Final **Report**

Database of Permitting Practices for Seawater Desalination Concentrate

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Database of Permitting Practices for Seawater Concentrate Disposal

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The Water Environment & Reuse Foundation (WE&RF) is a 501c3 charitable corporation seeking to identify, support, and disseminate research that enhances the quality and reliability of water for natural systems and communities with an integrated approach to resource recovery and reuse; while facilitating interaction among practitioners, educators, researchers, decision makers, and the public. WE&RF subscribers include municipal and regional water and water resource recovery facilities, industrial corporations, environmental engineering firms, and others that share a commitment to cost-effective water quality solutions. WE&RF is dedicated to advancing science and technology addressing water quality issues as they impact water resources, the atmosphere, the lands, and quality of life.

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Abstract & Benefits

Abstract:

The purpose of this research project was to identify the discharge information that permitting agencies need and the decision-making process they go through to permit discharge methods in order to help desalination project proponents focus and expedite their permitting efforts.

The project documented seawater reverse osmosis (SWRO) discharge regulatory issues and provided a critical overview of facility discharge-related information required for permitting desalination projects in the United States and selected countries with advanced environmental regulations and experience in implementing seawater desalination projects.

Information was gathered from the three key U.S. states (California, Florida, Texas) where interest in SWRO desalination has been highest. Due to the more extensive international experience with SWRO desalination, information was also obtained from the countries of Australia, Israel, and Spain – all countries of significant recent large-scale SWRO desalination projects. Case studies of 11 SWRO plants and analysis of regulatory systems and permitting processes supported detailed definition of the decision-making process to set discharge permit limits, as well as defining environmental and other regulatory issues associated with concentrate regulation.

Benefits:

- Bring clarity to the regulatory process by defining discharge permit decision-making steps and by analyzing associated regulatory and permitting issues.
- Benefits the understanding and implementation of SWRO desalination as a drought-proof water supply source and provides a strong framework for the development of federal and state desalination project permitting guidelines.
- Helps define areas of needed research to more firmly establish a scientific basis for setting permit limits for concentrate discharge.
- Provides an important step in the path to both strengthening (from a regulatory perspective) and simplifying and expediting (from a utility perspective) of SWRO concentrate management and permitting.

Keywords: Seawater reverse osmosis, desalination, concentrate discharge, NPDES permit, discharge regulations, permitting, brine discharge, case studies.

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Acronyms

ANZECC	Australian and New Zealand Environmental and Conservation Council
BMPs	best management practices
BOD	biochemical oxygen demand
BWRO	brackish water reverse osmosis
CCC	California Coastal Commission
CDP	Carlsbad Desalination Project
CFR	Code of Federal Regulations
CIP	clean-in-place
CWA	Clean Water Act
DEC	Department of Environment and Conservation (Western Australia)
DERM	Department of Environment and Resource Management (Queensland)
DO	dissolved oxygen
DSE	Department of Sustainability and Environment (Victoria, Australia)
DWI	deep well injection
EDTA	ethylenediaminetetraacetic acid
EIR	Environmental Impact Report
EPS	Encina Power Station
EQO	environmental quality objective (Western Australia)
FDEP	Florida Department of Environmental Protection
HBGS	Huntington Beach Generating Station
HR	high recovery
IEC	Israeli Electric Company
MCM	million cubic meters
MCRA	Marine Contamination Risk Assessment (Australia)
MEP	Ministry of Environmental Protection (Israel)
MF	microfiltration
NF	nanofiltration
NPDES	National Pollutant Discharge Elimination System
NTU	Nephelometric Turbidity Unit
ORP	oxidation-reduction potential
ppt	parts per thousand
psu	practical salinity units
RO	reverse osmosis
RWQCB	Regional Water Quality Control Board (in California)
STE	salinity tolerance evaluation
SWRCB	State Water Resources Control Board (California)
SWRO	seawater reverse osmosis
TCEQ	Texas Commission on Environmental Quality

TDS	total dissolved solids
TECO	Tampa Electric Company
TOC	total organic carbon
TPDES	Texas Pollutant Discharge Elimination System
TREs	toxicity reduction evaluations
TSS	total suspended solids
TU_a	acute toxicity units
UF	ultrafiltration
UIC	Underground Injection Control (program)
U.S. EPA	United States Environmental Protection Agency
WET	whole effluent toxicity
WQBELs	water-quality-based effluent limitations
W	
WRRF	water resource recovery facility
WWTP	wastewater treatment plant
ZID	zone of initial dilution
ZLD	zero liquid discharge

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Executive Summary

Permitting the disposal of concentrate and other waste streams is often one of the most challenging tasks associated with the development and implementation of desalination projects. This study focuses on the review of key regulatory requirements, support studies, and permitting practices for medium and large seawater reverse osmosis (SWRO) desalination plants in the United States and abroad. The size range (from 2.5 to 110 MGD or 9.5 to 440 ML/d) covers most plants built since 2005. The study is based on permitting experience with recent SWRO projects and is focused on the regulatory issues and considerations associated with the most commonly used concentrate management method: discharge to surface waterbodies. Issues specific to the permitting of thermal desalination plants are not addressed in the report because, although popular in the Middle East, thermal desalination has not found significant application in seawater desalination in the United States and most other developed countries.

The formal project objective was to identify the discharge information that permitting agencies need and the decision-making process they go through to permit discharge methods in order to help desalination project proponents focus and expedite their permitting efforts.

The project involved documenting SWRO discharge regulatory information and facility information for the United States and selected countries. In the United States, the National Pollutant Discharge Elimination System (NPDES) permit is the primary permit required for discharge to surface waters. Discussion focused on events, information, and issues associated with obtaining an NPDES-type permit.

One of the key limiting factors in the construction of new seawater desalination plants is the availability of suitable conditions and locations for disposal of the high-salinity sidestream commonly referred to as concentrate or brine. Concentrate is generated as a by-product of the separation of the minerals from the source water used for desalination. This liquid stream contains in concentrated form most of the source water's dissolved solids as well as some pretreatment additives (i.e., residual amounts of coagulants, flocculants, and antiscalants) and other chemicals, as well as microbial contaminants and particulates rejected by the reverse osmosis (RO) membranes. If chemical pretreatment is used, such as coagulants, antiscalants, polymers, or disinfectants, some or all of these chemicals may reach or may be disposed of along with the plant discharge concentrate. Chapter 1 of the report provides background and contextual information for the study including the relatively new interest and recent challenges associated with the permitting complexity of medium and large SWRO desalination plants in the United States.

The quantity of the concentrate is largely a function of the plant size and recovery, which in turn is highly dependent on the total dissolved solids (TDS) concentration of the source water. Chapter 2 describes how to determine the quantity and quality of concentrate depending on the plant source water quality and quantity and on key desalination plant design and performance parameters. This chapter also addresses the characterization of all other nonconcentrate waste streams generated at a typical SWRO desalination plant, such as spent filter backwash water and membrane cleaning solutions.
Concentrate water quality and especially water quantity determine to a great extent the type of concentrate management option that will be most suitable for a given desalination project. Chapter 3 of this report presents the most commonly used methods of seawater concentrate

discharge. Such methods include the following:

- surface water discharge via new outfalls
    - onshore or near-shore outfall
    - offshore outfall
- surface water discharge via existing outfalls
    - water resource recovery facility (WRRF) outfall
    - power plant outfall (co-location with power plant)
- subsurface discharge via shallow wells

For new onshore outfalls to have minimal environmental impact, discharge must be into very active receiving water with a high mixing energy at the shoreline (turbulent near-shore waters, tides, near-shore currents, etc.). Such conditions rarely exist, and onshore outfalls are often discouraged if not prohibited by regulatory agencies because of visual impacts and interference with the recreational use of the shoreline. Although co-discharge at some existing power plant outfalls may be considered onshore discharge, the pre-dilution of concentrate with cooling water mitigates some of the environmental impacts.

At present, more than 90% of all seawater desalination projects have near-shore or offshore ocean discharge outfalls. Near-shore outfalls are the most cost-effective means of seawater concentrate discharge via new outfalls and therefore are the most commonly used worldwide. Offshore outfalls with diffusers have become a recent trend at many new desalination plants because of the assurance of good mixing; they also have less visual impact and are not as sensitive to the available tidal mixing intensity. However, such outfalls are usually the costliest concentrate discharge option.

Although co-discharge with water resource recovery facility (WRRF) outfalls is practiced at several large desalination plants in Europe, this method of concentrate disposal has found limited application in the United States to date because of constraints associated with the availability of an adequate volume of WRRF effluent for complete mixing both diurnally and during the summer season when many plants practice enhanced water reuse and utilize a large portion of the plant effluent. WRRF outfalls are typically offshore.

Concentrate discharge via existing coastal power plant outfall is the most common method of desalination plant concentrate disposal in Israel and the Middle East and has been implemented at the Tampa Bay and Carlsbad desalination plants. Co-location of desalination plants and power generation stations is planned at several desalination projects in California, Florida, and Texas as well. The main advantage of this disposal method is the reduced project construction cost associated with the avoidance of the need to construct a new intake and outfall. Power plant outfalls are typically near-shore, and some may be considered onshore, such as a discharge into a canal that feeds into the shore water (e.g., Carlsbad, California; Tampa, Florida; Ashkelon, Israel).

A few plants worldwide have applied the use of shallow coastal wells for concentrate discharge. Most of these plants have a capacity of less than 5 MGD (19,000 m^3/day). The only recent successful desalination plant applying this disposal method in the United States is the 0.6 MGD (2300-m^3/day) Sand City brackish water facility, which currently operates at approximately 0.3 MGD (1150 m^3/day) because of salinity constraints incorporated in the plant discharge permit. Because the source water salinity of this plant increased almost two times over the first two years of its operation (which often occurs when beach wells are used) and the plant permit limits the maximum salinity to that of the ambient seawater, the plant capacity had to be derated because of this permitting constraint. Experiences with coastal exfiltration galleries in the Middle East have shown that their discharge capacity tends to diminish over time.

Chapter 4 provides a brief overview on other concentrate and residual management methods (including deep well injection, evaporation ponds, zero liquid discharge technologies, and beneficial concentrate reuse) and their applicability for managing concentrate and residuals from SWRO desalination plants. Such methods have found very limited full-scale application to date in the disposal of seawater concentrate, but some have been used frequently for the disposal of other SWRO plant residuals. Permitting of such methods has not posed a challenge as of yet.

Chapter 5 presents a general overview of the U.S. federal regulatory framework and details how effluent limitations for ocean discharge are determined. The process of determining effluent limits is summarized in Figure 5.1, which lists the sequence of events and the information required in establishing the regulatory limits contained in discharge permits issued to individual SWRO desalination facilities in the United States.

