impacts may also result from continuation of those water supply practices. For example, over-pumping of freshwater coastal aquifers for years in a number of areas has resulted in a significant increase in the salinity of the groundwater and has damaged these aquifers. In some arid areas, transfers of fresh water from a traditional water supply source, such as a river, river delta, or a lake, have impacted the eco-balance in this freshwater source to an extent that the long-term continuation of this water supply practice may result in significant and irreversible damage of the ecosystem of the traditional freshwater supply source. In such cases, the environmental impacts of the construction and operation of a new seawater desalination project should be weighed against the environmentally damaging consequences from the continuation/expansion of the existing fresh-water supply practices. In addition, the impacts of a seawater desalination facility should be considered against the impacts of water reuse alternatives, both potable and nonpotable.

Waste streams generated from desalination plants, with the exception of the high-salinity reject water, are similar to the waste streams generated by conventional water treatment plants and water reuse facilities. Water reclamation plants also generate waste streams that contain some of the same chemicals used for desalination and may also have elevated content of man-made waste substances, which may have potential impacts on the marine environment.

SOURCE WATER INTAKES

The main purpose of intakes is to collect source seawater of adequate quantity and quality needed to produce desalinated water. Because intake water quality has a significant impact on desalination plant operations, desalination intake design should target collection of water with minimal inorganic, to the extent possible, and organic content, including marine life. As indicated in Chapter 3 of this manual, seawater desalination plants use two types of source seawater collection facilities: subterranean or subsurface intakes (wells and infiltration galleries) and open ocean intakes. It should be noted that a subsurface infiltration gallery will typically operate like a well intake with respect to entrainment and impingement issues. However, it may face similar impacts during construction as an open intake, because construction is typically done offshore and because of the large area needed for this intake.

Impingement and entrainment of marine organisms by the desalination plant intake are considered the two main potential environmental impacts of these facilities, and are particularly associated with open ocean intakes. Impingement occurs when aquatic organisms are trapped against intake screens by the velocity and the force of the flowing source water. Entrainment occurs when marine organisms pass through the intake screens and enter into the process equipment and treatment facilities where some of them are destroyed.

The impacts of impingement and entrainment vary considerably with the volume and velocity of feed seawater and the use of mitigation measures developed to minimize their impact. Impingement and entrainment of aquatic organisms are not environmental impacts unique to open intakes of seawater desalination plants only. Conventional freshwater open intakes from surface water sources (i.e., rivers, lakes, estuaries) may also cause measurable impingement and entrainment. Often, freshwater sources contain a large content and variety of aquatic species, similar to open ocean waters. However, the impingement and entrainment impacts of these intakes have been either accepted or addressed at numerous freshwater supplies throughout the United States. Disproportionately elevated attention of impingement and entrainment issues associated with seawater intakes may stem, in part, from federal regulations that address this topic for power generation plants and from the environmental scrutiny associated with their public review process.

Similar to environmental impacts from other aspects of desalination plant operation, the magnitude of impacts due to entrainment and impingement varies significantly from one location to another. Therefore, when assessing the impacts caused by the intake of a desalination facility, it is essential to consider the applied technology and operational practices, the actual volumes and velocity of water being drawn into the desalination plants, and the species composition and abundance of the seawater surrounding the intake.

Subterranean or Subsurface Intakes—environmental impacts and mitigation measures**.**

Subsurface intakes could have a number of environmental impacts, such as loss of coastal habitat during construction, visual and aesthetic impacts, and impacts on nearby coastal wetlands depending on their method of construction and their design for well completion. The magnitude of these impacts and potential mitigation measures are discussed in the following sections for the installation of subsurface intakes constructed as wells, commonly referred to as beach wells. Such impacts and widely used mitigation measures are also discussed.

