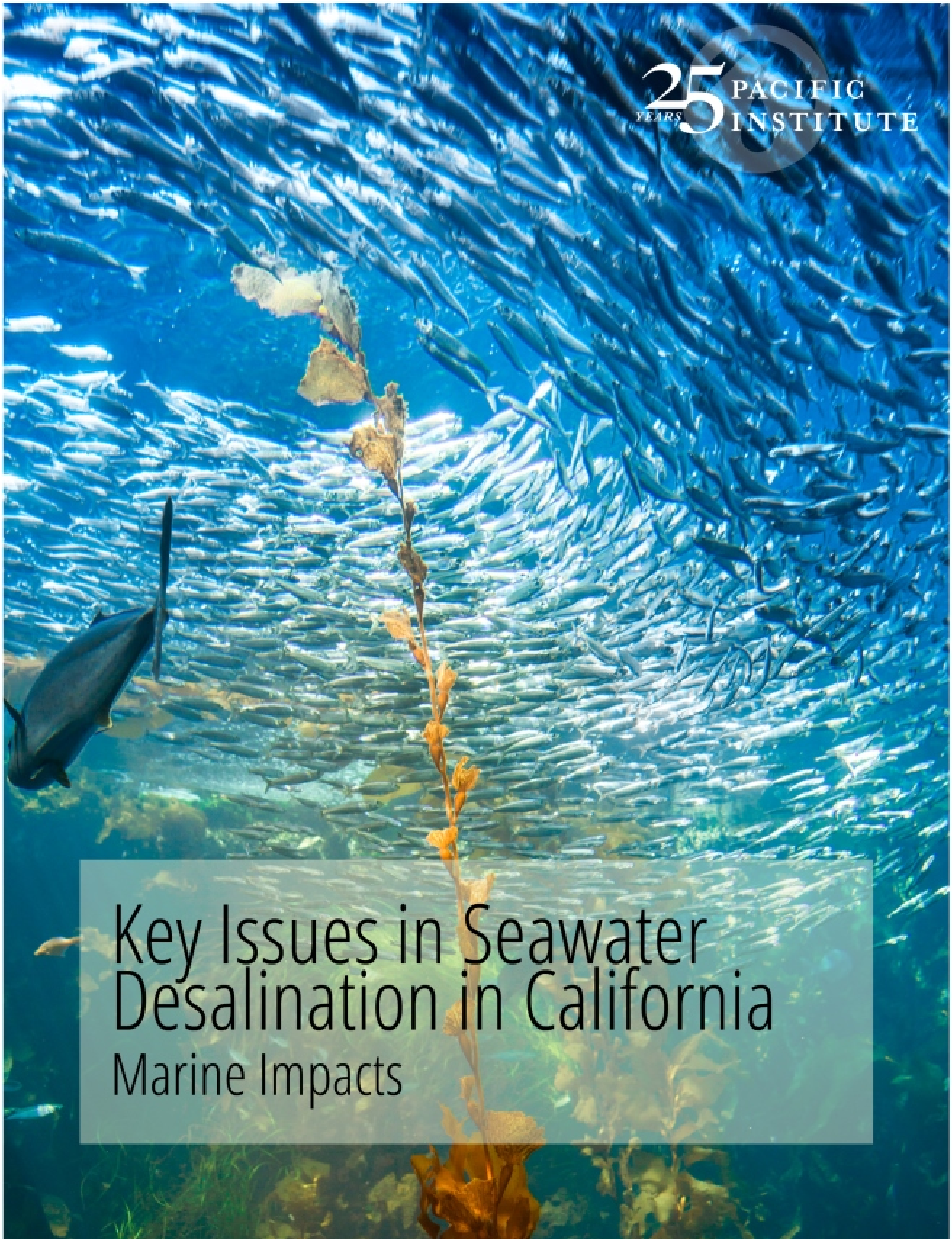

Key Issues in Seawater Desalination in California

Marine Impacts

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December 2013

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1 Introduction

In June 2006, the Pacific Institute released Desalination, With a Grain of Salt, an assessment of the advantages and disadvantages of seawater desalination for California. At that time, there were 21 active seawater desalination proposals along the California coast. Since then, only one project, a small plant in Sand City, has been permitted and built. A second, much larger project is now under construction in Carlsbad, 35 miles north of San Diego, and is scheduled to go online in 2016. Interest in seawater desalination remains high in California, and several agencies are conducting technical and environmental studies and constructing pilot projects to determine whether to develop full-scale facilities.

In 2011, the Pacific Institute began a new research initiative on seawater desalination. As part of that effort, we conducted some 25 one-on-one interviews with industry experts, environmental and community groups, and staff of water agencies and regulatory agencies to identify some of the key outstanding issues for seawater desalination projects in California. This is the fourth in a series of research reports that addresses these issues. The first report, released in July 2012, describes the 19 proposed projects along the California coast. The second report, released in November 2012, discusses the costs, financing, and risks related to desalination projects. The third report, released in May 2013, describes the energy requirements of seawater desalination and the associated greenhouse gas emissions and the impact of short-term and long-term energy price variability on the cost of desalinated water.

In this report, we describe the marine impacts of seawater desalination plants. We focus on plants that use reverse osmosis, because that is the technology that would be used for all proposed plants in California. Chapter 1 provides a brief introduction to the study. Chapter 2 describes the impacts of intakes withdrawing large volumes of water from the ocean. This chapter includes a review of our current understanding about these impacts and an overview of some of the technological, operational, and design measures that have been developed to reduce marine impacts, including subsurface intakes. Chapter 3 focuses on the discharge of concentrated brine produced by desalination plants and includes a review of brine studies that have been conducted at recently completed plants and a description of observed impacts, and identifies research gaps. Chapter 4 describes the processes for regulating seawater intakes and brine disposal as it is evolving in California, with an emphasis on those processes controlled by the State Water Resources Control Board. Finally, Chapter 5 provides conclusions and recommendations for minimizing the impacts of seawater desalination plants on the marine environment.

2 Seawater Intakes

Modern seawater reverse-osmosis desalination plants, such as those planned or proposed on the California coast, take in large volumes of seawater, pass it through fine-pored membranes to separate freshwater from salt, and discharge the hyper-saline brine back into the ocean. Seawater intakes generally fall into two categories: direct intakes and indirect intakes. Figure 1 shows the categories and relationships of intakes in use or proposed for desalination plants around the world. Direct intakes – also referred to as open water intakes – extract seawater directly from the ocean. These intakes may be located at the surface, in deep water, or less commonly, on a flotation plant. The vast majority of existing desalination plants uses surface intakes, which typically consist of a set of intake screens to exclude marine life, trash, and debris; a conveyance pipeline; and a wet well or other mechanism for housing the pumps (Mackey et al. 2011). These intakes generally require some sort of pre-treatment system to remove silt, algae, dissolved organic carbon, and other organic material that may clog the membranes.