This chapter also describes the scope of studies needed to develop data for discharge permit applications. Such studies include:

- salinity dispersion modeling,
- the study of discharge effluent toxicity,
- the study of concentrate water quality characterization, and
- the study of salinity tolerance evaluation.

For each type of study, the report presents a methodology and guidance for the implementation of the study as per applicable federal and state regulations and illustrates the study scope with examples from U.S. seawater desalination projects.

Chapter 6 addresses key environmental issues and other issues associated with regulatory guidance and the process of providing information required to determine discharge permit limitations that address potential environmental impacts. Particular emphasis is given to environmental issues that are related to discharge permitting and permit limits:

- salinity tolerance of aquatic species
- concentration of source water constituents to harmful levels
- discharge discoloration and low oxygen content

Other issues discussed affect the permitting process through their effect on:

- studies performed to develop data for permit applications,
- analytical methods producing numerical data for permit applications and for permit monitoring requirements, and
- a regulatory agency’s framework and basis for developing permit policy and making permit decisions.

Chapter 7 summarizes regulations specific to the three key states in the United States with the most desalination projects: California, Texas, and Florida. The recently promulgated (May 2015) California Desalination Amendment to the California Ocean Plan, which contains portions addressing concentrate discharge, is discussed in detail.

Chapter 8 presents permitting case studies for the Carlsbad, Huntington Beach, and Tampa Bay SWRO projects. These case studies define the permitting process associated with these projects, key permit discharge requirements, and specific studies completed to support the permitting process, while highlighting similarities and differences.

In Chapter 9, the report presents an overview of regulatory permitting practices abroad with a focus on Australia, Spain, and Israel – countries that have advanced regulatory frameworks and comprehensive experience with medium and large seawater desalination projects. It is interesting to point out that in all of the referenced countries, the environmental review and the permitting process have many similarities with those of the United States.

Chapter 10 provides case studies of the permitting of desalination plants in Australia, Spain, and Israel. The featured Australian desalination projects are Perth I (Kwinana) Desalination Plant and the Gold Coast Desalination Plant. The referenced Spanish desalination plants are Torrevieja Plant, Alicante 1 Plant, San Pedro del Pinatar Desalination Plant, and Mas Palomas II Desalination Plant for the Canary Islands. The Israeli desalination projects for which case studies are provided are Ashkelon Desalination Plant and Sorek Desalination Plant.

Each of the desalination plant case studies contains a project description, receiving water characterization, a description of discharge streams, a description of plant outfall, key discharge permit requirements, and permit compliance observations. The presented case studies indicate that when designed and operated well, desalination plant discharges are environmentally safe and do not result in measurable impacts on marine life in the vicinity of the discharge.

The results of the long-term operation of the described plants indicate that the desalination plant concentrate is completely dispersed to salinity levels of less than 10% of the ambient water within 80 to 250 ft (24-76 m) from the point of discharge.

Another observation is that in all countries other than the United States, the time needed to complete the environmental review and issue a desalination plant discharge permit (one to two years) is usually shorter than the time to construct the plant (two to three years). In comparison, the environmental review and permitting of the Tampa Bay SWRO project took approximately 2.5 years, and that of the Carlsbad Desalination Plant from project inception (2000) to permit process completion (2010) took approximately 10 years with a permitting period of more than five years.

An underlying conclusion drawn from the comparative observation of the permitting regulations and process in the United States and in other developed countries of proven track record (with successful and environmentally safe desalination projects) is that the U.S. regulatory process would benefit from the development of federal desalination guidelines to streamline the permitting process.

A final chapter, Chapter 11, brings observations and findings from previous chapters together by presenting conclusions and making recommendations. Recommendations include the following:

- Development of federal regulatory and permitting guidelines for desalination projects, similar to the U.S. Environmental Protection Agency (U.S. EPA) Water Reuse Guidelines, will benefit significantly the use of desalination as an alternative drought-proof water supply source and provide a strong framework for the development of statewide guidelines.
- Development of statewide desalination guidelines to address desalination-specific permitting challenges will also benefit the use and application of desalination.
- Creation of frequent opportunities for state regulators to exchange information, practices, and experience in the permitting of desalination projects will be beneficial and is highly recommended.
- Enhancement of the Standard Methods for Analysis of Water and Wastewater to include the analysis of seawater and concentrate for total suspended solids, radionuclides, and metals will be of great benefit in streamlining concentrate management and permitting.
- Development of a uniform methodology to establish the salinity tolerance of site-specific marine organisms by the U.S. EPA will simplify the desalination project permitting process and establish the opportunity to minimize expenditures associated with the construction of costly outfalls.
- Enhancement of the existing whole effluent toxicity (WET) testing procedures for seawater discharges will allow them to reflect the site-specific conditions of a receiving marine environment.

Increased funding of state regulatory agencies to enhance the number and qualification of staff with desalination experience will benefit the use and application of desalination

Chapter 1

Project Context and Report Content

1.1 Chapter Content

In this introductory chapter, the report content is described, followed by discussion of the broader context of seawater desalination and regulation to explain and position the subject focus and project approach.

1.2 Report Content

Chapter 2 characterizes and discusses the seawater reverse osmosis (SWRO) residuals of concentrate, backwash water, and membrane flush water. Chapter 3 reviews seawater concentrate management options with an emphasis on the surface water discharge of concentrate. In Chapter 4, other seawater residual management options are discussed. Much of the information in the first four chapters may be considered background for understanding and defining the permit-related information gathered to meet the project objective. Chapter 5 discusses the federal framework of surface water discharge regulation and permitting and identifies events and information required for the determination of numerical discharge (effluent) limits. Chapter 6 reviews environmental and other issues associated with the determination of effluent limitations. Chapter 7 focuses on regulations and permitting practices in the states of California, Florida, and Texas. Case studies of three U.S. facilities are provided in Chapter 8. Chapter 9 discusses regulation and permitting practices in Australia, Spain, and Israel. Chapter 10 presents several case studies of permitting associated with large desalination projects abroad. Chapter 11, the final chapter, presents a summary of the project work and results along with conclusions and recommendations.

1.3 The Subject

There is considerable interest in seawater desalination in many U.S. coastal areas. Historically, however, less than 3% of the estimated 340+ U.S. municipal desalination plants that have been built were seawater facilities, the vast majority being inland brackish water plants (Mickley et al., 2013). At the time of the preparation of this report (2015), the Tampa Bay desalination facility (25 MGD or 95,000 m^3/day) is the only large-scale SWRO desalination plant operating in the United States. The second largest SWRO plant (6 MGD or 23,000 m^3/day) built in the United States was the Santa Barbara facility, which was constructed in 1992 during a drought crisis and subsequently moth-balled once the rains came back. In light of the present California drought, the Santa Barbara facility is currently undergoing refurbishment and is not in operation, and the new 50-MGD (189,000-m^3/day) Carlsbad SWRO Desalination Plant is undergoing construction. In addition to drought and the resulting reduction in conventional water resources, other factors contributing to the increased interest in seawater desalination include the following:

- growing coastal populations and the need for additional water resources
- decreasing costs of desalination
- prolonged drought patterns in the arid Southwest

Over the last 10 years, several U.S. coastal communities have conducted feasibility and pilot studies, and several large SWRO projects are in development. Historically, the three major limiting factors for developing seawater desalination projects in the United States have been cost, aquatic life impacts by the plant intake, and concentrate disposal. Environmental impacts associated with concentrate discharge are managed and limited through federal and state discharge regulations. U.S. permitting protocols and issues associated with SWRO concentrate discharge are in various stages of investigation, definition, and clarity that could benefit from broad consideration, study, and the definition of appropriate guidelines. Although the same might be said of global discharge regulation and permitting of desalination plants, there is considerable experience outside of the United States in documenting and addressing environmental discharge issues. The main purpose of this study is to provide an overview of key regulatory requirements and permitting issues associated with the implementation of seawater desalination projects in the United States and abroad.

The formal project objective is

> Identify the discharge information that permitting agencies need and the decision-making process they go through to permit discharge methods in order to help desalination project proponents focus and expedite their permitting efforts.

More specifically, the project involves documenting SWRO discharge regulatory issues and providing critical overview of facility discharge-related information for desalination projects in the United States and selected countries. In the United States, the NPDES permit is the primary permit required for discharge to surface waters.

1.4 Context of Seawater Concentrate Management and Regulation

In the remaining portion of this chapter, the broad context of issues addressed by the project is discussed in terms of brief overviews of global seawater desalination, U.S. desalination and concentrate management, seawater concentrate discharge options, discharge regulation and permit issues, and discharge permitting as part of the total desalination project development and implementation.

1.4.1 Overview of Global Desalination

Nearly all municipal desalination plants utilize either thermal evaporative or membrane separation technology to produce freshwater from seawater and brackish water. Both types of technologies were developed in the United States using federal funding. More than $1.5 billion (2006 dollars) of investment in desalination research, primarily from 1959 through 1974 via the Office of Saline Water and later the Office of Water Research and Technology, resulted in more than 1200 research reports (NRC, 2008).

Thermal desalination processing by multi-stage flash distillation and multi-effect distillation became commercially viable first. This method was widely implemented where the high energy requirements of water evaporation could be met in oil- and energy-rich Middle Eastern locations and in the Caribbean; it was used to meet freshwater shortages that did not yet exist in the United States. Until the early 1980s, the number of desalination plants using thermal evaporation and their cumulative capacity were greater than the number and capacity of those applying SWRO technology. Since then, largely because of cost and energy reductions that resulted from technology improvements, each year SWRO technology has provided greater numbers and capacity than thermal technology. As of 2012, approximately 65% of all desalination plants worldwide use reverse osmosis (RO) membrane separation for the production of freshwater (GWI, 2014).

Another global trend has been the predominance of seawater desalination installed capacity over that of inland brackish desalination, except in a few locations including the United States (GWI, 2014). Globally, municipal desalination facilities account for 61% of the installed capacity. Municipal desalination plants are, in general, much larger than industrial desalination facilities, and the information available about facilities, environmental issues, and regulation comes almost exclusively from the municipal sector.

1.4.2 Overview of U.S. Desalination and Concentrate Management

Discussion of this broader context of U.S. desalination serves to introduce characteristics and issues that are unique to SWRO and that reflect the relatively recent development of large-scale SWRO projects in the United States. As mentioned in the introductory paragraph and shown in Table 1.1, the majority of U.S. municipal desalination facilities treat brackish water rather than seawater. Figures 1.1 and 1.2 show the growth rate of both types of desalination plants and the cumulative capacity of the municipal facilities built in the United States. All the facilities use membrane technologies with the mix of technologies shown in Table 1.1.

The microfiltration (MF)/RO and MF/nanofiltration (NF) facilities are all water reclamation facilities. Although the growth rate and interest in brackish desalination continues, more recently the interest in SWRO desalination has significantly increased.