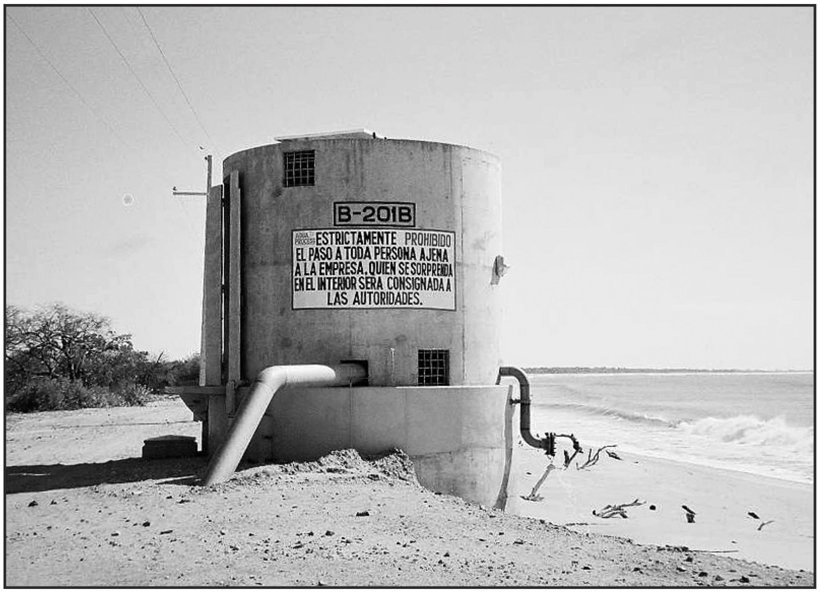
Impingement and entrainment. Because subsurface intakes naturally filter the collected seawater at low velocities through the granular formations of the coastal aquifer in which they operate, their use minimizes entrainment of marine organisms into the seawater desalination plant. It should be noted however, that to date no scientific or engineering studies have been performed to assess and document the entrainment impact of subsurface intakes because usually regulatory agencies assume that such impact is insignificant. The source seawater collected by this type of intake typically does not require mechanical screening, and therefore, subsurface intakes do not cause impingement impacts on the marine organisms in the area of the intake.

Visual and aesthetic impacts and mitigation measures. The visual and aesthetic impacts of beach well intakes are dependent on the location of the wellhead and the style of well completion used. If the beach intakes (wells) can be constructed below grade, at grade, or near grade to minimize impacts, submersible well pumps can be installed below grade and the structures made watertight. The electrical controls and auxiliary equipment can be installed within the watertight structure or located at a remote location near the intake, off the beach, for protection. In these cases, there may be little or no visual or aesthetic impacts for this kind of intake completion.

If the beach intake must be constructed above grade (see Figure 4-1), the magnitude of this impact will vary according to the physical placement of the wells and the height above grade that is required. With radial collector wells, it is possible to locate the well structure back from the beach and extend the well screens out underneath the beach to reduce visual impacts.

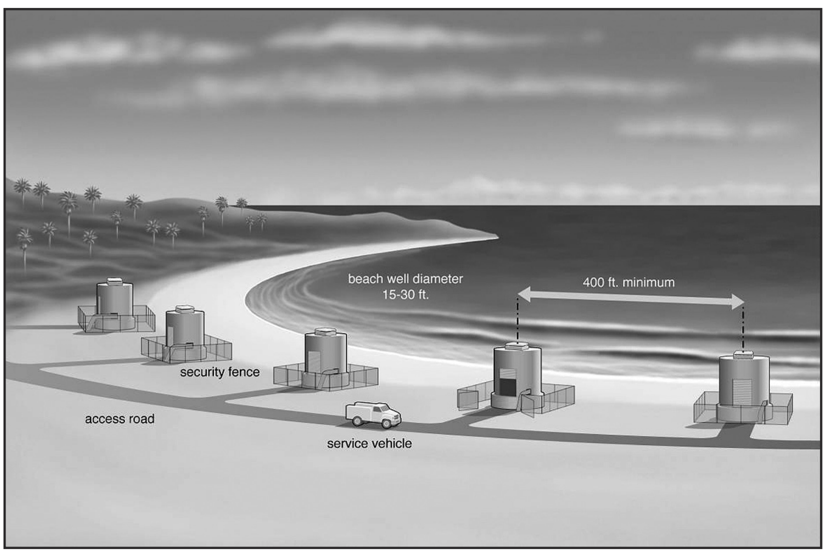
Considering that the desalination plant source water must be protected from acts of vandalism and terrorism, the individual beach wells may have to be fenced off or otherwise protected from unauthorized access (see Figure 4-2).