A small but growing number of desalination plants use indirect intakes, also referred to as subsurface intakes. While not suitable in all locations, they have the advantage of virtually eliminating marine life impacts associated with

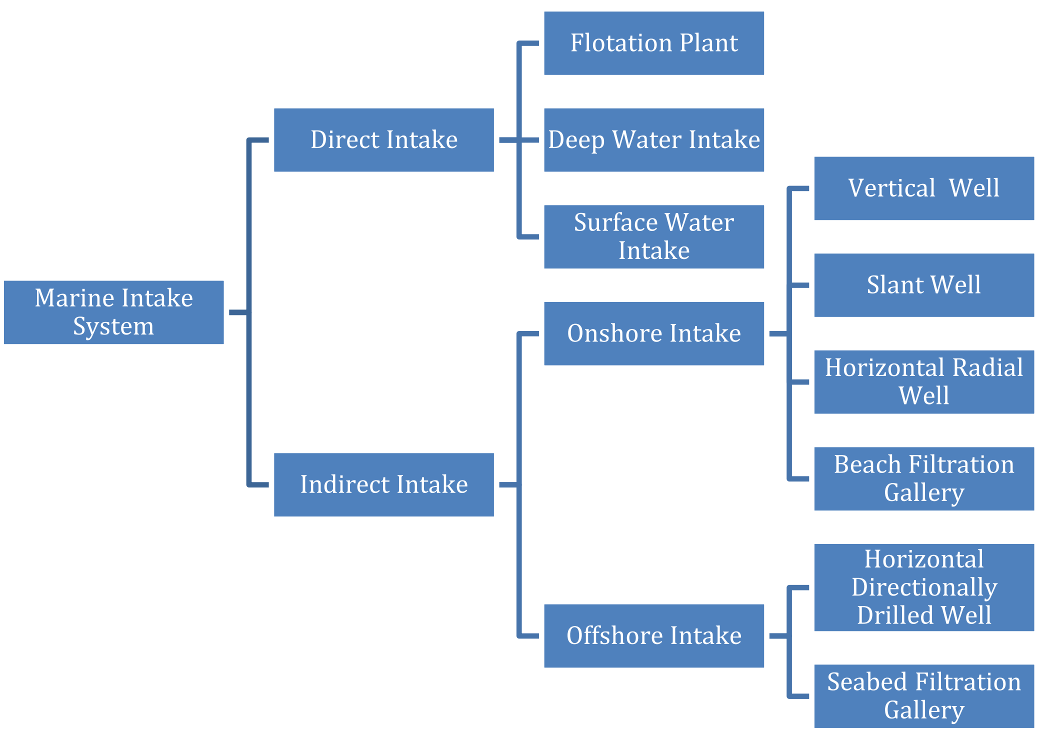

Figure 1. Marine Intake Systems for Seawater Desalination Plants.
Source: Adapted from Pankratz 2008

the intakes and reducing pretreatment requirements. Subsurface intakes extract seawater from beneath the seafloor or a beach and may be located on- or off-shore. They typically consist of buried pipes and/or wells and do not generally require a pre-treatment system because sand acts as a natural filter. Several design configurations of subsurface intakes are available and are described in more detail beginning on page 9 of this report.

Marine Impacts of Seawater Intakes

On average, seawater desalination plants withdraw two gallons of water for every gallon of freshwater produced. As noted in a 2005 California Energy Commission analysis, "seawater… is not just water. It is habitat and contains an entire ecosystem of phytoplankton, fishes, and invertebrates" (York and Foster 2005). As a result, the intake of seawater from the ocean results in the impingement and entrainment of marine organisms. Impingement occurs when fish and other large organisms are trapped on the intake screen, resulting in their injury or death. Entrainment occurs when organisms small enough to pass through the intake screens, such as plankton, fish eggs, and larvae, are killed during processing of the salt water. Entrained organisms are killed by pressure and velocity changes caused by circulating pumps in the plant, chlorine and other chemicals used to prevent corrosion and fouling, and predation by filter feeders like mussels and barnacles that line the intake pipes and themselves are considered a fouling nuisance (Mackey et al. 2011).

The impacts of impingement and entrainment from desalination plants on the marine environment are not well understood. Much of what is known has been drawn from studies on coastal power plants that use once-through cooling (OTC) systems. In an analysis of coastal and estuarine power plants in California, York and Foster (2005) find that "impingement and entrainment impacts equal the loss of biological productivity of thousands of acres of habitat" (York and Foster 2005). But while it is widely acknowledge that these systems damage the marine environment, the full extent of these impacts "may never be fully understood because comprehensive monitoring and evaluation of the surrounding ecosystems was not done" (Kelley 2010).

Further, OTC studies along the California coast have found that impingement and entrainment at coastal power plants vary considerably based on the location, year, and even time of year. For example, the state's two largest nuclear power plants, Diablo Canyon and San Onofre, withdraw similar quantities of water, but their impact on marine life differed dramatically. In an average year, Diablo Canyon entrains 1.8 billion fish and fish larvae and impinges about 400 fish and one large marine animal. San Onofre, by contrast, annually entrains 5.6 billion fish and fish larvae and impinges 3.5 million fish (SWRCB 2008). The differences in impact are not due to a single cause, but "arise from the plants' local marine environments, respective designs, and intake and discharge technologies" (McClary et al. 2013). Even for a single facility, impingement and entrainment rates may be subject to daily, seasonal, annual, and even decadal variation. Because of this variability, site-specific analyses are needed to determine the type and extent of impingement and entrainment (see Box 1 for two analyses conducted in California).

Project developers typically conduct impingement and entrainment studies to inform plant design and to obtain the permits needed for operation. Sampling studies and monitoring at pilot plants can provide useful information, but neither can paint a full picture of the actual impacts a desalination plant will have on marine life over its lifetime of operation. As previously noted, the distribution and abundance of a fish

Box 1: Case Studies

Several desalination project developers in California have recently built and operated small pilot projects to determine the feasibility of the projects and to test various design configurations. In several cases, project developers have conducted impingement and/or entrainment studies. Two of these are described below.

Santa Cruz

The City of Santa Cruz Water Department and Soquel Creek Water District have proposed to build a 2.5 million-gallon-per-day (MGD) desalination plant on California's central coast, at the tip of the Santa Cruz Bight at the northern end of Monterey Bay. The agencies operated a 50 gallon-per-minute (gpm, or 0.07 MGD) pilot desalination plant in Santa Cruz for 13 months from 2008-2009. To estimate impingement and entrainment, scientists collected samples at offshore locations and at a test intake at the end of a downtown pier and used video cameras to monitor intakes for impinged fish and invertebrates. In its 2013 Draft Environmental Impact Report for the project, the agency found that impingement and entrainment impacts were "less than significant" (SCWD2 2013). That is, the agency estimated impacts would occur, but that they do not rise to the level that requires any mitigation under California's environmental laws. One reason for the "less than significant" designation is that no endangered or threatened species were found during sampling. The study, by Tenera Environmental, concluded that intakes would kill some fish and invertebrate species (including gobies, croakers, anchovies, halibut, rockfishes, shrimp, and crabs), but the numbers killed are not likely to exceed "about six-hundredths of one percent of their populations (0.0006%) within the source water at risk of entrainment" (Tenera Environmental 2010a).

San Francisco Bay

In the San Francisco Bay Area, five large water utilities are jointly exploring the development of a regional desalination project. With some funding the from California Department of Water Resources, the project partners built and operated a 50 gpm (0.07 MGD) pilot plant from October 2008 to April 2009 near Pittsburgh, California. The pilot plant was located in an estuary, with widely fluctuating salinity levels and relatively high biological productivity compared to the open ocean. The plant's source water is home to the Delta smelt (*Hypomesus transpacificus*), listed as an endangered species by the state and federal governments, and the longfin smelt (*Spirinchus thaleichthys*), listed as threatened under the California Endangered Species Act (Tenera Environmental, Inc. 2010b). A 2010 study, also performed by Tenera Environmental, found both types of smelt during sampling. An estimated 13 Delta smelt were identified during a 30-minute survey in March 2009 that filtered about 240,000 gallons of water. While Delta smelt eggs adhere to substrate and are not likely to be entrained, the larvae are planktonic and susceptible to entrainment (Tenera Environmental, Inc. 2010c). The presence of an endangered species in the proposed plant's source water means it would likely have a "significant" environmental impact, and mitigation plans would be required.

species may change dramatically from one year to the next, or at different times during the year. This variability may not be adequately captured with short-term studies. For desalination projects in California, ongoing monitoring will likely be required to evaluate impingement.[1] Monitoring will better show how these impacts occur, when these impacts occur, and which species are affected. This information is useful for "adaptive management," allowing us to better manage those projects that are developed. Additionally, it will help us to plan for and design future projects so that they have less impact. As previously noted, marine impact data related to actual desalination operations have rarely been collected in California or elsewhere, and this information will be of use to regulators, policymakers, and the general public.