Table 1.1. Number and Percentage of Different Membrane Processes Used in U.S. Municipal Desalination, as of 2010.

Membrane Process	Number	Percentage
BWRO	236	73
NF	43	13
Electrodialysis reversal	21	6
SWRO	11	3
MF/RO	10	3
MF/NF	3	1

Note: BWRO = brackish water reverse osmosis
Source: Mickley et al., 2013

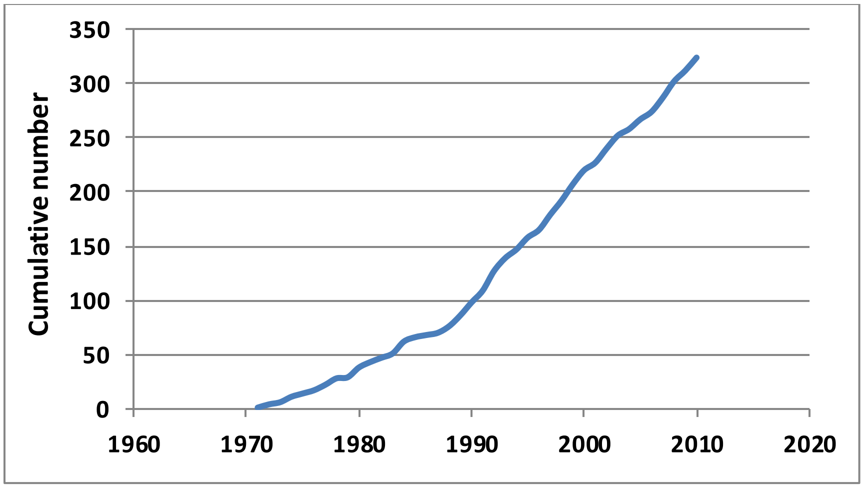


Figure 1.1. Cumulative Number of U.S. Municipal Desalination Plants.
Source: Mickley et al., 2013

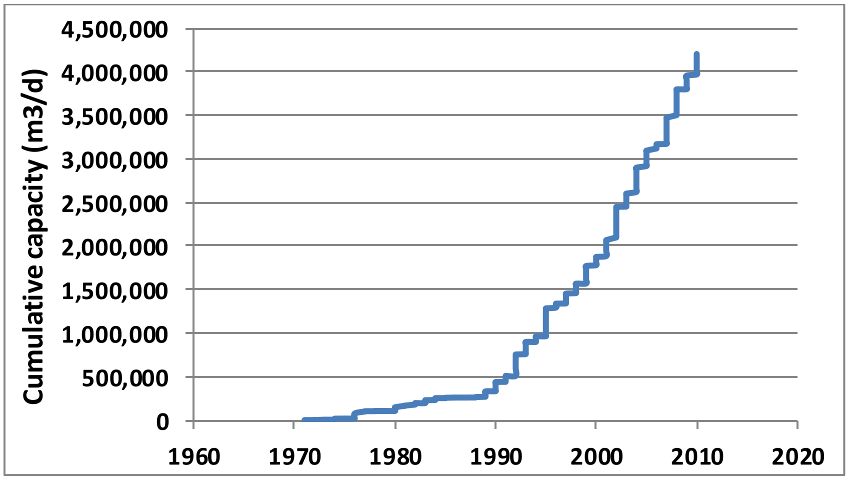


Figure 1.2. Cumulative Capacity (m^3/d) of U.S. Municipal Desalination Plants.

From the most recent survey conducted (Mickley et al., 2013), as of 2010, 34 states had municipal desalination facilities. More than 98% of these plants manage concentrate via one of the five conventional disposal options listed in Table 1.2. In theory, all of these options might be used in SWRO concentrate management; in practice, however, the properties and management of SWRO concentrate are considerably different from those of brackish water concentrate primarily in having:

- larger volumes (generally),
- substantially greater salinity, and
- a composition dominated by sodium chloride.

Table 1.2. Desalination Residuals Management Options.

Five conventional disposal options:

- Surface water discharge
    - for seawater plants
        - direct offshore ocean outfall (includes brine line when direct to ocean)
        - onshore or near-shore ocean outfall
        - existing WRRF ocean outfall
        - existing power plant ocean outfall
    - for inland plants
        - discharge to inland rivers, canals, lakes, etc.
- Disposal to sewer
    - sewer line
    - direct line to WRRF outfall
    - brine line (where brine line goes to WRRF)
    - trucking of concentrate to WRRF
- Subsurface injection
    - deep well injection (DWI)
    - shallow well (beach well) discharge
- Evaporation pond
    - conventional pond
    - enhanced evaporation ponds or schemes
- Land application
    - percolation pond or rapid infiltration basin
    - irrigation

Landfill disposal options (for waste solids or sludge only)

- dedicated monofill
- industrial landfill

Recycle to front end of WRRF (for low salinity concentrate at WRRFs)

Beneficial use (other than irrigation)

Notes: All the conventional options are used for brackish concentrate management; surface water discharge is the typical concentrate option used for SWRO concentrate management; the other options may be used for management of other SWRO residuals; the same options as those in Table 1.2 apply to the residuals of high recovery [HR; including zero liquid discharge (ZLD)] processing; WWTP = wastewater treatment plant

Use of options other than surface water discharge is typically considered only for SWRO residuals other than concentrate (e.g., membrane cleaning solutions, spent filter backwash). In contrast to the brackish concentrate, more than 90% of SWRO concentrates in the United States and globally are disposed of by discharge back to the source of seawater (sea, ocean, bay, estuary, etc.).

Table 1.3 lists the frequency of use of the disposal options and the number of states utilizing the options in U.S. municipal desalination plants. As shown in Table 1.4, most of the subsurface injection sites and land applications are in Florida, whereas evaporation ponds are restricted by climate and thus are mostly found in dryer southwest locations. An extensive description and characterization of U.S. municipal desalination facilities is found in previous publications (Mickley, 2012; Mickley et al., 2013).

Because of the regulatory constraints on SWRO concentrate for total dissolved solids (TDS), SWRO concentrate disposal to sewer or direct to a water resource recovery facility (WRRF) is not a feasible option except possibly for very small-volume plants. Of importance relative to the management of other SWRO residuals is that the use of several of the options other than surface water discharge is limited owing to climate (evaporation ponds and land application) and hydro-geological conditions (subsurface injection), as reflected in Table 1.4.

Table 1.3. Number of States Using Various Disposal Options in Municipal Desalination Plants, as of 2010.

	Percent Use	Number of States	States Using Option
Surface water discharge	47	25	many
Discharge to sewer	24	22	many
Subsurface injection	17	3	FL, CA, KS
Land application	7	4	FL, CA, TX, AZ
Evaporation ponds	4	3	FL, TX, AZ
Recycle	1	3	CA, AZ, PA

Notes: FL = Florida, CA = California, KS = Kansas, TX = Texas, AZ = Arizona, PA = Pennsylvania

Table 1.4. States Using Various Disposal Options and Number of Plants in Each State.

	FL	CA	TX	KS	AZ	PA
Subsurface injection	50	1	1	1	0	0
Land application	20	1	1	0	1	0
Evaporation ponds	3	0	7	0	3	0
Recycle	0	2	0	0	1	1

Unlike most brackish water reverse osmosis (BWRO) processes, in addition to concentrate, SWRO process residuals generally include backwash water in a volume significantly less than that of the concentrate. These residuals may be discharged along with the concentrate but for small plants (less than 0.3 MGD or 1000 m^3/day) frequently are disposed of to the sewer.

In addition to sea discharge, a few of the U.S. SWRO facilities (usually with a capacity of less than 1.3 MGD or 5000 m^3/day) such as that in Sand City, CA, dispose of concentrate via shallow coastal wells.

More detailed discussion of concentrate management options is provided in Chapters 3 and 4.

Because of the relatively limited number of U.S. SWRO facilities, there are few regulatory precedents on which to base the permitting decisions that will need to be made as a result of the growing implementation of large SWRO projects in the United States.

1.4.3 Seawater Concentrate Discharge Options

The discharge options presently used by SWRO plants include the following:

- surface water discharge via new outfalls
    - onshore or near-shore outfall
    - offshore outfall
- surface water discharge via existing outfalls
    - wastewater treatment plant (WWTP) outfall
    - power plant outfall (co-location with power plant)
- subsurface discharge via shallow wells

Table 1.5 lists several SWRO facilities that utilize these options. Descriptions of the discharge options, including their advantages and disadvantages and factors contributing to their consideration, are presented in Chapters 3 and 4.

1.4.4 Discharge Permit Issues of Seawater Concentrate and Discharge Regulation

The primary environmental issues that are the reasons for discharge permitting and permit limits include:

- the salinity tolerance of aquatic species,
- the concentration of source water constituents to harmful levels, and
- discharges with discoloration and low oxygen content.

These are all long-time recognized environmental impact issues. A more recently identified issue (Jenkins et al., 2012) associated with concentrate discharge is the impact on marine organisms because of shear and turbulence associated with the high-velocity diffuser jets discharging the concentrate into the receiving water. This issue has not been widely researched or addressed in discharge permits, and the reader is referred to the literature (Jenkins et al., 2012) for details.

The report focuses on the three primary environmental issues that have been globally recognized and addressed in the discharge permits from all the states and countries reviewed in the report.

Several other issues are associated with regulatory guidance and the process of providing the information required to determine discharge permit limitations that address the environmental concerns. These issues affect the permitting process through their effect on:

- studies performed to develop data for permit applications,
- analytical laboratories producing numerical data for permit applications and for permit monitoring requirements, and
- a regulatory agency’s framework and basis for developing permit policy and making permit decisions.

These issues are described in Chapter 5.

The project provides an overview of the federal and state regulatory framework for issuing NPDES permits, the methodology used by the regulatory agencies in determining discharge permit limits, and discussion of the issues identified previously.

The states with the most activity in and consideration of SWRO are California, Florida, and Texas. This project focuses on detailing discharge permitting in these three states.

Because of the high level of SWRO desalination project implementation in Spain, Australia, and Israel, as reflected in Table 1.5, and because of the level of sophistication of the discharge regulations in these countries, the report also discusses their discharge permitting issues.

1.4.5 Concentrate Management as Part of a Desalination Project

A final context item that frames SWRO NPDES discharge permitting is how it fits within the sequence of events associated with the consideration, development, and implementation of a desalination project.

A SWRO project typically includes a number of phases such as:

- a feasibility study
- conceptual or preliminary design
- pilot testing
- an environmental review and permitting
- final design
- construction
- startup and operation

Although represented here as a linear sequence of phases, some phases may overlap and happen concurrently, such as when construction begins prior to completion of the final design.