The larger beach well (e.g., concrete) must have secured access and/or be fenced off, which damage's the beaches visual and aesthetic appeal, while subgrade or near-grade completion could utilize secured access hatches and would have limited impacts. Because beaches are visually sensitive areas, the installation of above-grade beach wells may affect the recreational and tourism use and value of the seashore, and may change the beach appearance and character if structures cannot be located at strategic locations within the area.



Courtesy of Water Globe Consulting

Figure 4-1 3.8 MGD intake beach well of a large seawater desalination plant



Courtesy of Water Globe Consulting

Figure 4-2 Beach well intake system (abovegrade completion)

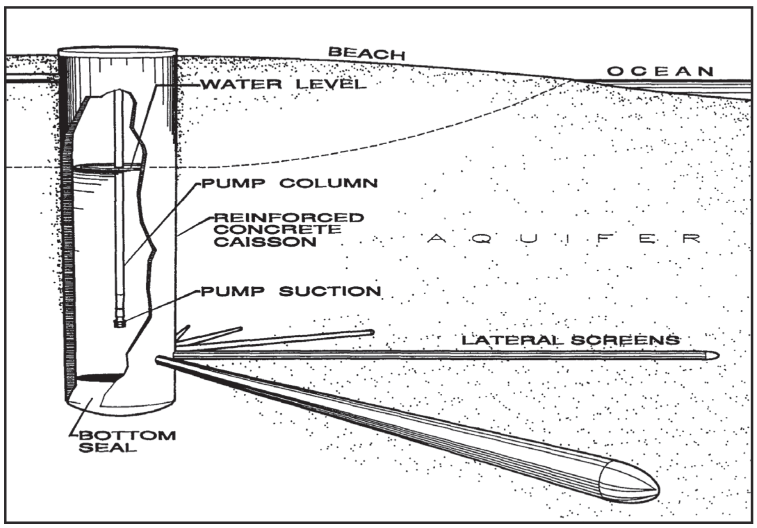
For comparison, open coastal intakes that can have the pumping facilities located back from the shoreline are typically lower-profile structures that may blend better with the coastal environment and its surroundings. However, if a large pumping structure is needed to house numerous pumps and/or screening systems, even a well-set-back structure, whether open intake or beach well, may have visual impacts on the environment.

Installing the intake wells and pumping gallery in a set-back location, often located behind the beach, is usually preferable, especially if less environmentally sensitive area of adequate size is available near the desalination plant site and the shore (see Figures 4-3 and 4-4). These two general locations for the wells can utilize different well designs to accommodate local geographic settings and other social-environmental issues. These designs include wells that are:

a. Completed below grade, which can include the wellhead being completely buried to eliminate visual impacts, either on or behind the beach.