Minimizing Marine Life Impacts from Intakes

Various technological, design, and operational measures are available to reduce the marine impacts of seawater intakes. These are described in more detail in this section. While several measures are available to reduce impingement, fewer measures are available to minimize entrainment losses. As a result, habitat restoration is often used to mitigate these losses (Strange 2012). Box 2 describes the methodology commonly used in California to estimate the area of habitat needed to produce the organisms lost to entrainment.

Design and Operational Measures

The majority of desalination plants in operation around the world employ surface intakes. For these intakes, there are several design and operational measures that can reduce impingement and entrainment, e.g., locating the intake in areas of low biological productivity, such as in deep waters or outside of bays and estuaries (Ferry-Graham et al. 2008, NRC 2008). Deeper intakes, however, are not a panacea. In particular, they may not be effective in areas where fish spawn in deeper water or strong tidal currents distribute larvae throughout different depths. For example, California's San Onofre Nuclear Generating Station has the longest and deepest intake of any California power plant but also the highest impingement rate. The intake pipeline itself seems to be part of the cause, as "biologists and regulators seem to agree that […] the long intake pipe is attractive to marine animals as a place of refuge, potentially for food, and possibly for other reasons not yet determined" (Ferry-Graham et al. 2008).

Improving the recovery rate of a desalination facility can also reduce impingement and entrainment. Typically seawater desalination plants are designed to recover (turn into freshwater) 45 to 55% of the seawater collected by the intake. Designing the plant to operate closer to the upper limits of recovery (i.e., 50 to 55%) would require withdrawing less water and as a result, would reduce both impingement and entrainment. Other design and operational measures include installing low-velocity intakes that allow some organisms to swim out of the current or temporarily reducing pumping or intake velocity during critical periods for marine organisms, such as during spawning or important larval stages.

Technological Measures

Several technologies are available to reduce impingement and entrainment from surface intakes. These measures generally fall into two broad categories: physical barriers and behavioral deterrents. In the following section, we provide additional detail on some of these measures. We

[1] It is generally believed that entrainment impacts are fairly well understood due to the data available from power plants operating along the California coast.

Box 2: Quantifying and Mitigating Entrainment Losses through Habitat Restoration

In California, entrainment impacts are commonly compensated for or “offset” by creating or restoring fish habitat at a nearby location. The concept of offsets to mitigate the environmental impact of projects has been required by many regulators in the US and Europe since the 1970s. Under this approach, a project aims to achieve a “net neutral” impact on fish populations by creating habitat where fish feed and reproduce to make up for those killed by a project’s construction and operations. The size and type of habitat required is estimated by fisheries biologists using a method referred to as the Area Production Foregone, or APF. This method is used by the California Energy Commission, California Coastal Commission, and other state regulatory entities.

The APF provides an estimate of the area of habitat needed to produce the organisms lost to entrainment and is intended to balance entrainment losses with the gains expected from a restoration project (Strange 2012). It is calculated using the area of habitat from which the larvae could be drawn into the intake (referred to as the “source water area”) and is based on a determination of the period that the larvae are vulnerable to entrainment and the distance the larvae could have traveled during that period. The source water area is then multiplied by the percentage of larvae that are actually pulled into the intake to obtain the APF.[a] This calculation is repeated for all *meroplankton* – organisms that grow out of the larval stage to larger adult stages – entrained within the intake, and the results are averaged. The restored habitat may be of a different type or quality than the impacted habitat, and thus some conversion factor is typically applied. For example, one acre of highly productive wetlands may be restored to offset losses from 10 acres of open-ocean habitat. In a recent analysis for the California Energy Commission, Strange (2012) provides several cautions about the method. In particular, while the APF method may be reliable for bay and estuary settings, they are not reliable for the open coast. Additionally, monitoring is needed to ensure that the restoration projects provide the benefits expected.

[a] This percentage is based on the number of larvae entrained, larval density and abundance, and the proportion of sampled source water to total source water.

also describe the application of subsurface intakes and some of the advantages and disadvantages of these systems.

Physical barriers

Physical barriers are intended to block fish passage into the desalination plant and, depending on their design, can reduce both impingement and entrainment. Physical barriers have been used on power plant intakes for over a century. The earliest versions were essentially metal bars, or "trash racks," designed to keep large debris out of the intakes. Today, open intakes are typically equipped with primary coarse screens, which have openings of 20 mm to 150 mm, and smaller, secondary screens with openings of 1 mm to 10 mm. The coarse screens are stationary, whereas the secondary screen may be stationary (passive) or move periodically (active).

Barrier nets are suspended from booms or buoys and can exclude some marine organisms from intakes. Barrier nets are relatively inexpensive and easy to employ but are only effective in reducing impingement and do not reduce entrainment because larvae are able to pass through the nets (Ferry-Graham et al. 2008). As with many types of screens with small openings, barrier nets are subject to fouling, and cleaning clogged or fouled nets in the marine environment can be difficult (Hogan 2008). Additionally, barrier nets may impede navigation and eliminate some benthic and open-water habitat (Mackey et al. 2011).[2]

Travelling screens are mesh screens that are in continuous movement. The screens are equipped with mesh panels, and as the panels move out of the flow of water into the desalination plant, a high-pressure spray dislodges the accumulated debris and washes it into a trench for disposal in

Figure 2. Example of a Travelling Screen Over an Intake

a landfill or back into the ocean (Figure 2). These screens have been employed on seawater intakes since the 1890s (Pankratz 2004). Originally intended to prevent trash from entering the intake, traveling screens were designed to impinge items, including organisms, on the mesh screens. These screens, however, have been modified to reduce entrainment and impingement, including by using angled or Risotroph screens (Ferry-Graham et al. 2008).

Ristroph screens are simple modifications of conventional traveling screens, by which water-filled buckets collect the impinged organisms and return them to the source water body by a sluiceway or pipeline. Impinged fish, however, may suffer lacerations or other mechanical damage to their gills or fins. Additionally, the locations where fish are returned to the environment often turn into a "fish feeding station for larger fish and birds." According to a recent study, "The effectiveness of such systems…is relatively easy to measure, but the survival and ecological success of the returned organisms is difficult to observe or quantify" (Mackey et al. 2011). In most cases, Ristroph screens and other fish-collection systems are not commonly employed and are often still

[2] Benthic habitat refers to the ecological zone on the sediment surface and in some sub-surface layers.

considered experimental (Ferry-Graham et al. 2008).

Wedgewire screens are passive screens that combine a fine-mesh screen with low-velocity intakes (Figure 3). Although they have been shown to be effective in reducing impingement and entrainment, wedgewire screens are susceptible to clogging and must be cleaned periodically with bursts of compressed air to dislodge material from the screens, where natural currents then remove the dislodged material (Mackey et al. 2011). These currents are commonly found in riverine systems but are less common in the marine environment. As a result, wedgewire screens may have limited application for seawater desalination plants. These screens, however, have been tested at several pilot and demonstration plants in California, including in Santa Cruz, Marin, and Los Angeles. In Santa Cruz, wedgewire screens with 2-millimeter (mm) openings were found to eliminate impingement and reduce entrainment of by 20%. For the pilot study, the natural currents exceeded the intake velocity (0.33 feet per second), which helped to clean the intake screens and reduce impingement (Tenera 2010c). A full-scale plant would operate at a higher intake velocity, suggesting that impingement would be higher.