Because of the critical nature of concentrate permitting to the general feasibility of a desalination project, it is addressed at the earliest stage of desalination plant consideration – that is, the feasibility study phase. At the conceptual or preliminary design phase of project development, significant detail of all permits required for the desalination plant, including right of way, land acquisition, pilot system, intake system, construction, and operation permits, as well as the discharge permit, are identified. Most of the permits have environmental concerns associated with them, which are identified and evaluated in the environmental review and permitting phase. This document precedes issuance of most permits as it is used to support the issuance of permits and approvals. All permit conditions and environmental mitigation measures are reflected in the final design, construction, and startup and operation phases of the project.

The issuance of an NPDES permit takes place within a sequence of several phases of project development and usually occurs when all environmental reviews are complete. Because of the complexity of the broader full desalination project permitting as well as the dedicated project focus on the NPDES permit, the broad project context will not be addressed further in this report.

Table 1.5. SWRO Discharge Options and Example Facilities.

Plant	Country/State	Size [MGD (ML/d)]	Start Year	Comments
NEAR-SHORE OUTFALL				
Ashkelon	Israel	85 (322)	2005	No diffusers
Hadera	Israel	72 (274)	2010	No diffusers
Santa Catalina	California	0.13 (0.5)	1991	With diffusers
OFFSHORE OUTFALL				
Gold Coast (Tugun)	Australia	35 (132)	2009	Tunneled outfall with diffusers
Sydney (Kurnell)	Australia	66 (250)	2011	Tunneled outfall with diffusers
Perth I (Kwinana Beach)	Australia	38 expansion to 63 (143/239)	2006/2012	Tunneled outfall with diffusers
Perth II (Bunbury/Binningup)	Australia	37/74 (140/280)	2011/2012	Tunneled outfall with diffusers
Melbourne	Australia	110/414	2012	Tunneled outfall with diffusers
Adelaide (Port Stanvac)	Australia	40/80 (150/300)	2011/2012	Tunneled outfall with diffusers
WWTP OUTFALL				
Santa Cruz	California	2.5 (9.5)	Plant in planning	With diffusers
Barcelona	Spain	50 (189)	2009	With diffusers
Fukuoka	Japan	13 (50)	2006	With diffusers
POWER PLANT OUTFALL				
Tampa Bay	Florida	25 (95)	2007	No diffusers
Alicante I	Spain	18 (68)	2003	No diffusers
Alicante II	Spain	18 (68)	2008	Short outfall; no diffusers
San Pedro Del Pinatar I	Spain	18 (68)	2006	With diffusers
SHALLOW WELLS				
Stock Island	Florida	1.5 (5.7)	2000	Shallow wells
Marathon	Florida	1.5 (5.7)	2000	Shallow wells
Sand City	California	0.3 (1.1)	2010	Shallow wells

1.4.6 Summary of Background and Context Information

This brief discussion of the project context orients and explains the project focus on SWRO discharge permitting and the approach taken in accomplishing the project objective. The project work was primarily information gathering followed by the analysis and synthesis of the information obtained. Information was gathered from interactions with regulatory agencies and SWRO facilities, as well as from the published literature.

Chapter 2

Desalination Plant Discharge Characterization

2.1 SWRO Residuals

Typically, seawater desalination plants generate the following three key sidestreams: (1) concentrate from membrane salt separation, (2) backwash water from the plant pretreatment system, and (3) membrane flush water from the periodic chemically enhanced cleaning [clean-in-place (CIP)] of RO and pretreatment membranes (if membrane pretreatment is used; see Figure 2.1). The other two sidestreams shown in Figure 2.1 (filter-to-waste and out-of-specification permeate) are of an intermittent nature and have a volume and content of contaminants that are several orders of magnitude smaller than those of the three main sidestreams.

During normal desalination plant operation, concentrate is produced continuously, whereas spent filter backwash water is only generated after every backwash cycle of each filtration unit or cell of the pretreatment system, which can be as long as 24 to 48 h when conventional granular media filters are used for pretreatment, and from 30 to 60 minutes for membrane pretreatment systems. Spent RO and pretreatment membrane cleaning sidestreams are generated intermittently (typically every one to six months).

2.2 Concentrate

Concentrate is generated as a by-product of the separation of the minerals from the seawater used for desalination. This liquid stream contains most of the source water's dissolved solids in concentrated form, some pretreatment additives (i.e., residual amounts of coagulants, flocculants, and antiscalants) and other chemicals, and microbial contaminants and particulates rejected by the RO membranes.

2.2.1 Quantity

Concentrate quantity is a function of the desalination plant size and recovery. Desalination plant size is defined as the freshwater production capacity of the plant. Typically, plant recovery is expressed as the percentage of the total volume of saline source water that is converted into freshwater by the desalination plant. The recovery rate of SWRO plants is typically 40 to 55%. Operation at higher plant recovery results in the generation of a smaller concentrate volume of higher salinity.

The daily volume of concentrate produced by the desalination plant can be calculated by the following formula:

$$Q_c = Q_p \times (1 - R)/R \tag{2.1}$$

where Q_p and Q_c are the volumes of the plant freshwater production flow and concentrate flow, respectively, and R is the plant recovery in decimal.

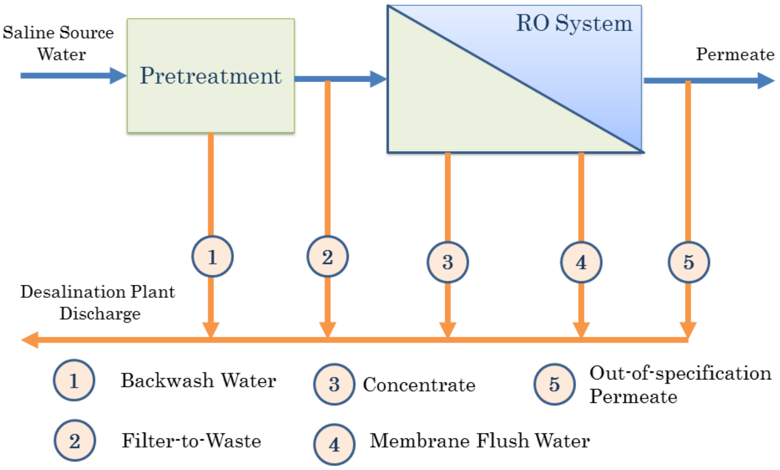


Figure 2.1. Desalination Process Sidestreams.

Applying Formula 2.1, a seawater desalination plant producing 10.6 MGD (40,000 m^3/day) of freshwater and operating at 45% recovery (R = 0.45) will generate concentrate of the following volume:

$$Q_c \text{ seawater plant} = 40{,}000 \text{ m}^3\text{/day} \times (1 - 0.45)/0.45 = 48{,}889 \text{ m}^3\text{/day (12.9 MGD)}$$

2.2.2 Quality

Concentrate water quality depends on the quality of the saline source water, the salt rejection characteristics of the desalination membranes, and the desalination plant recovery. Higher seawater salinity, SWRO membrane salt rejection, and desalination plant recovery yield higher concentrate salinity.

Seawater concentrate usually has 1.5 to 2.0 times higher mineral content than the source water. Concentrate TDS can be calculated as a function of seawater and product water TDS concentrations and plant recovery (R) as follows:

$$TDS_c = TDS_s \times [1/(1 - R)] - R \times (TDS_p)/(1 - R) \qquad (2.2)$$

where the plant recovery, $R = \dfrac{\text{product water flow rate}}{\text{seawater flow rate}}$

The ion concentration factor based on 100% rejection can be calculated from the following equation:

$$CF = 1/(1 - R) \qquad (2.3)$$

where CF = concentration factor, dimensionless.

For more accurate calculation, if the membrane salt passage (SP) is known, the concentration factor can be calculated using the following formula:

$$CF = [1 - (R \times SP)]/(1 - R) \qquad (2.4)$$

Where SP, the salt passage = 1 - salt rejection, salt rejection = permeate TDS/feed TDS; all quantities are expressed as decimal.

Because RO membranes reject some chemicals better than others, variable concentration factors may apply to specific chemicals. Exactly how the salinity concentration factor impacts the disposal of concentrate depends mainly on the means of disposal. In some cases, volume minimization (high salinity concentration factor) may be preferred, whereas in cases where the concentrate is to be discharged to waterways, achieving lower TDS concentration is usually more important than low volume.

The salinity concentration factor is primarily limited by the increasing osmotic pressure of the generated concentrate. For RO seawater desalination systems, this limit is approximately 65 to 80 parts per thousand (ppt). The combined effect of membrane rejection and seawater concentration typically renders the optimum recovery from a single-pass SWRO system to be as low as 40 to 45% (R = 0.40-0.45). Therefore, concentration factors for single-pass seawater desalination processes are often in a range of 1.5 to 1.8.

The following rules can be used to predict concentrate quality based on seawater characteristics: (1) RO membranes reject heavy metals in a similar ratio as they do calcium and magnesium; (2) most organics are rejected in excess of 95% (except for organics of very low molecular weight); and (3) the pH of concentrate is generally higher than the pH of seawater because concentrate has higher alkalinity.

If pretreatment is used, the RO membrane feed water has lower levels of certain constituents (i.e., particulates associated heavy metals, microorganisms, and particles) than the source water. Unless specifically targeted for pretreatment removal, most dissolved metal concentrations are materially unchanged. However, seawater pretreatment may result in a slight increase in the content of inorganic ions, such as sulfate, chloride, and iron, in the RO system feed water if coagulants and/or pretreatment with disinfectants are used. Concentrate may also contain residual organics from seawater conditioning with polymers and antiscalants.

Concentrate has low turbidity [usually <2 Nephelometric Turbidity Units (NTU)] and low total suspended solids (TSS) and biochemical oxygen demand (BOD) levels (typically <5 mg/L) because most of the particulates contained in the water are removed by the desalination plant pretreatment system. However, if plant pretreatment sidestreams 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 seawater are rejected by the SWRO membranes in the concentrate and also have an impact on its overall mineral content and quality. Scale inhibitor levels in the concentrate are typically <20 mg/L.

2.3 Backwash Water

Spent filter backwash water (backwash water) is a waste stream periodically produced by a desalination plant's pretreatment filtration system. Depending on the type of pretreatment system used (granular or membrane filters), the backwash water will vary in quantity and quality.

At present, the most widely used backwash treatment process is gravity settling in conventional or lamella plate sedimentation tanks followed by solids thickening and dewatering by belt filter presses or centrifuges (see Figure 2.2).

Spent wash water from membrane pretreatment systems is usually treated in separate MF or ultrafiltration (UF) membrane modules or lamella settlers. Filter backwash sedimentation tanks are often designed for a retention time of 3 to 4 h and allow removal of more than 90% of the backwash solids.