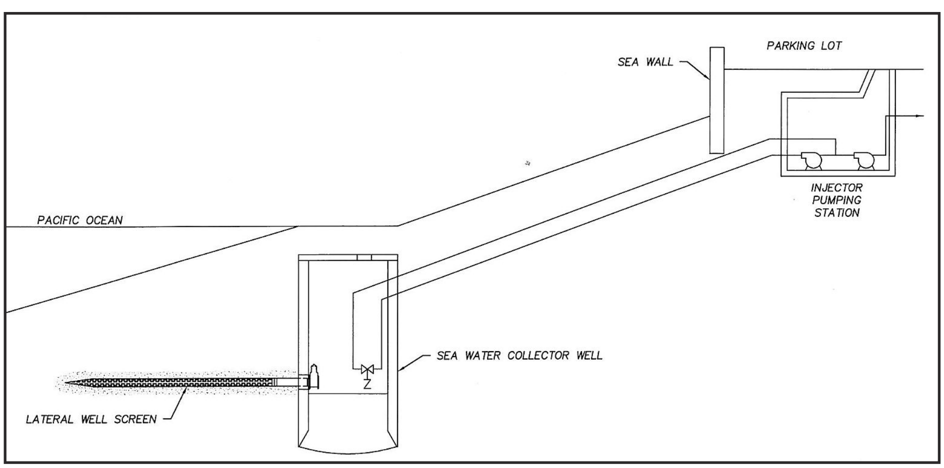
b. Completed at or near grade with only minimal surface features to provide low visual impacts for locations in public use and residential areas (Figure 4-3).

c. Completed above grade, especially where the top of the well structure needs to be above known or anticipated flood elevations, and to allow access during high water events, on or behind the beach (Figure 4-4).



Courtesy of Ranney Collector Wells – Layne Christensen

Figure 4-3 Beach well intake system (at grade completion)



Adapted from Rando & Brady 1966

Figure 4-4 Beach well intake system (dual completion)

d. Completed with a dual-design, whereby the well portion of the system can be located closer to the source water (e.g., out on the beach), and the pumping portion of the system can be located further back from the source water to minimize impacts, typically connected with underground piping (Figure 4-4).

It should be noted that the use of the more environmentally palatable intake well configurations shown on Figures 4-3 and 4-4 will result in increase of the overall costs for intake construction.

Loss of coastal habitat during construction—impacts and mitigation measures. Smaller seawater desalination plants typically require a limited number of intake wells, and their impact on the coastal habitat during construction is generally minimal. These lower capacity wells can often be constructed as low-profile structures to minimize visual impacts. Because of the higher number of wells needed to supply adequate amounts of water for a large seawater desalination plant, construction of these facilities may result in impacts over a larger area of coastal habitat, and because these structures are often constructed as above-grade structures, they have more visual and aesthetic impacts.

Due to the increased size of the impacted seashore area for larger intake well systems, use of beach wells may result in another site-related implication, i.e., encountering artifacts of historical and archeological significance. At many locations worldwide, the probability of discovering remains of ancient habitats along the seashore is much higher than further inland as coastal or "near-water" settings were often the site of previous communities. This probability would increase with increasing the footprint of the disturbed seashore area.

Coastal wetland habitat—impacts and mitigation measures. Any intake wells that are operated in coastal areas will likely have impacts on local groundwater resources and other features such as perched water, wetlands, or saltwater-freshwater interfaces as the hydraulic influence from pumping in the area will affect water levels and alter groundwater flow gradients. Special attention should be given to seawater intake well sites in the vicinity of existing coastal wetlands and other groundwater users to evaluate these hydraulic impacts. The operation of large intake wells located adjacent to coastal wetlands may result in a drawdown of the groundwater table that could affect (dry up or destroy) the wetland habitat or impact local groundwater quality (e.g., salinity). A potential mitigation measure in this case is installation of a higher number of smaller capacity wells, where the radius of influence does not reach the wetlands, or the use of a Ranney well-type configuration. Similar concern and solution can be applied to conditions where the radius of influence of the intake wells extends to the area of landfill or other contaminated site (i.e., leaking fuel storage tanks of gas station) located near the coast. In this case, the subsurface intake could immobilize hazardous compounds contained in the hazardous waste site and contaminate the water source. Voutchkov (2004) discusses additional key factors that influence the feasibility of using subsurface intakes.