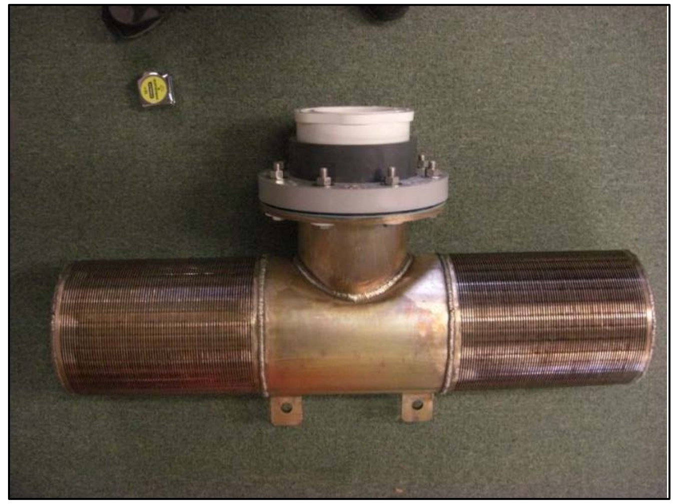

Figure 3. Wedgewire Screen Module Used in Testing During Studies for Santa Cruz and Soquel Creek Water Districts in 2009 and 2010
Source: Tenera 2010c

Behavioral Deterrents

Behavioral deterrents can be installed near intakes to discourage fish from entering the area or to encourage them to enter a bypass. In general, these devices may reduce impingement but have no effect on entrainment (Hogan 2008, Mackey et al. 2011, Foster et al. 2012). Behavioral deterrents include sound generators, strobe lights, air bubble curtains, and velocity caps.

Air bubble curtains are created by pumping air through a diffuser to create a continuous curtain of bubbles. Most studies have found that air bubble curtains are not effective, although a handful of studies suggest they may be effective at some sites and for some species (EPRI 2005).

Strobe lights and sound generators have been used to illicit an avoidance response from power plants and other water intake structures. However, a 2008 study by the Electric Power Research Institute (EPRI) on strobe-light and subsonic sound systems at cooling water intakes found that "there is no evidence that the impinged total fish numbers or impinged individual species numbers were reduced when the deterrent systems were operating." EPA (2001) notes that sound systems may be effective at targeting particular species, such as alewife, but are ineffective for others.

A **velocity cap** is essentially a device placed over an open intake pipe that creates variations in horizontal flow, triggering an avoidance response in fish and signaling it to step away from the intake. Studies have shown that velocity caps reduce impingement but there is some debate about whether they reduce entrainment (EPA 2001, Ferry-Graham et al. 2008). Velocity caps, which are usually combined with other devices, have been used at many offshore intakes, including at several power plants in California and at the desalination plant in Sydney, Australia (EPA 2001, Ferry-Graham et al. 2008, Pankratz 2008).

The effectiveness of behavioral deterrents is highly varied. The EPA finds that most studies "have either been inconclusive or shown no tangible reduction in impingement or entrainment" (EPA 2001). Indeed, some critics have noted that behavioral deterrents may cause undue stress to marine organisms, with an unknown effect on marine ecosystems. Most behavioral deterrents, with the possible exception of velocity caps, are not widely employed or recommended as a means for reducing impingement and entrainment, although they may be employed in combination with other measures or to target a specific species (Chow et al. 1981, EPA 2001, Pankratz 2004).

Subsurface Intakes

Subsurface intakes extract seawater from beneath the seafloor or a beach. These intakes, which include vertical, slant, and horizontal wells and galleries, may be located onshore or offshore. Here, we provide a short summary of the various subsurface intakes currently in use in desalination plants around the world and some of the advantages and disadvantages of these systems.

Vertical beach wells consist of a series of shallow wells near the shoreline that use beach sand or other geologic deposits to filter water (Figure 4). Each well has a yield of 0.1 to 1.0 MGD (Pankratz 2004), and several wells may be needed at a desalination plant to meet its source water requirements. Beach wells may need to be located sufficiently far from shore so that they are not intercepting fresh groundwater, either because of quality concerns or an obligation not to cause salinization of freshwater aquifers. The largest plant using vertical beach wells is the Sur Desalination Plant in Oman, which has a production capacity of 21.2 MGD (Pankratz 2008).

Slant wells, also sometimes referred to as angle wells, are drilled at an angle such that the wellhead and related infrastructure may be onshore, while the well extends below ocean sediments and draws seawater through the seabed. With this technology, the wellhead can be located some distance from the beach to minimize "loss of shoreline habitat, recreation access, and aesthetic value" (Mackey et al. 2011).

Compared to vertical wells, slant wells have a larger surface area in contact with the aquifer, which allows for higher yields (Williams 2008). While slant wells have been used for some applications, they have not yet been employed at a full-scale desalination plant. They are, however, currently being evaluated in field tests and research studies (Missimer et al. 2013). The Municipal Water District of Orange County (MWDOC), for example, pilot-tested a slant well intake system at Doheny State Beach in Dana Point, California. The 12-inch diameter well

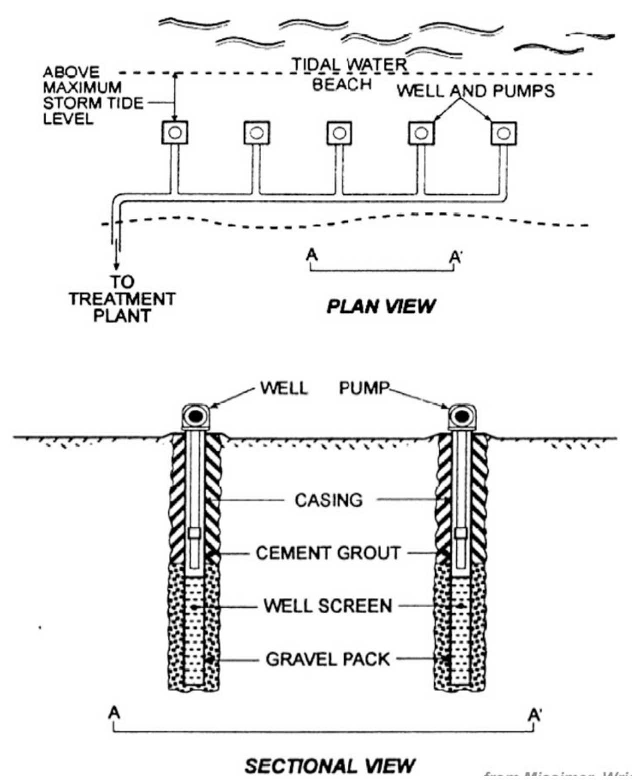

Figure 4 Beach Well Conceptual Design

Source: Wright and Missimer (1997)

withdrew 3 MGD of source water, and the "pump and aquifer performed exceptionally well" (MWDOC 2013). Based on the results from the pilot plant, it is expected that the full-scale plant could withdraw 30 MGD of water through a slant beach well system consisting of nine wells.

Horizontal directionally drilled (HDD) wells are non-linear slant wells. While slant wells are drilled at an angle from the surface, HDD wells typically begin as vertical wells before changing direction. Fluid and pressure are used to drill a pilot hole which is usually reamed to sufficient diameter before installation of the pipeline and screen. HDD wells are more difficult to install in areas with unconsolidated cobbles or boulders, which can drive the drill bit off course (Williams 2008). HDD well technology is used extensively by the oil exploration industry and has been used in desalination plants. The 34 MGD San Pedro del Pinatar (Cartagena) plant in Spain is the largest desalination plant using this technology. The HDD intake system, which has operated successfully for several years, consists of 9 wells that provide about half of the source water requirements for the plant (Mackey et al. 2011). Hydrological constraints necessitated the use of open intakes for the remainder of the source water requirements for the plant (WateReuse Association 2011a).

Horizontal radial wells, also referred to as radial collector wells or Ranney collectors, consist of a central chamber, called a caisson, from which several collector wells extend laterally as much as 300 feet. The collector wells can be oriented radially (like a bicycle wheel) or in some other formation toward the source water. The higher capacity of horizontal radial wells relative to vertical wells results in fewer wellheads and potentially less visual and construction-related impacts on the beach environment. This increases the options for siting the pumping station, something that can be difficult in coastal areas with high populations or sensitive ecosystems. Horizontal radial wells are designed to induce vertical flow, resulting in a greater yield per well (Missimer et al. 2013). Indeed, each horizontal collector well is typically designed to withdraw from 0.5 MGD to 5 MGD of source water (Mackey et al. 2011).