2.3.1 Quantity

Backwash quantity mainly depends on the type of pretreatment (granular media or membrane filtration) and the solids content in the source water. Usually, granular media filtration pretreatment systems use 3 to 6% of the intake source water for backwash. In comparison, the backwash water generated by membrane pretreatment systems is 5 to 10% of the total volume of the intake source water.

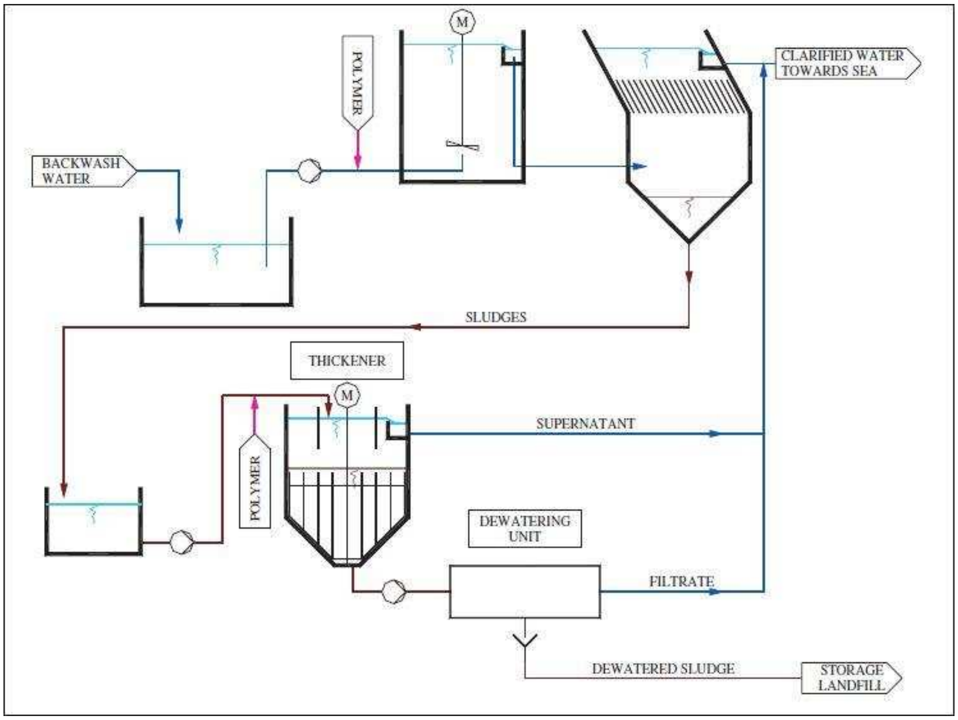


Figure 2.2. Schematic of a Typical Backwash Treatment System.

The daily volume of backwash water can be calculated as a function of the production capacity of the desalination plant, the plant recovery, and the volume of backwash water as a percentage of the plant intake water flow as follows:

$$Q_{bw} = Q_p \times (BW/R) \qquad (2.5)$$

where Q_{bw} and Q_p are the daily flows of backwash water and plant product water capacity, respectively, expressed in m^3/day; R is the desalination plant recovery expressed as a percentage of intake water; and BW is the volume of backwash water expressed as a percentage of the volume of the plant intake.

Backwash volume increases with the increase of source water turbidity because the filter cycles between two backwashes shorten (because of accelerated solids accumulation in or on the filtration media), and the filters therefore need to be backwashed more frequently.

2.3.2 Quality

The main constituents of the spent filter backwash water are the source water solids removed by the pretreatment system and the spent coagulant (if coagulant is used for source water conditioning prior to filtration). Compared to MF or UF membrane pretreatment filters, granular media filters typically require larger dosages of coagulant for pretreatment and therefore contain larger amounts of solids. Depending on the source water quality and the pretreatment technology, membrane pretreatment may be successfully operated without the addition of coagulant. Spent pretreatment filter backwash water may also include filter aid and coagulants.

When ferric salts (ferric chloride or ferric sulfate) are used for saline source water coagulation, backwash water contains a mix of coagulated solid and colloidal particles and ferric hydroxide. The concentration of TSS in the spent backwash water can be estimated as a function of the TSS concentration of the seawater and the dosage of the applied iron coagulant using the following formula:

$$TSS_{bw} = \frac{(TSS_s + 0.8 \times Dose_{Fe}) \times Q_s}{Q_{bw}} \qquad (2.6)$$

where TSS_{bw} and TSS_s are the TSS concentrations of backwash water and source water, respectively, in mg/L; $Dose_{Fe}$ is the dose of ferric salt expressed as iron concentration, in mg/L; and Q_{bw} and Q_s are the daily flows of desalination plant backwash water and intake source water, respectively, in m^3/day.

Using Formula 2.6, the TSS concentration of the backwash water generated by the pretreatment system of the 10.6-MGD (40,000-m^3 /day) desalination plant described in the previous example, with a TSS concentration of the seawater of 2.5 mg/L, that is treated with ferric chloride coagulant at a dosage of 5.0 mg/L (as iron) before pretreatment, will be

$$TSS_{bw} = \frac{(2.5\ mg/L + 0.8 \times 5.0\ mg/L) \times 40{,}000\ m^3/day}{4444\ m^3/day} = 58.5\ mg/L$$

This example indicates that backwash water could contain a significant amount of solids, and its concentration could exceed the 30-mg/L TSS discharge limit (secondary treatment standard for WRRFs) commonly applied for surface water discharges.

2.3.3 Disposal of Spent Backwash Water

If equalized and mixed with the desalination plant concentrate, the TSS backwash concentration could be reduced below the regulatory threshold for suspended solids (i.e., 30 mg/L). As indicated in a previous example, a 10.3-MGD (40,000-m^3/day) seawater desalination plant operating at 45% recovery will have a daily concentrate discharge volume of 12.9 MGD (48,889 m^3/day). Because concentrate can be assumed to be void of suspended solids (TSS = 0 mg/L), the TSS of the blend of 48,889 m^3/day of concentrate and 4444 m^3/day of backwash water with 58.5 mg/L of TSS will be

$$\mathrm{TSS_{blend}} = \frac{(58.5\ \mathrm{mg/L} \times 4444\ \mathrm{m^3/day}) + (0\ \mathrm{mg/L} \times 48{,}889\ \mathrm{m^3/day})}{(4444\ \mathrm{m^3/day} + 48{,}889\ \mathrm{m^3/day})} = 4.9\ \mathrm{mg/L}$$

This calculation indicates that blending the concentrate and the backwash water will be beneficial. However, the continuously low solids content can only be achieved if the backwash water and the concentrate are mixed and equalized before their discharge. In practical terms, backwash water from the washing of the media of the individual pretreatment filter cells is generated periodically, and solids load discharge is not evenly distributed unless it is equalized. As a result, if the spent filter backwash is released as it is generated, even if blended with the concentrate, such release will cause discharge TSS spikes of undesirable magnitude. Therefore, backwash water is typically stored in equalization tanks and released from these tanks at a near constant rate. The released backwash water may undergo dechlorination and pH neutralization (if needed).

Because ferric hydroxide (commonly known as rust) is red in color, the backwash water of pretreatment systems using ferric coagulants is discolored. Therefore, a direct discharge of the backwash water into a surface waterbody without equalization causes discoloration of the entire plant discharge. Although iron contained in the backwash water is typically not harmful to the marine environment, concentrate discoloration usually is not acceptable from an aesthetic point of view. To address this challenge, regulatory requirements often necessitate backwash treatment in an on-site solids handling system to remove the iron hydroxide. Such treatment is of critical importance if the desalination plant discharge will be disposed by shallow beach well injection or by shallow or onshore surface water discharge.

Although surface water discharge after blending with concentrate is the most commonly practiced method of spent filter backwash disposal at present, alternatively, at small plants, this sidestream could be discharged to the sanitary sewer for further treatment at the local WRRF. Usually, coagulant contained in the backwash water can have a positive impact on the WRRF primary clarification process. However, backwash water may inhibit the secondary biological treatment of the wastewater because of its high salinity. Therefore, discharging spent filter backwash water to the sanitary sewer requires careful consideration of the impact of this discharge on the operation of the receiving WRRF. In addition, possible effects of the discharge on the wastewater conveyance network need be considered.

Besides iron, other conditioning chemicals that may be contained in the spent filter backwash water include flocculants, chlorine compounds, acids, and biocides. These conditioning chemicals are usually in quantities that do not have a significant impact on the overall desalination plant discharge water quality after the dilution of the spent backwash water with desalination plant concentrate. Because such concentrate dilution is of critical importance to the mitigation of the environmental impact of the spent filter backwash water, most desalination plants have an interim retention (buffer) tank for blending the desalination plant waste streams prior to their discharge.

Another option becoming a widely practiced backwash management alternative is on-site treatment prior to surface water discharge or recycling upstream of the filtration system. The filter backwash water must be treated at the membrane treatment plant when its direct discharge does not meet surface waterbody water quality requirements.

The settled filter backwash water can be either disposed of with the desalination plant concentrate or recycled at the head of the pretreatment filtration system for reuse. It may be more cost-effective to recycle and reuse the settled filter backwash water rather than to dispose of it with the concentrate. However, when considering the recycling of on-site-treated backwash water to the head of the desalination plant, careful consideration should be given to the potential for recirculating sludge polymers and to any other process chemistry changes that may result from such recycling.

Blending and disposal with the concentrate may be more beneficial if the concentrate water quality is inferior and if it cannot be disposed of to a surface waterbody without prior dilution with a stream of lesser salinity. The solid residuals (sludge) retained in the sedimentation basin are often discharged to the sanitary sewer in liquid form (typically practiced at small to medium plants) or dewatered on-site in a designated solids handling facility.

2.4 Disposal of Spent Membrane Flush Water

Membranes used for seawater pretreatment and RO separation have to be cleaned periodically with chemicals to remove foulants accumulated on the membrane surface during routine plant operations. Because the cleaning is completed without removing the membranes from the membrane vessels that contain them during normal operation, such a cleaning process is referred to as clean-in-place (CIP). The type and combination of CIP chemicals are selected based on the predominant type of fouling occurring on the membrane surface (particulate, colloidal, organic, or microbiological). Because often more than one type of fouling occurs on the membrane surface, a combination of CIP chemicals may need to be used to recover membrane performance. The typical cleaning frequency of the RO membranes is three to four times per year, and that of the pretreatment membranes is six to eight times per year.

Membrane trains are usually cleaned sequentially. A chemical cleaning solution is circulated through the membrane train for a preset time. After the cleaning solution circulation is completed, the spent cleaning solution is evacuated from the train to a storage tank, and the membranes are flushed with permeate (flush water). The flush water is used to remove all the residual cleaning solution from the RO train to prepare the train for normal operation. The flush water is stored separately from the rest of the plant permeate in a flush tank.