Subsurface intake construction—impacts and mitigation measures. The permanent construction-related impacts are mainly associated with the excavation and disposal of sand and other materials from the shoreline in order to drill the intake wells. From this perspective, the infiltration galleries would have the highest impact on the ocean bottom habitat, because their construction involves removing 6 to 8 feet of the ocean bottom habitat and replacing it with artificial sand and gravel. The area of the ocean bottom habitat that will be removed and destroyed is significant, especially for construction of intakes for large seawater desalination plants.

Open Ocean Intakes—environmental impacts and mitigation measures.

Similar to subsurface intakes, open ocean intakes would have environmental impacts associated with their construction and operation.

Impingement and entrainment impacts and mitigation measures. As indicated previously, impingement and entrainment are considered the two most significant environmental impacts of open ocean intakes. Impingement rates from a desalination plant open ocean intake depend on the intake design, location, and the velocity of the feed-water. Impingement mortality of marine species is typically caused by starvation, exhaustion or injury caused by the suction force of the water, or from the physical force of water jets used to clear the screens of debris.

While specific intake design may be able to reduce or eliminate impingement, all desalination open water intake systems will cause a certain degree of entrainment. Entrainment impact is associated with marine species mortality caused by the equipment, chemicals, or treatment facilities used for water treatment.

Entrainment impact is typically proportional to the volume of source water collected by the intake and varies widely based on the amount of seawater required by the facility; intake velocity; location; depth; existing biological conditions of the affected area of the intake structure; and the intake technology/equipment used. To predict and assess impacts from a desalination plant intake, site-specific studies are necessary to identify habitats and species in the area that might be vulnerable to impingement or entrainment.

The methods for mitigation of impingement and entrainment of marine organisms can be divided in three categories:

- Alternative Open Intake Technologies;
- Operational Impingement Reduction Measures;
- Impact Mitigation Measures.

Alternative desalination plant open intake technologies. Table 4-1 presents a number of technologies that are classified based on biological effectiveness (i.e., ability to achieve significant reductions in both impingement and entrainment).

The feasibility of these technologies for the site-specific condition of a given desalination project should be evaluated based on the following criteria:

- Ability to achieve a significant reduction in impingement and entrainment (IM&E) for all species, taking into account variations in abundance of all life stages;
- Feasibility of implementation at the desalination plant;
- Cost of implementation (including installed costs and annual O&M costs);
- Impacts during desalination plant operations.

*Operational measures***.** Operational mitigation measures are used to reduce the amount of flow and velocity of entrance of the source water into the desalination plant intake to minimize entrainment and impingement of marine organisms.

Operational measures may consider reduction of plant intake flow during certain periods of the day (typically at night) and/or of the year (typically during the summer and spring months) when the concentration of marine species in the source water is at its highest levels.

Plant intake flow may be reduced by either reduction of desalination plant overall fresh water production yield and/or by operating the desalination plant at higher recovery.

Entrainment of marine organisms is mainly proportional to intake flow. Therefore, installation of variable frequency drives (VFDs) on the intake pump motors would also reduce the flow that enters the desalination plant by collecting only as much flow as needed at any given time to meet the desalination plant freshwater production target.

Impact mitigation measures. In addition to the implementation of technological and operational measures to minimize impingement and entrainment impacts, the effect of these impacts on the surrounding aquatic environment can be mitigated by implementing projects aimed to preserve, restore, or enhance this environment by creating additional habitat for species in kind to the impacted marine organisms.