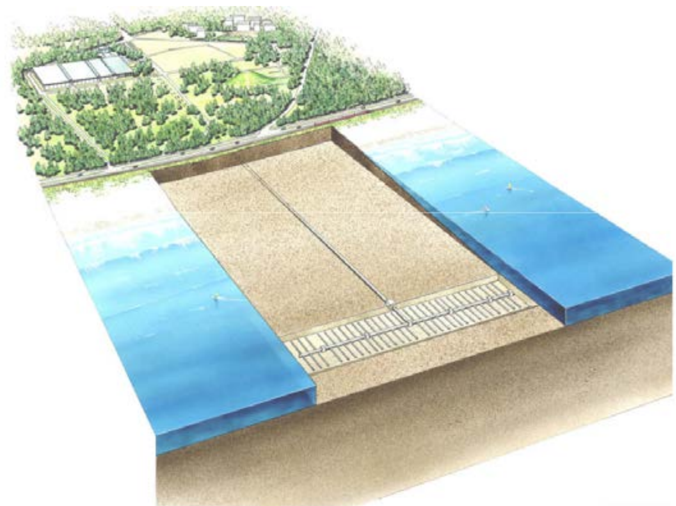

Figure 5. Infiltration Gallery Design at the Fukuoka District Waterworks, Japan.
Source: Reprinted from Pankratz 2008

Infiltration galleries are typically constructed by removing soil or rock, placing a screen or network of screens within the excavated area, and then backfilling the area with a porous media to form an artificial filter around the screens. A pipe then connects the intake screens to an on-shore pump. Infiltration galleries can be located on the beach near or above the high tide line, within the intertidal zone of the beach, or in the seabed. These systems are best suited for sandy areas without significant concentrations of mud (Missimer et al. 2013). Seabed galleries have been used in a limited number of desalination plants, the largest of which is the 13 MGD Fukuoka desalination plant in Japan (Figure 5). The seabed gallery, which has been in operation since 2006, has an intake flow of 27 MGD and covers an area of 5 acres (Pankratz 2008), or slightly less than the size of three football fields. Over the past eight years of operation, the gallery system has not required cleaning, and the filter membranes have required only minimal maintenance (Missimer et al. 2013). The City of Long Beach, California has also been operating a pilot seabed gallery for several years, and several other systems around the world are in design or have been proposed. Subsurface intakes provide several important advantages. By using sand and sediment as a natural filter, they virtually eliminate impingement and entrainment (Hogan 2008). Subsurface intakes also provide significant water quality improvements, reducing the complexity of the pre-treatment system, lowering the energy requirements of the system, and improving the operational reliability of the plant (e.g., by avoiding production losses that could occur during algal blooms). In a recent review of subsurface intakes, Missimer et al. (2013) find that while the capital costs of subsurface intakes can be slightly to significantly higher than open-ocean intakes, the overall operating costs are 5 to 30% lower, resulting in significant cost saving over operating periods of 10 to 30 years.

Subsurface intakes, however, may not be appropriate in all locations because their installation depends on having the proper geology and sediment characteristics, such as sand and gravel with a sufficiently high porosity and transmissivity. However, with new drilling technologies, e.g., directional drilling, it may be possible to find a pocket with the right conditions surrounded by generally unfavorable ones. A report by the Middle East Desalination Research Center noted that subsurface intakes should be explored even where they are initially assumed to be infeasible because “an adequate geological configuration may be encountered, even within the most precipitous coastal environment, in some deltaic deposits, river outlets, closed harbors and short sandy shores” (Schwarz et al. 2000).

Subsurface intakes have several other disadvantages. Among the concerns are the higher construction costs relative to surface intakes, and the cost and complexity of survey methods to determine site properties and evaluate the feasibility of subsurface intakes (Schwarz et al. 2000). As described above, subsurface intakes tend to have lower treatment costs, which can reduce total project cost over the life of the plant. However, the presence of inorganic minerals, such as iron and manganese, in the source water can necessitate pre-treatment and additional cost (Mackey et al. 2011). Finally, some plant operators and designers argue that the technology is new and untested, although this is changing as subsurface intakes are being used in a growing number of plants around the world.

3 Brine Disposal

The seawater desalination process produces two major waste streams: brine and spent cleaning solutions. The cleaning solution, which is produced intermittently and in relatively small amounts, typically contains chemicals used in the cleaning process and contaminants removed during this process. The brine, also referred to as concentrate, is produced continuously and in relatively large amounts. One of the key features of the concentrate is elevated salinity levels, which depend on the salinity of the source water, the desalination method employed, and the recovery rate of the plant. In addition to elevated salinity levels, brine from a seawater desalination plant has the following characteristics:

Natural Constituents of Seawater: The process of desalting seawater concentrates constituents normally found in seawater, such as magnesium, boron, calcium, and sulfate (Water Consultants International 2006).

Chemical Additives: A variety of chemicals are used throughout the desalination process. For example, coagulants, such as ferrous chloride and aluminum chloride, are used to remove suspended matter from the source water (Lattemann and Höpner 2008, NRC 2008). Antiscalants, including polyphosphates and phosphonates, are added to the feedwater to prevent the formation of scale precipitates and salt deposits on the desalination equipment (NRC 2008). Other chemicals used include biocides, anti-foaming additives, and detergents. The majority of these chemicals are added during the pretreatment process to prevent membrane fouling (Amalfitano and Lam 2005). Some of these chemicals can be toxic to marine organisms, even at low concentrations.

Heavy Metals: Desalination equipment can corrode during operations, resulting in the release of heavy metals, such as copper, zinc, and nickel, into the waste stream. Corrosion chemicals are unlikely to be a major concern for reverse osmosis (RO) plants, although RO plants will discharge minor amounts of iron, chromium, nickel, and molybdenum in their concentrate from stainless steel (Lattemann and Höpner 2008). While these elements may occur in seawater in trace amounts, higher concentrations can be toxic to the aquatic environment and can impair biological communities (Jenkins et al. 2012, NRC 2008, Water Consultants International 2006).

Temperature: Desalination plants may produce brine that is warmer than the receiving waters, although this is of greater concern for plants using thermal desalination technologies than for those using membrane technologies, e.g., reverse osmosis. Typically, brine for reverse osmosis plants are usually within 1°C of the ambient seawater temperature and will not likely have an impact on the marine environment (Water Consultants International 2006). Even for RO plants, however, temperature can be an issue if the brine is mixed with cooling water from a power plant, industrial process water, or effluent from a wastewater treatment plant.

Brine Disposal

There are several options available to dispose of the concentrate produced from a desalination plant. Concentrate from inland desalination plants – which is typically less saline than that from a seawater desalination plant and of lesser volume than for a similar-sized seawater desalination plant – can be disposed via evaporation ponds; deep well injection; land application (e.g. used for lawns, parks, golf courses, or crop land); solar energy ponds; or sewer system (this is also an option for small coastal plants). Disposal options for seawater desalination plants include discharge into evaporation ponds, the ocean, or saline rivers that flow into an estuary, or injection into a confined aquifer (NRC 2008, Cooley et al. 2006). An inland or coastal desalination plant may also be equipped with a zero liquid discharge (ZLD) system that evaporates water from the concentrate, leaving a salt residue for disposal or reuse. Disposal options, and their associated cost, depend on site-specific factors, such as hydrologic conditions, low season flows, permitting requirements, the concentration of chemicals, and the toxicity of the brine (NRC 2008). Disposal options should also be informed by the brine tolerance thresholds of native marine species inhabiting the discharge site, although the scientific information needed to define these thresholds is often limited.

Each disposal method has a unique set of advantages and disadvantages. Large land requirements make evaporation ponds uneconomical for many developed and urban areas. Sites along the California coast, for example, tend to have high land values, and coastal development for non-coastal-dependent industrial processes is discouraged by regulators. Injection of brine into confined groundwater aquifers is technically feasible, but it is both expensive and unless comprehensive and competent groundwater surveys are done, there is a risk of unconfined brine plumes appearing in freshwater wells. Discharges into estuaries and the ocean can disrupt natural salinity balances and cause environmental damage to marine ecosystems, especially sensitive marshes and fisheries. Currently, all seawater desalination plants of significant capacity worldwide discharge brine into oceans and estuaries (NRC 2008), and all of the proposed plants in California, would discharge brine in this manner.