All membrane cleaning streams listed previously are typically conveyed to one or more wash water or buffer tanks, often named “scavenger tanks,” for retention and treatment. These tanks must be able to retain the waste cleaning solution from the simultaneous cleaning of a minimum of two membrane trains and at least two CIP cleaning and flushing cycles. The scavenger tanks should be equipped with mixing and pH neutralization systems. The mixing system should be installed at the bottom of the tanks to provide complete mixing of all the cleaning solution streams listed previously.

After mixing with flush water, the concentration of the spent cleaning solution chemicals will be reduced significantly. The spent membrane cleaning solution should be neutralized to a pH compatible with the pH requirements for discharge to the wastewater collection system. At many plants, only the most concentrated first flush is discharged to the wastewater collection system. The rest of the flush water usually has only trace levels of contaminants and is most often suitable for a surface water discharge (i.e., discharge to the ocean or other nearby waterbody). As indicated previously, desalination plants are often provided with a buffer tank that receives and blends all plant waste streams prior to discharge (Figure 2.3).

The buffer tank is sometimes equipped with a pH adjustment system to control discharge pH and an aeration system to mix tank content and to boost the oxygen of the discharge. Such a configuration is most common for ocean water discharges.

It is essential that the WRRF's sewer system flow limitations and requirements and pretreatment requirements are fully understood and taken into account in developing the approach to managing the spent flush water from CIP and to discharging such water to the wastewater collection system. The volume of discharge as well as the chemical content and pH need to be compatible with both the sewer conveyance network and the WRRF's operation. All waste stream discharges to the sewer system are usually regulated by local utility requirements, and this desalination plant waste stream has to be pretreated (usually by pH adjustment) to comply with such pretreatment requirements.

2.4.1 Quantity

The total quantity of the spent CIP chemicals depends on the size of the desalination plant, the number and type of the plant's pretreatment and RO membranes, the quantity and type of the membrane foulants, the fouling potential of the source water, and the type of fouling that accumulates on the membrane surface.

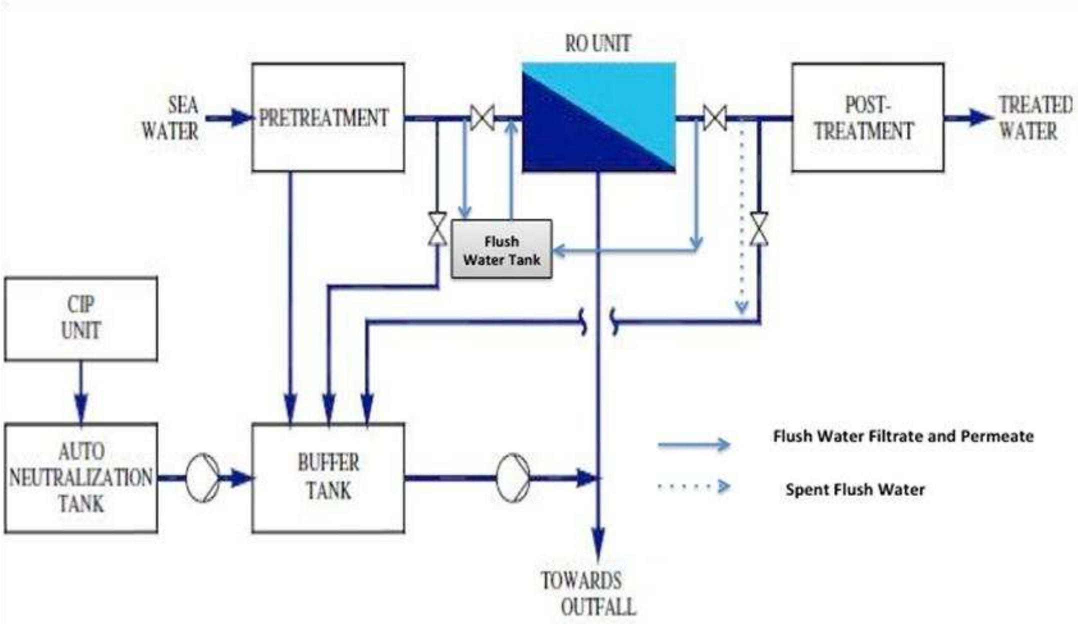


Figure 2.3. Schematic of a Waste Stream Management System.

Typically, the cleaning solution volumes generated during a CIP of RO membranes are 1.0 to 1.8 L/m^2 of membrane surface (0.025-0.045 gal/ft^2). This volume does not include the flush water volumes. The total cleaning solution volume is estimated by adding the total volume of the RO system and the interconnecting pipe volume. The volume of the RO system is calculated as follows:

$$V_{RO\ system} = N_t \times N_{vpt} \times N_{epv} \times A_{ro} \times U_{cl} \tag{2.7}$$

where

- $V_{RO\ system}$ is the volume of the RO system,
- N_t is the number of RO trains,
- N_{vpt} is the number of vessels per train,
- N_{epv} is the number of elements per vessel,
- A_{ro} is the total membrane surface area of one RO element (m^2), and
- U_{cl} is the unit cleaning volume (L/m^2).

For example, in a 10.6-MGD (40,000-m^3/day) RO system with six RO trains that have 72 RO vessels per train and seven 8-in. elements per vessel, and given RO elements with a surface area of 37.2 m^2, as well as 4900 ft (1500 m) of average distribution system pipe with a diameter of 8 in. (200 mm), the total volume of cleaning solution for all RO trains is approximately 57,020 gal (215,840 L) per cleaning chemical and per cleaning event. This volume is calculated assuming a cleaning volume of 1.5 L/m^2 of membrane area. The volume is estimated as follows:

$V_{RO\ system}$ = 6 RO trains × 72 vessels per train × 7 RO elements per vessel × 37.2 m^2 per RO element × 1.5 L/m^2 of cleaning solution = 168,740 L (44,580 gal)

The volume of the cleaning solution for the 1500 m of pipe of 8 in. (200 mm) diameter is $(3.14 \times 0.2 \times 0.2/4) \times 1500\ m = 47.1\ m^3 = 47{,}100\ L$ (12,440 gal).

This volume is specific for each chemical solution and RO system configuration. RO system cleaning is often completed in multiple steps, so the total annual volume is the sum of the volumes used in each step. Depending on the foulants, a low-pH solution is usually followed by one with a high pH. The trains are also cleaned in steps.

A typical approach for large RO trains (100 vessels or more) is to first clean the modules in one-half of the vessels in the first stage, then the other half in the first stage, and finally all modules in the second stage.

Membrane cleaning is followed by draining the spent cleaning chemicals and flushing the RO membranes. Therefore, the waste streams generated during the RO train cleaning are (1) concentrated waste cleaning solution, (2) first flush, (3) spent flush water permeate from consecutive flushes, and (4) flush water concentrate.

Concentrated waste cleaning solution contains the actual spent membrane cleaning chemicals. The quality and quantity of this stream was described in detail previously. Flush water residual cleaning solution (first flush) is the first batch of clean product water used to flush the membranes after the recirculation of cleaning solution is discontinued. This first flush contains diluted residual cleaning solution. Flush water permeate is the spent cleaning water used for several consecutive membrane flushes after the first flush. This flush water is of low salinity and contains only trace amounts of cleaning solution. Flush water concentrate is the flush water removed from the concentrate lines of the membrane system during the flushing process. This water contains very little cleaning chemicals and has a slightly higher salinity concentration than the flushing permeate.

The total volume of flushing water for cleaning an RO system depends on the size of the RO system and of the individual trains and on the number of different cleaning chemicals applied per cleaning; as a rule of thumb, flushing water volume is five to 10 times more than the volume of the cleaning chemicals.

It should be pointed out that the total annual volume of the membrane flush water is usually less than 0.1% of the total volume of the total discharge flow, and therefore its impact on the discharge water quality is insignificant. In many cases, however, this sidestream is discharged to the wastewater collection system. Discharge will require approval of the local WRRF, and the compatibility of the sidestream flow level and chemical content with the local wastewater facility's operation should be considered early in the design process.

Assuming that three different chemicals are used for cleaning and that the volume of flush water is seven times the volume of the cleaning chemicals, for the previous example of a 40,000-m^3/day plant, the total volume of membrane flush water generated for one cleaning of the entire RO system will be 3 chemicals × 215,840 L × (1+7) (for chemicals and flushing water) = 1,726,720 L/cleaning = 456,200 gal/RO system cleaning. The average is approximately 76,000 gal per RO train.

If all RO membrane trains are cleaned four times per year, then the total volume of the membrane flush water for the entire year is 1,726,720 L/1000 × 4 times = 6910 m^3/year (1,824,800 gal/year). Taking under consideration that the desalination plant will produce 40,000 m^3/day × 365 days = 14,600,000 m^3 of freshwater per year, for this example, the total annual volume of the membrane flush water is only 0.05% of the plant's annual production flow and less than 0.04% of the total plant discharge flow.

2.4.2 Quality

The water quality of the spent membrane cleaning solution (containing CIP residuals) reflects the chemical characteristics of both the spent cleaning solution and the material removed from the membrane system during CIP. Reaction with foulants tends to raise the pH of acid solutions and lower that of basic ones.

Table 2.1 presents typical cleaning formulations developed to remove various types of foulants. Some of the cleaning solutions, such as citric acid, may have a relatively high BOD concentration (2000 to 3000 mg/L) and therefore may contribute to the increase in the BOD level of the desalination plant discharge. Others, such as phosphoric and nitric acid, can add undesirable nutrients to the discharge.

2.4.3 Disposal

When blended with the desalination plant concentrate, which has very low nutrient and BOD contents and a several-order-of-magnitude larger volume, spent membrane flush water streams usually do not result in a measurable impact on the surrounding environment. If an increase in nutrient and/or BOD load in the discharge from spent CIP chemicals is limited because of site-specific regulatory requirements, these waste streams are typically directed to the sanitary sewer for further treatment at the local WRRF.

Table 2.1. Typical Membrane Cleaning Solutions.

Foulant Type	**Cleaning Solution(s)**
Inorganic salts (e.g., $CaCO_3$, $CaSO_4$, $BaSO_4$)	0.2% HCl; 0.5% H_3PO_4; 2% citric acid
Metal oxides	2% citric acid; 1% $Na_2S_2O_4$
Inorganic colloids (silts and particulates)	0.1% NaOH; 0.05% sodium dodecyl benzene sulfonate;
Biofilms and organics	Hypochlorite; hydrogen peroxide; 0.1% NaOH/0.05%; sodium dodecyl benzene sulfonate; 1% sodium tripolyphosphate; 1% trisodium phosphate; 1% sodium EDTA

Notes: $CaCO_3$ = calcium carbonate; $CaSO_4$ = calcium sulfate; $BaSO_4$ = barium sulfate; HCl = hydrochloric acid; H_3PO_4 = phosphoric acid; $Na_2S_2O_4$ = sodium hydrosulfite; NaOH = sodium hydroxide

Chapter 3

Seawater Concentrate Discharge Methods

3.1 Surface Water Discharge of Concentrate

Section 1.4.3 lists the most widely used seawater concentrate discharge methods:

- Surface water discharge via new outfalls
  - onshore or near-shore outfall
  - offshore outfall
- Surface water discharge via existing outfalls
  - wastewater treatment plant (WWTP) outfall
  - power plant outfall (co-location with power plant)
- Subsurface discharge via shallow wells

This chapter discusses the first four of these methods; the last is discussed in Chapter 4 along with other, lesser-used methods.