Table 4-1 Potential impingement/entrainment reduction technologies

Technology	Impact Reduction Potential	
	Impingement	Entrainment
Modified traveling screens with fish return	Yes	No
Replacement of existing traveling screens with fine mesh screens	Yes	Yes
New fine mesh screening structure	Yes	Yes
Cylindrical wedge-wire screens – fine slot width	Yes	Yes
Fish barrier net	Yes	No
Aquatic filter barrier (e.g., Gunderboom)	Yes	Yes
Fine mesh dual flow screens	Yes	Yes
Modular inclined screens	Yes	No
Angled screen system – fine mesh	Yes	Yes
Behavior barriers (e.g., light, sound, bubble curtain)	Maybe	No
Variable speed drives	Yes	Yes

Courtesy of Water Globe Consulting

Mitigation projects that should be considered will target the generation or restoration of a coastal habitat comparable to that impacted by the intake. Key eligibility criteria for such mitigation projects may include

- Consistency with the applicable requirements of federal, state, and local agencies that have jurisdiction over coastal habitat restoration actions.
- Restoration of marine habitat similar to the marine habitat impacted by the intake operations.
- Projects located in close vicinity and preferably in the watershed near the intake.
- Projects that hold the promise for long-term environmental enhancement benefits.
- Projects that have opportunities for leveraging of funds/availability of matching funds.

Examples of types of mitigation projects include:

- Wetland restoration
- Coastal lagoon restoration
- Restoration of historic sediment elevations to promote reestablishment of eelgrass beds
- Marine fish hatchery enhancement
- Contribution to a marine fish hatchery stocking program
- Artificial reef development
- Kelp bed enhancement

Selection of the most suitable mitigation measures would need to be completed based on a life cycle cost-benefit analysis.

Open intakes—construction impacts and mitigation measures. Open intakes can generally be divided into two types—onshore and offshore. Construction of onshore open intakes involves minimum disturbance of marine life in the vicinity of the intake but they are often highly visible structures with potential impacts on beach aesthetics. Offshore intakes are typically constructed by installing intake pipeline directly on the surface of the ocean bottom and securing the pipeline with weighted blocks; by installing the intake pipeline in an excavation trench; or by directional drilling of the intake pipeline/tunnel under the ocean floor. Intake pipeline installation in a trench excavated from the ocean bottom usually is the most environmentally intrusive. Therefore, if the intake area contains environmentally sensitive habitats, the preferred method of intake pipeline installation is directional drilling 5 to 15 feet (1.5 to 4.5 meters) under the ocean floor. While the onshore open intake is lowest in cost, it is the most visible structure-wise, and often for this reason it is avoided. Intake structure drilled under the ocean floor is the most costly and complex type of such facility, but has the advantage of minimal disturbance of the ocean flora and fauna during construction.

CONCENTRATE DISCHARGE

One of the key limiting factors for the construction of new desalination plants is the availability of suitable conditions and locations for disposal of concentrate or concentrate stream.

Introduction

Concentrate is generated as a by-product of the separation of the minerals from the source water used for desalination. This liquid stream contains most of the minerals and contaminants of the source water and pretreatment additives in concentrated form. The concentration of minerals and contaminants in the concentrate from seawater desalination plants is usually 1.5 to 2.5 times of that in the source water depending on the recovery of the desalination plant. If chemical pretreatment is used, such as coagulants, antiscalants, polymers, or disinfectants, some or all of these chemicals may be disposed of along with the plant discharge concentrate.

The quantity of the concentrate is largely a function of the plant recovery, which in turn is highly dependent on the TDS concentration of the source water. Seawater desalination plant recovery is typically limited to 40 to 65 percent. The TDS level of concentrate from seawater desalination plants usually is in a range of 65,000 to 85,000 mg/L, while that from brackish plants may vary between 1,500 mg/L and 25,000 mg/L. The amount of particles, total suspended solids (TSS), and biochemical oxidation demand (BOD) in the concentrate is usually below 5 mg/L because these constituents are removed by the plant's pretreatment system. However, if plant pretreatment waste streams are discharged along with the concentrate, the blend may contain elevated turbidity, TSS, and occasionally BOD. Acids and scale inhibitors added to the desalination plant source water will be rejected in the concentrate and will impact its overall mineral content and quality. Often scale inhibitors contain phosphates or organic polymers.