Brine from a seawater desalination plant is typically twice as saline as the ocean. Because of its relatively high salt concentration, brine has a greater density than the waters into which it is discharged, and when released from an outfall, tends to sink and slowly spread along the ocean floor. There is typically little wave energy on the ocean floor to mix the brine, and as a result, dilution occurs more slowly that at the surface. The result is a layer of brine with an elevated salt concentration near the outfall. As has been observed in Perth and in other shallow bays, dissolved oxygen levels can also become depleted near the outfall (Hodges et al. 2011,Spigel 2008), further increasing stress for marine organisms along the seafloor.

There are several proven methods to disperse concentrated brine. For example, multi-port diffusers can be placed on the discharge pipe to promote mixing. Brine can also be diluted with effluent from a wastewater treatment plant or with cooling water from a power plant or other industrial user, although these approaches have their own drawbacks. All of these options are discussed in more detail on page 14 of this report.

Marine Impacts of Brine Disposal

Field-based monitoring as well as field and laboratory experiments can be used to evaluate the marine impacts of brine discharge. Despite the long history of seawater desalination plants operating in some regions, however, data on their ecological impacts are limited (NRC 2008). The majority of studies conducted thus far focus on a limited number of species over short time periods with no baseline data (Roberts et al. 2010, Fernández-Torquemada and Sánchez-Lizaso 2007). In a recent review, Roberts et al. (2010) identified 62 peer-reviewed research articles concerned with brine discharge in marine waters and found that the majority (44%) of articles are discussions or opinion pieces with little quantitative data. Likewise, Jenkins et al. (2012) find that studies on the impacts of brine on California biota in particular are "extremely limited, often not peer-reviewed, not readily available, or have flaws in the study design."

Because of a lack of baseline ecological data, most of the available studies are based on a comparative analysis of environmental conditions at the discharge location and at least two other nearby locations believed to be unaffected by brine discharge. Most of these studies report some sort of environmental degradation due to exposure to desalination discharge (Fernandez-Torquemeda et al. 2005, Gacia et al. 2007,Sanchez-Lizaso et al. 2008, Ruso et al. 2007, 2008). In a recent review, Roberts et al. (2010) conclude that both laboratory and field studies "clearly demonstrate the potential for acute and chronic toxicity and small-scale alterations to community structure in marine environments."

The few studies available indicate that the ecological impacts of brine discharge vary widely and are a function of several factors, including the characteristics of the brine, the discharge method, the rate of dilution and dispersal, and the sensitivity of organisms. For example, brine discharge can cause widespread changes in the benthic community in shallow and/or semi-enclosed bays, whereas impacts can be undetectable in areas with heavy wave activity or significant flushing. Based on a literature review, Jenkins et al. (2012) find that some species are affected by salinity increases of only 2-3 parts per thousand (ppt) above ambient, while others are tolerant of salinity concentrations of up to 10 ppt above ambient. They further note that sub-lethal effects of desalination discharges have not been well studied in the field or in the laboratory.

Minimizing Impacts of Brine Disposal

As noted above, the common practice for large coastal seawater desalination plants is to discharge brine into oceans or estuaries. Over 90% of the large plants in operation today dispose of brine through a new ocean outfall specifically designed and built for the desalination plant (Voutchkov 2011). The addition of *diffusers* can promote mixing and improve dilution of the brine and are commonly used at desalination plants worldwide, including at all of the recently constructed plants in Australia and for many plants in Spain, the Middle East, Africa, South America, and the Caribbean (WateReuse Association 2011b). The diffusers may consist of a single port at the end of the pipe or multiple ports along a section of the pipe and are generally angled upwards to promote mixing. Recent research and modeling efforts suggest that a discharge angle of 30º–45º enhances mixing and dilution in moderate-to-steep coastal waters (Bleninger and Jirka 2008, Jirka 2008, Maugin and Corsin 2005). There is also general consensus among modeling studies that optimal mixing is achieved by discharging the brine in sub-tidal, off-shore environments with persistent turbulent flow (Roberts et al. 2010). However, the length and location of the pipe and the placement of the diffusers are typically determined by modeling for the conditions at the discharge location (WateReuse Association 2011b).

Brine dilution prior to disposal is also being used by some plants to reduce the potential marine impacts. The Carlsbad desalination plant, for example, will mix the brine with cooling water from the adjacent Encina Power Station prior to discharge into a lagoon leading to the ocean. Recently, the State of California adopted new standards for implementing Section 316(b) of the Clean Water Act that effectively prohibits California power plants from using once-through cooling systems. Thus, cooling water will not be available for dilution in the near future. In order to comply with its discharge permit, the Carlsbad plant will withdraw additional seawater for dilution, a practice referred to as “in-plant dilution.” This approach produces a more dilute brine discharge, which may reduce some of the environmental risks associated with brine discharge. However, it requires a larger amount of water to be withdrawn from the ocean, increasing the environmental risks associated with intakes, i.e., impingement and entrainment.

Dilution can also be achieved by mixing brine with treated wastewater effluent. Co-discharge of brine and wastewater effluent is still fairly uncommon but is practiced by several large-scale seawater desalination plants, including a 50 MGD plant in Barcelona and a 30 MGD plant in Japan (WateReuse 2011b). This approach is being considered for nearly a quarter of the proposed plants in California (Cooley and Donnelly 2012). Co-discharge of brine and wastewater effluent raises several concerns. First, if the combined mixture is denser than seawater, it may introduce nutrients to the seafloor, a zone with limited mixing. Second, while brine production is relatively constant, wastewater flows are variable and are especially low at night. To account for this variability, desalination plants may need to adjust operations or construct brine storage facilities (WateReuse Association 2011b). Moreover, California’s goal to increase the use of recycled water by at least one million acre-feet by 2020 and at least two million acre-feet by 2030 (SWRCB 2009) would reduce the availability of wastewater effluent to dilute brine discharges. Finally, there may be synergistic effects associated with combining brine with wastewater effluent that are not yet well understood (Kämpf 2009, Jenkins et al. 2012).

Reducing the amount of chemicals used in the desalination process can decrease the environmental impact of brine discharge. In particular, pretreating the source water with membrane technologies, such as microfiltration or ultrafiltration, can reduce the use of chemicals throughout the desalination process (Elimelech and Phillip 2011, Peters and Pinto 2008). Developing membranes resistant to fouling can reduce the need for anti-fouling chemicals (Elimelech and Phillip 2011). Additionally, as described previously, subsurface intakes use sand as a filter, reducing the complexity of the pre-treatment system and the amount of chemicals required during the pretreatment process (Missimer et al. 2013).

Finally, a coastal desalination plant may be equipped with a zero liquid discharge (ZLD) system that evaporates water from the concentrate, leaving a salt residue for disposal or reuse. Reducing the volume and increasing the salinity of the discharged brine might enable the harvesting of salts and minerals from drying ponds to be feasible. In a modeling and bench-scale experiment, Davis (2006) evaluated a process to use electrodialysis on the brine to further concentrate the waste stream and improve the recovery of the desalination plant.[3] Generally, the process has been shown to be technically feasible, but has not yet proven to be economically feasible.

[3] Electrodialysis is an electrochemical separation process that uses electrical currents to move salt ions selectively through a membrane, leaving fresh water behind.