Surface water discharge involves the disposal of concentrate from the desalination plant to an open waterbody such as a bay, tidal lake, brackish canal, river, or ocean. Each of these concentrate management methods has benefits, limitations, and potential environmental impacts on the aquatic environment (Hoepner and Windelberg, 1996; Hoepner, 1999; Rhodes, 2006), which are discussed in this chapter.

3.1.1 Impacts of Surface Water Discharge on the Marine Environment

Key impacts of discharge on the receiving water marine environment may be due to the discharge water's quality characteristics, including salinity, constituent concentrations, and toxicity. The degree of impact is also dependent on the characteristics of the receiving water environment including the water quality, the specific marine population, and hydrodynamic conditions. Water quality standards are developed for each area of potential impact so that requirements for the discharge water will be met quickly within a short distance from the point of discharge. This requires a certain level of dilution to be achieved within set regulatory physical limits (i.e., mixing zones).

The dilution necessary to meet regulatory limits may result from the following:

- hydrodynamic conditions (wind, waves, tidal movement, currents) of the receiving water
- discharge conditions (velocity, size, depth, and configuration of the discharges; i.e., number and location of the outfall diffusers and exit velocity at the diffusers)
- co-discharge with other effluents (such as wastewater from a WRRF or cooling tower discharge from a power plant)
- pre-dilution with source water (i.e., augmentation)

Mixing zones and dilution requirements are defined, as necessary, for salinity, chemical pollutants, and toxicity. A key environmental issue has been salinity and the related whole effluent toxicity (WET) requirements for surface discharge. Consequently, much of the discussion in this and the following chapters focuses on the effects of salinity.

For a desalination plant discharge not to cause a material impact on the marine environment that receives it, this discharge has to be mixed with the receiving waters and diluted to generally within 10% of ambient salinity levels in a reasonably short time commensurate with the tolerance of aquatic life and within a short distance from the discharge. The "10% from ambient salinity rule" is an industry-wide accepted criterion that is based on the broader U.S. Environmental Protection Agency (U.S. EPA) environmental anti-degradation rules, which apply to all constituents that do not have specific numeric limits. Another reason for noting the "10%" reference is that natural salinity in all oceans varies at least within 10% (and sometimes more) of average annual levels because of seasonal evaporation rate variations, and therefore marine species are already adapted to such a range of variations (Jenkins and Wasyl, 2005b).

The size of the regulatory mixing zone is mainly driven by the sensitivity of the marine species inhabiting the discharge. However, because the actual species and the regulator-determined test species can vary from location to location, this size can vary significantly from one project to another.

The federal framework for determining effluent limitations, the need for and design of outfall diffusers, and mixing zone size to meet effluent limitations is discussed in Chapter 5. The resulting effluent or discharge limitations are part of the NPDES permit required for discharge. State-specific requirements are discussed in Chapter 7.

3.2 Concentrate Treatment Prior to Surface Water Discharge

Usually, concentrate from seawater desalination plants has an ion composition very similar to that of the ambient seawater, and therefore its direct ocean discharge does not pose ion-imbalance-driven toxicity challenges. Therefore, seawater concentrate can typically be discharged to the ocean without additional treatment, especially if the source seawater is collected by an open ocean intake. However, concentrate generated from desalination plants with subsurface intakes could have an elevated content of iron and manganese, which may result in concentrate discoloration and noncompliance with discharge limits for iron and manganese if such limits are contained in the applicable regulations. Not all state regulations have maximum limits for iron and manganese; for example, the California Ocean Plan does not have such limitations, but regulatory requirements of Florida and Texas do.

Usually, concentrate is either discharged using a diffuser system or is blended with source seawater down to a salinity level that is safe for direct discharge without the need for a complex diffusion structure. The actual maximum salinity threshold that does not cause impact on the ambient marine environment is very site-specific and depends on the salinity tolerance of the marine organisms inhabiting the discharge area. For example, site-specific salinity tolerance studies completed during the environmental review of the Carlsbad and West Basin seawater desalination projects indicate that the maximum long-term salinity level that will not cause stress to marine species is 40 ppt. For very sensitive marine species or lower source-water salinities, such levels could be lower.

To date, the U.S. EPA has not established a maximum acceptable salinity threshold, and indirectly such a threshold is defined based on WET studies. California decided to establish a maximum salinity threshold of 2000 mg/L (2 ppt) over ambient conditions in their latest California Ocean Plan amendment. The threshold is applicable at the edge of the salinity mixing zone rather than at the point of discharge.

Although blending concentrate with ambient seawater prior to discharge is relatively simple to implement, it may result in an elevated impingement and entrainment of marine organisms and in additional energy use to collect the source water needed for concentrate dilution. Federal regulations of the Clean Water Act [40 CFR 125.3(f), where CFR is the Code of Federal Regulations] allow blending with source water to be considered on a case-by-case basis under certain conditions:

1. if technology-based treatment requirements are not sufficient to achieve the standards;
2. if the discharger agrees to waive any opportunity to request a variance under Section 301(c), (g), or (h) of the Clean Water Act; and
3. if the discharger demonstrates that such a technique is the preferred environmental and economic method to achieve the standards after the consideration of alternatives such as advanced waste treatment, recycle and reuse, land disposal, changes in operating methods, and other available methods.

As an example, the blending of desalination plant concentrate with river water prior to its discharge to the river was permitted for the Taunton BWRO plant. Blending with source water prior to discharge (other than with cooling water from power plants) is discouraged in California because of the additional entrainment and impingement related to additional intake volumes. It should be pointed out, however, that the NPDES discharge permit of the Carlsbad SWRO desalination plant allows blending of the plant discharge with intake source water if the discharge salinity exceeds the maximum permitted threshold of 42 ppt and if cooling water is not available for dilution because of the shutdown of the power plant with which it is co-located. Blending with source seawater is also conditionally allowed for the Tampa Bay Desalination Project if the temperature of the cooling water of the power plant with which it is co-located exceeds 38°C because of the potential for the permanent damage of the RO membranes.

Whereas seawater concentrate from open ocean intakes typically does not require treatment prior to discharge, if subsurface (well) intake is used to collect source seawater, the plant concentrate may be discolored because of an elevated concentration of iron and sometimes of manganese. The source water may have a very low oxygen concentration or may contain other contaminants such as ammonia that may trigger the need for additional source water or concentrate treatment. Experience to date shows that the manganese in seawater collected by subsurface intakes (e.g., vertical wells, infiltration galleries) is not usually at levels above those of ambient seawater. However, iron is almost always observed in order-of-magnitude higher levels.

Often, source seawater collected from alluvial coastal aquifers by beach wells contains high levels of iron and manganese in reduced form. In many applications, such source seawater is processed through the desalination plant pretreatment and RO facilities without exposure to air (i.e., oxygen), which keeps the iron and manganese in a dissolved, reduced form in which they are colorless. Because iron and manganese are easily removed by the RO membranes, after membrane separation they are retained in the concentrate. If this concentrate is exposed to air, iron will convert from a reduced form (typically ferric sulfide) to an oxidized form (ferric hydroxide). Because ferric hydroxide (commonly known as rust) is red in color, it will discolor the concentrate, which degrades the visual appearance of the discharge area. Therefore, the iron in the source seawater needs to be oxidized and removed in the pretreatment system to address the elevated iron content, or the concentrate needs to be treated by sedimentation to remove the ferric hydroxide. An elevated content of manganese could cause dark brown or black discoloration of the discharge, but usually the levels of manganese in source water collected using subsurface intakes are not as high as those of iron. In addition to discoloration and the associated aesthetic degradation of the discharge area, discharges of iron and manganese could result in noncompliance with the numeric limits for these metals if such limits are included in the regulations. At present, the California Ocean Plan does not have maximum discharge limits for iron and manganese, but applicable regulatory requirements in the states of Florida and Texas do.

If a large desalination plant delivers concentrate with low dissolved oxygen (DO) to the surface waterbody, the discharge could cause oxygen depletion and stress to aquatic life. Therefore, such concentrate must be re-aerated before surface water discharge to reach the target DO content, that is, the DO content of the receiving surface water; depending on the applicable regulatory requirements, this could be 4 mg/L (minimum) or 5 mg/L (daily average) or could be within 10% of the ambient DO concentration of the receiving waters. The risk of low DO levels is discussed in Section 6.5.

As with any potable water supply, source water protection and source water influences can have an impact on a desalination plant's source water quality and consequently on the concentrate quality and the constituents of concern for its management. Potential sources of pollution of source water supply aquifers or surface waterbodies are existing landfills, pesticide use, septic tank leachate fields, industrial and military installations, and cemeteries. Intakes and therefore discharges from desalination plants with polluted source water contain elevated concentrations of contaminants related to the source water pollutant sources. The compounds of concern can be treated by a number of available technologies, including enhanced sedimentation, activated carbon filtration, ultraviolet irradiation, hydrogen peroxide oxidation, and ozonation. However, because these treatment systems need to be constructed in addition to the RO system, this supplemental concentrate treatment may measurably increase the overall desalinated water production cost.

3.3 New Onshore, Near-shore, or Offshore Outfall

3.3.1 Description

Discharge of concentrate and other desalination plant waste streams through a new surface water discharge system (near-shore discharge structure, onshore discharge structure, or offshore outfall) is widely used in SWRO desalination projects of all sizes.

More than 90% of the large seawater desalination plants worldwide dispose of their concentrate through a new outfall specifically designed and built for that purpose. Examples of large SWRO desalination plants with new ocean outfalls for concentrate discharge are the 36-MGD (136,000-m^3/day) Tuas Seawater Desalination Plant in Singapore, the 165-MGD (624,000-m^3/d) Sorek plant in Israel, and the majority of large SWRO plants in Spain and Australia (see Table 1.5).

The main purpose of outfalls is to discharge the plant concentrate to a surface waterbody in an environmentally sound manner, which in practical terms means to minimize the size of the mixing zone of the discharge, in which the salinity is elevated above the typical TDS range of tolerance of the aquatic organisms inhabiting the area.