Because membranes are more permeable to some chemicals than others, variable concentration factors may apply for specific chemicals. Exactly how the concentrate concentration factor impacts the disposal of concentrates depends heavily on the means of disposal. In some cases, volume minimization (high concentrate concentration factor) will be preferred, whereas in cases where the concentrate is to be discharged to waterways, low concentration may be more important than low volume.

For example, the Perth Seawater Desalination Plant in Australia is a two-stage RO plant operating with a first pass recovery of 45 percent and a second pass recovery of 90 percent. This corresponds to an overall concentrate concentration factor of approximately 1.7 times. Based on a source water TDS of 33,000-37,000 mg/L, the plant produces an overall RO concentrate TDS of approximately 65,000 mg/L.

With most seawater desalination plants producing concentrate 1.5 to 2 times more concentrated than ambient seawater, the concentrate may have a negative impact on the aquatic environment in the area of the discharge. This impact is very site-specific and depends mostly on the salinity tolerance of the specific marine organisms inhabiting the water column and benthic environment influenced by the discharge. The existing USEPA whole effluent toxicity (WET) tests are indicative of the level of salinity that causes mortality of preselected test organisms, which may or may not inhabit the discharge area. WET testing is an important element of the comprehensive evaluation of the effect of the concentrate discharge on the aquatic life. Completion of both acute and chronic toxicity testing is recommended for the salinity levels that may occur under worst-case combination of conditions in the discharge (Voutchkov 2006).

Mechanisms of Concentrate Impact on the Environment

Concentrate from seawater desalination plants using open ocean intakes generally has the same color, odor, oxygen content and transparency as the source seawater from which it was produced, and an increase or decrease in salinity will not change its physical characteristics or aesthetic impact on the environment.

There is no relationship between the level of salinity and biological or chemical oxygen demand of the desalination plant concentrate. More than 80 percent of the minerals that encompass concentrate salinity are sodium and chloride, and they are not a prime food source or macro- or micronutrients for aquatic organisms.

Salinity contained in concentrate discharges from seawater desalination plants is not of anthropogenic origin as are the pollutants contained in discharges from industrial or municipal wastewater treatment plants or water reclamation plants. The minerals contained in the seawater desalination plant concentrate discharge originated from the same source to which they usually are returned. As a result, the environmental effect of seawater desalination on the ocean is somewhat equivalent to the effect of naturally occurring evaporation.

Naturally occurring evaporation tends to concentrate salinity in shallow nearshore ocean embayments during the high-temperature dry periods of the year, and they are diluted during the rainy periods of the year keeping a net zero sum salinity effect. Similarly, seawater desalination plants temporarily remove a small portion of ocean water producing fresh drinking water, which in turn may be returned to the ocean via the ocean discharges of the wastewater treatment plants located in the vicinity of the desalination plant. Even at locations where extensive water reuse projects are utilized, a portion of the water will almost universally be returned to the ocean with salinities lower than the background salinity in the ocean.

Salinity Tolerance of Marine Organisms

Environmentally safe disposal of the concentrate produced at seawater desalination plants is one of the key factors determining the viability, size, and costs of a given project. The maximum total dissolved solids (TDS) concentration that can be tolerated by the marine organisms living in the desalination plant outfall area is defined as a *salinity tolerance threshold* and depends on the type of the aquatic organisms inhabiting the area of the discharge and the period of time these organisms are exposed to the elevated salinity (Voutchkov 2006). These conditions are very site-specific for the area of each desalination outfall, and therefore, it is very difficult to determine the salinity tolerance threshold.

Marine organisms have varying sensitivity to elevated salinity. Some marine organisms are *osmotic conformers*, meaning that they have no mechanism to control osmosis, therefore their cells conform to the same salinity as their environment. A large increase in salinity in the surrounding marine environment due to concentrate discharge can cause