Case Studies

As described previously, comprehensive monitoring data are not available for the vast majority of desalination plants that have been constructed around the world, in part because many of these plants have been built in places and at times when environmental concerns were not at the fore. This is changing, and several recently constructed plants have monitoring programs in place to evaluate environmental impacts associated with brine discharge. In this section, we provide case studies of the monitoring programs in place at two desalination plants built in Florida and Australia, and the results of these programs. Results from the Tampa Bay desalination plant suggest that some of the short-term impacts of brine discharge can be addressed through dilution. In Australia, however, while diffusers may help to minimize some of the impacts of brine discharge, monitoring and adaptive management are needed to evaluate short- and mid-term impacts. In all cases, additional monitoring is needed to evaluate the long-term impact of discharges on the marine environment.

Tampa Bay Desalination Plant

The 25 MGD Tampa Bay desalination plant is located in the southeastern part of Tampa Bay, Florida. Initial operation of the plant began in 2003, although the facility was taken offline between 2005 and 2007 for remediation. The plant was brought back online in 2007. Seawater for the desalination plant is obtained by diverting cooling water from the adjacent TECO Big Bend Power Station, which discharges an estimated 1.4 billion gallons of cooling water per day. At full capacity, the desalination plant produces 19 MGD of brine, which is mixed with cooling water from the power plant in a ratio of 70:1 prior to discharge into Hillsborough Bay (PBS&J 2010).

The National Pollution Discharge Elimination System (NPDES) permit issued by the State of Florida specifies effluent limits and monitoring requirements for the operation of the plant. Monitoring is conducted by Tampa Bay Water independently of the plant operator, American Water-Acciona Agua, and data are submitted to the Florida Department of Environmental Protection. Tampa Bay Water also conducts supplemental monitoring not required by the permit.

The monitoring program has biological and water quality components (PBS&J 2010). Biological monitoring includes an analysis of seagrass, benthic macroinvertebrates, and fish. Benthic invertebrates are sampled quarterly along three transects near the facility discharge. Data on fish and seagrass communities are collected by other ongoing monitoring programs in the area. The water quality monitoring program includes continuous monitoring of conductivity, salinity, dissolved oxygen, and temperature for a 72-hour period every two months. Grab samples are also collected to measure chloride and pH levels. Three continuous water-quality monitoring stations were established near the intake, discharge, and a nearby embayment (PBS&J 2010). Additional water quality testing occurs near the biological monitoring sites.

Monitoring of the plant commenced in 2002, about a year before the initial operation of the plant (McConnell 2009). The water quality sampling indicates that there were small differences in salinity levels between the intake and discharge canals but that these differences were likely not ecologically significant, even at maximum production (PBS&J 2010). The Shannon Diversity Index was used to determine the biological integrity at each of the sampling locations, and a change in the index in excess of 25% relative to the control site was defined as a change in the biological integrity. The difference in the diversity of benthic, fish, and seagrass communities at the sampling locations was less than the 25% benchmark during operation and no-operation periods in each of the three designated monitoring zones (PBS&J 2010).

Perth Seawater Desalination Plant, Australia

The 38 MGD Perth desalination plant supplies over 17% of the drinking water for Perth, a city of 1.9 million, and the largest city on Australia's west coast. The plant, which began operating in 2006, is located in Cockburn Sound, a shallow inlet of the Indian Ocean with limited natural mixing. Cockburn Sound is the most intensely used embayment in Western Australia and is the site of a diverse mix of activities, including military operations, commercial industries, commercial and recreational fishing, mussel farming, and recreational diving and swimming (Environmental Protection Authority 2009).

To reduce the impacts of brine discharge, the plant is equipped with a discharge pipe that extends 1,500 feet offshore and includes a 40-port diffuser along the last 600 feet of pipe. The diffusers are located 1.5 feet above the seabed at a 60-degree angle (Water Reuse 2011b). Solids from the sludge that accumulate on the backwash filter are not discharged with the brine; rather, they are disposed of in a landfill. This reduces the turbidity of the brine discharge and minimizes the visible impact of the effluent on the Cockburn Sound.

Environmental permits were required before the plant could begin operations. The plant's operational permit, issued by the Department of Environment and Conservation (DEC), specifies that the brine discharge will meet a dilution factor of 45 at a distance of 50 meters in all directions from the diffuser (the edge of the defined mixing zone). The permits also required implementation of a monitoring program, which includes computer modeling for diffuser design and validation, Rhodamine dye testing, toxicity tests with local species, real-time dissolved oxygen and brine monitoring, and surveys of sediment characteristics and benthic macrofauna. A baseline survey of nearby sites in the Cockburn Sound was conducted six months before the plant went online to map the spatial pattern of the benthic communities.

The monitoring program began in 2006. The impacts of the plant, and the monitoring program put in place to evaluate those impacts, have been subject to significant debate. Dissolved oxygen levels are a key concern. A drop in dissolved oxygen levels has been observed at the ocean bottom, and these levels fell below the limit set in the operating permit twice in 2008. As stipulated in the permit, the plant reduced production during those periods.[4] The Water Corporation has asserted that the plant does not affect oxygen levels in the deep portions of the Sound and poses no significant risk to Cockburn Sound (Water Corporation 2008). In a subsequent review, however, the National Institute of Water & Atmospheric Research (NIWA) concluded that the desalination plant has "an effect on dissolved oxygen concentrations in Cockburn Sound. The effect may be small or even negligible much of the time; it may become significant only infrequently; and it may be so localised geographically that affected areas are recolonised over time. But it undoubtedly adds a further increment to existing stress on the Cockburn Sound ecosystem" (Spigel 2008, 3). The author further finds that the impact of the desalination plant may be masked by natural variability and unable to be resolved through modeling alone; therefore, additional monitoring and measures are required. These findings were supported by the Western Australia Environmental Protection Authority (WA EPA 2009) and monitoring is ongoing.

[4] All other water quality parameters were below the permit requirements.

4 Regulatory Framework

Project developers must obtain several permits from state and federal agencies for the construction and operation of seawater intake and brine disposal facilities. A full analysis of the permitting requirements for these facilities is beyond the scope of this paper. In this section, we focus on the requirements set forth by the State Water Resources Control Board (State Board) covering seawater intake and brine disposal facilities in California.

The State Board, under the federal Clean Water Act and the Porter-Cologne Water Quality Control Act, has regulatory authority for protecting the water quality of California's lakes, bays and estuaries, rivers and streams, and about 1,100 miles of coastline. Porter-Cologne, passed in 1969 and codified in the California Water Code, addresses water quality and waste discharge. In particular, it authorizes the State Board to adopt statewide water quality control plans (including the Ocean Plan to protect the state's ocean waters) and directs each of the nine Regional Boards to adopt regional water quality control plans. Additionally, as required under the federal Clean Water Act, the Water Boards (both state and regional) issue National Pollution Discharge Elimination System (NPDES) permits that have requirements for intakes and discharges to surface waters.

As part of its charge to protect water quality, the State Board has the authority to regulate seawater intakes for industrial facilities, including for desalination plants. Specifically, Section 13142.5(b) of the California Water Code requires each new or expanded coastal power plant or other industrial facility using seawater for cooling, heating, or industrial processing to use "the best available site, design, technology, and mitigation measures feasible…to minimize the intake and mortality of all forms of marine life." In May 2010, amid growing concern about the impacts of power plant intakes on coastal ecosystems, the State Board promulgated new standards to reduce impingement and entrainment from existing power plants. The new policy defines recirculating cooling systems, also referred to as "closed-loop" cooling systems, as the best available technology. As a result, power plants operators will have to reduce impingement and entrainment to a level commensurate with those achieved with recirculating cooling systems. This, in effect, forces operators to shut down OTC systems. While they could have applied this standard to desalination intakes, the State Board decided to address desalination intakes through a separate policy (SWRCB 2010).

Ocean Plan Amendments

The Ocean Plan, first adopted in 1972 and most recently updated in 2009, sets water quality objectives and policies to protect ocean waters. The Plan prohibits diluting brine with seawater prior to discharge, but does not "have an objective for elevated salinity levels in the ocean, nor does it describe how brine discharges are to be regulated and controlled, leading to permitting uncertainty" (Jenkins et al. 2012). Additionally, the Ocean Plan does not address impacts to marine life from desalination intakes. These issues have been raised during several Ocean Plan reviews but have not yet been resolved due to staff limitations and other priorities, namely the once-through cooling policy. However, the 2011-2013 Ocean Plan Triennial Review determined that an evaluation of desalination intakes and brine disposal regulations was a very high priority.

The State Board is currently developing amendments to the Ocean Plan, as well as the Enclosed Bays and Estuaries Plan, to address the impacts of desalination facilities. These amendments will have five components: (1) best available intake siting and design requirements, including identifying the best available technology; (2) mitigation requirements for surface water intakes; (3) a narrative salinity water quality objective; (4) implementation of the salinity objective; and (5) monitoring requirements. The State Board initiated three studies to gather scientific data and obtain technical input on key issues, including two expert panels (one on intakes and one on brine) and a salinity toxicity study on several test species. It was anticipated that the amendments would be complete by 2013, however, the deadline has been extended into 2014.

5 Conclusions and Recommendations

Desalination, like other major industrial processes, has environmental impacts that must be understood and mitigated. These include effects associated with the construction of the plant and, especially, its long-term operation, including the effects of withdrawing seawater from the ocean and discharging the highly concentrated brine. Environmental impacts are also indirectly associated with the substantial use of energy, which is discussed in more detail in Cooley and Heberger (2013).

Seawater Intakes

One of the key environmental impacts of seawater reverse-osmosis desalination plants is associated with their intakes, which generally withdraw two gallons of water for every gallon of freshwater produced. The majority of desalination plants extract water directly from the ocean through open water intakes which have a direct impact on marine life. Fish and other larger marine organisms are killed on the intake screens (impingement); organisms small enough to pass through the intake screens, such as plankton, fish eggs, and larvae, are killed during processing of the salt water (entrainment). The impacts of impingement and entrainment on the marine environment are not fully understood but are likely to be species- and site-specific. Additionally, impingement and entrainment rates, even for a single desalination plant, may be subject to daily, seasonal, annual, and even decadal variation.

Several operational, design, and technological measures are available to reduce impingement and entrainment from open water intakes. These measures generally fall into two broad categories: physical barriers and behavioral deterrents. Physical barriers, e.g., mesh or wedgewire screens, block fish passage into the desalination plant and may be coupled with some sort of fish collection and return system. Behavioral deterrents, e.g. strobe lights or air bubble curtains, provide a signal to keep fish and other organisms away from the intake area or prevent them from crossing a threshold where they may be impinged. Additionally, subsurface intakes offer an alternative to open water intakes and can virtually eliminate impingement and entrainment.

The choice of intake design will ultimately be site-specific. While some project developers contend that subsurface intakes are infeasible due to their higher construction costs, desalination plants in many other countries have made use of these systems, including beach wells and onshore and offshore infiltration galleries. Subsurface intakes, however, may not be appropriate in all locations because their installation depends on having the proper geology and sediment characteristics, such as sand and gravel, with a sufficiently high porosity and transmissivity. However, with new drilling technologies, e.g., directional drilling, it may be possible to find a pocket with the right conditions surrounded by generally unfavorable ones. When the appropriate site conditions are present, the advantages are clear. These systems can virtually eliminate impingement and entrainment; they also provide a level of pre-filtration that can reduce plant chemical and energy use and operating costs over the long term.

Brine Disposal

Safe disposal of the concentrated brine produced by desalination plants presents a major environmental challenge. All large coastal seawater desalination plants discharge brine into oceans and estuaries. Brine, by definition, has a high salt concentration, and as a result, it is denser than the waters into which it is discharged. Once discharged, brine tends to sink and slowly spread along the ocean floor. Mixing along the ocean floor is usually much slower than at the surface, thus inhibiting dilution and resulting in elevated salt concentrations near the outfall. Diffusers can be placed on the discharge pipe to promote mixing. Brine can also be diluted with effluent from a wastewater treatment plant or with cooling water from a power plant or other industrial user, although these approaches have their own drawbacks.

The impacts of brine on the marine environment are largely unknown. The majority of studies available focus on a limited number of species over short time periods and lack baseline data which would allow a comparison to pre-operation conditions. The laboratory and field studies that have been conducted to date, however, indicate the potential for acute and chronic toxicity and changes to the community structures in marine environments. The ecological impacts of brine discharge, however, vary widely and are a function of several factors, including the characteristics of the brine, the discharge method, the rate of dilution and dispersal, and the sensitivity of organisms.

Despite the long history of seawater desalination plants operating in some regions, data on their ecological impacts are limited. Several recently constructed plants, including plants built in Tampa Bay, Florida and Perth, Australia, have monitoring programs in place to evaluate impacts associated with brine discharge. These studies suggest that the short-term impacts of brine discharge can be addressed through dilution and use of multi-port diffusers. However, additional monitoring is needed to evaluate mid- and long-term impacts.

Regulatory Framework

There is considerable uncertainty about the regulatory requirements for seawater intakes and brine disposal, especially as it relates to those requirements set forth in the federal Clean Water Act and the Porter-Cologne Water Quality Control Act. The State Water Resources Control Board has the authority to regulate seawater intakes for industrial facilities, including for desalination plants, and to protect the water quality of California’s lakes, bays and estuaries, rivers and streams, and about 1,100 miles of coastline. Water quality objectives and implementation policy for the protection of ocean waters are set forth in the state’s Ocean Plan. As noted by the State Board, however, this plan “does not currently have an objective for elevated salinity concentrations, nor does it specifically describe how brine is to be regulated and controlled, leading to permitting uncertainty and possible delays.”

The State Board is currently developing amendments to the Ocean Plan, as well as the Enclosed Bays and Estuaries Plan, to address the impacts of desalination facilities, including the best available intake technology, siting, and design requirements; mitigation requirements for surface water intakes; a salinity water quality objective; and monitoring requirements. It was anticipated that the amendments would be complete by 2013; however, the deadline has been extended into 2014. Once complete, these amendments will provide greater clarity on the regulatory requirements and theoretically allow for a more effective and efficient regulatory process.

Recommendations

This report examines the impacts of seawater desalination on the marine environment. We conclude with a series of recommendations.

Surface seawater intakes result in impingement and entrainment of marine organisms, which may pose a serious threat to the marine environment.

- Intake pipes should be located outside of areas with high biological productivity and designed to minimize impingement and entrainment.
- For all desalination projects, proponents should thoroughly investigate the feasibility of subsurface intakes, including the evaluation of alternative siting and reduced design capacity of the project.

Desalination produces highly concentrated salt brines that contain other chemicals used throughout the desalination process. Steps should be taken to ensure its safe disposal.

- Water managers should avoid disposing of brine in close proximity to sensitive habitats, such as wetlands and some benthic areas.
- Water managers should carefully monitor, report, and minimize the impacts of brine disposal on the marine environment.
- More comprehensive studies are needed to determine the impacts of brine on the marine environment and to mitigate these impacts.

More research is needed to fill gaps in our understanding about the impacts of seawater intakes and brine disposal on the marine environment.

- Studies should examine the sub-lethal and chronic effects of brine exposure and the toxicity of brine effluent mixtures, i.e., brine and wastewater effluent.
- Studies should be conducted under a range of climatic conditions to evaluate seasonal and inter-annual differences to species response.
- Given differential response among species, more research is needed on those species found along the California coast.
- To evaluate the accuracy of existing models, comparisons are needed of early modeling efforts with field observations once the plant is in operation.

Monitoring of existing and proposed desalination plants is vital to improving our understanding of the sensitivity of the marine environment and can help to promote more effective operation and design to minimize ecological and biological impacts.

- Regulators should require desalination plant operators to develop adequate monitoring programs that include multiple sites, adequate replication of samples, and baseline data.
- Monitoring should account for natural seasonal and inter-annual variability.
- Monitoring data should be subject to third-party validation and be made easily available at no cost by internet in an accessible format, e.g. data files rather than PDF summaries where appropriate, to all concerned parties, including the general public.

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