The two key options available to accelerate the concentrate mixing with the water of the receiving waterbody are (1) to rely on the naturally occurring mixing potential of the tidal (surf) zone and (2) to discharge the concentrate beyond the tidal zone and to install diffusers at the end of or along the length of the discharge outfall to improve mixing. Although open-ocean near-shore tidally influenced zones of the sea usually carry a significant amount of turbulent energy and provide much better mixing than the end-of-pipe-type of diffuser-outfall system, such zones have a limited capacity to transport and dissipate the saline discharge load into the surface waterbody. If the mass of the saline discharge exceeds the threshold of the tidal zone's salinity load transport capacity, the excess salinity begins to accumulate in the tidal zone and could ultimately result in a long-term salinity increment in this zone beyond the level of tolerance of the aquatic life in the area of the discharge. Therefore, the tidal zone is usually a suitable location for salinity discharge only when it has adequate capacity to receive, mix, and transport this discharge into the surface waterbody (ocean, river, bay, etc.). The site-specific salinity threshold mixing and transport capacity of the tidal zone in the area of the desalination plant discharge can be determined using hydrodynamic modeling (Bleninger and Jirka, 2008).

In the United States, most states allow ocean tidal zones to be used for concentrate disposal. Two examples are the near-shore discharge of the Carlsbad SWRO plant, which is only 700 ft (212 m) offshore, and the onshore discharge of the Tampa Bay Desalination Plant, where discharge is into a discharge canal. Both of these plants rely on the natural tidal mixing occurring in the area of the discharge in combination with concentrate dilution by blending with cooling water from an existing power plant.

Examples of large new desalination plants with discharges in the tidal zone are the 95-MGD (360,000-m^3/day) Ashkelon seawater desalination plant and the 72-MGD (274,000-m^3/day) Hadera SWRO plant in Israel (Figure 3.1) and the 36-MGD (136,000-m^3/day) Point Lisas SWRO plant in Trinidad. It should also be noted that all SWRO desalination plants in Oman, Saudi Arabia, United Arab Emirates, and Bahrain and a number of desalination plants in Spain also use onshore discharges.

For small desalination plants (i.e., plants with production capacities of 0.3 MGD or 1000 m^3/day or less), the outfall is typically constructed as an open-ended (sometimes perforated) pipe that extends several hundred meters into the tidal (high mixing intensity) zone of the receiving waterbody. This type of discharge usually relies on the mixing turbulence of the tidal zone (for ocean discharges) to dissipate the concentrate and to reduce the discharge salinity to ambient conditions.

Ocean outfalls for large seawater desalination plants usually extend 0.3 to 1.2 miles (500 to 2000 m) offshore beyond the tidal zone. Large ocean outfalls are equipped with diffusers to provide the mixing necessary to prevent the heavy saline discharge plume from accumulating at the ocean bottom in the immediate vicinity of the discharge.

Figure 3.1. Near-shore Discharge of the Hadera SWRO Plant, Israel.
Source: IDE Technologies, an Israeli desalination company

The length, size, and configuration of the outfall and diffuser structures for large desalination plants are typically determined based on hydrodynamic or physical modeling of the discharge mixing and the diffuser structure for the site-specific conditions of the outfall location (Purnama et al., 2003; Purnama and Al-Barwani, 2004; Bleninger and Jirka, 2010).

Examples of desalination plants with new offshore outfalls are all large SWRO plants in Australia: the 38-MGD (143,000-m^3/day) Perth I (Kwinana) plant; the 74-MGD (280,000-m^3/day) Perth II (Binningup) plant; the 35-MGD (132,000-m^3/day) Gold Coast plant; the 66-MGD (250,000-m^3/day) Sydney plant; the 80-MGD (300,000-m^3/day) Adelaide plant; and the 110-MGD (414,000-m^3/day) Melbourne (Victoria) plant. A number of SWRO plants in Spain (see Chapter 9), Cyprus, and the Caribbean also have offshore pipeline outfalls.

3.3.2 Potential Environmental Impacts and Discharge Feasibility

The main challenges associated with selecting the most appropriate location for a desalination plant's outfall discharge are the following:

- finding an area without endangered species that is not already stressed
- avoiding areas where discharge may reach marine reserves, parks, and conservation areas (called Marine Protected Areas in the California Ocean Plan)
- avoiding areas where discharge may affect indigenous species that may be particularly sensitive to changes in salinity
- avoiding areas with frequent shipping traffic that could damage the outfall facility and change mixing patterns
- identifying a location with strong underwater currents that allow quick and effective dissipation of the concentrate discharge
- identifying a discharge location that is in relatively shallow waters and close to the shoreline, to minimize outfall construction expenditures

Key environmental considerations associated with the management of concentrate disposal to surface waters include the salinity tolerance of aquatic species inhabiting the discharge area, the concentration of some source water constituents to potentially harmful levels, and discharge discoloration and low DO content.

The key issues to address during the feasibility evaluation of the disposal of desalination plant concentrate to a surface waterbody include (1) assessment of discharge dispersion and recirculation of the discharge plume to the plant intake; (2) evaluation of the potential for WET of the discharge; (3) determination of whether the discharge water quality meets the numeric and qualitative effluent water quality standards applicable to the point of discharge and established by regulatory agencies; and (4) determination of the aquatic organism salinity tolerance threshold for the site-specific conditions of the discharge location and outfall configuration, to design the outfall for dilution that meets this threshold within a minimal distance from the point of discharge. Overviews of key environmental challenges associated with the surface water disposal of desalination plant discharges in the United States and abroad are presented in Chapter 6.

Salinity dispersion of the concentrate is of critical importance in the assessment of the potential environmental impacts of a desalination plant's discharge on the receiving aquatic environment. More detailed discussion of models used to predict salinity dispersion as well as other studies typically needed to complete the environmental review of medium and large desalination projects is presented in Chapter 5.

3.4 Co-disposal with Wastewater Effluent

3.4.1 Description

Co-disposal of SWRO concentrate with wastewater effluent has the benefit of the accelerated mixing that stems from blending the heavier-than-ocean-water concentrate with the lighter wastewater effluent. Depending on the volume of the concentrate and on how well the two waste streams are mixed prior to the point of discharge, the blending may reduce the size of the wastewater discharge plume and dilute some of its constituents. Co-discharge with the lighter-than-seawater wastewater effluent also accelerates the dissipation of the saline plume by floating this plume upwards and expanding the volume of the ocean water with which it mixes.

Use of existing WRRF outfalls for concentrate discharge has the key advantages of avoiding the costs and environmental impacts associated with the construction of a new outfall for the seawater desalination plant. Mixing of the buoyant wastewater discharge with the heavier-than-ocean-water concentrate promotes the accelerated dissipation of both the wastewater plume (which tends to float to the ocean surface) and the concentrate (which tends to sink towards the ocean bottom). In addition, concentrate often contains metals, organics, and pathogens at concentrations an order of magnitude lower than those found in the wastewater discharge. The presence of concentrate can thus reduce the overall waste discharge concentration of these items by an amount dependent on the relative concentrations and volumes of concentrate and wastewater.

3.4.2 Potential Environmental Impacts

Seawater concentrate may trigger ion-imbalance-based toxicity when blended with wastewater and discharged to a surface waterbody with a significantly different ion composition in the receiving water. This impact is site specific and will need to be investigated on a case-by-case basis.

Bioassay tests completed on blends of desalination plant concentrate and wastewater effluent from the El Estero WWTP in Santa Barbara, CA, indicate that this blend can exhibit toxicity on fertilized sea urchin (*Strongylocentrotus purpuratus*) eggs. The desalination plant concentrate and the wastewater plant effluent did not exhibit toxicity separately. Unfortunately, the plant ran for a relatively short period of time, and the exact causes of this synergistic toxicity effect were not studied and determined. Parallel tests on desalination plant concentrate diluted to a similar TDS concentration with seawater rather than wastewater effluent did not show such toxicity effects on sea urchins (SCCWRP, 1994; WRA, 2011).

Long-term exposure of red sea urchins to the blend of concentrate from the Carlsbad seawater desalination demonstration plant and ambient seawater discharged by the adjacent Encina power plant confirm the fact that sea urchins can survive elevated salinity conditions when the discharge is devoid of wastewater.

The most likely factor causing the toxicity effect on the sensitive marine species is the difference in ratios between major ions (calcium, magnesium, sodium, chloride, and sulfate) and TDS in the wastewater-effluent-concentrate blend away from those found in seawater. That is, as the major ion ratios deviate from those found in seawater, ion imbalance may trigger an effluent toxicity effect. Such toxicity is also referred to as major ion toxicity (Mickley, 2000).

The SWRO membranes reject all major seawater mineral ions at approximately the same high level. As a result, the ratios between the concentrations of the individual major mineral ions that contribute to the seawater salinity and the TDS of the concentrate are approximately the same as these ratios in ambient seawater. Therefore, marine organisms are not generally exposed to conditions of ion imbalance if this concentrate is directly disposed of in the ocean.

An additional environmental concern of combining wastewater and desalination plant discharges is that the high salinity may cause wastewater contaminants and other constituents to aggregate in particles of different sizes than they would otherwise. This could result in an enhanced sedimentation of some of the metals and solids contained in the WRRF effluent and could potentially impact benthic organisms and phytoplankton in the vicinity of the existing discharge.

3.4.3 Feasibility Considerations

Although the use of an existing WRRF outfall may seem attractive for its simplicity and low construction costs, this disposal method has to be evaluated for site-specific challenges. Because of potential toxicity effects of the concentrate-wastewater-effluent blend, the direct discharge of the seawater concentrate through existing wastewater discharge outfalls may be limited to relatively small concentrate discharge flows. For this concentrate disposal option to be feasible, there has to be an existing WRRF in the vicinity of the desalination plant, and this plant has to have available extra outfall discharge capacity. In addition, the fees associated with the use of the WRRF outfall must be reasonable, and the WRRF owner must allow the use of the outfall for concentrate disposal. The WRRF owner also must be agreeable to any potential modifications of the existing outfall and the downtime associated with the implementation of these modifications. Usually, this beneficial combination of conditions is not easy to find, especially for discharging large seawater concentrate volumes.

Other feasibility considerations related to the use of existing WRRF outfalls for desalination plant concentrate discharge are (1) the potential need for modification of the diffuser system of the WRRF's outfall because of the altered buoyancy of the concentrate-wastewater mix and (2) the compatibility of the diurnal fluctuation of the secondary effluent flow with the concentrate discharge flow.

The buoyancy of the mixed wastewater-effluent-concentrate plume and the ability of the existing wastewater outfall's diffuser system to provide proper mixing are key factors associated with co-discharge feasibility. Because the heavier concentrate discharge will reduce the buoyancy of the wastewater effluent, the initial momentum and mixing energy that are delivered by the existing effluent diffuser structure will be altered.

A number of studies show that the heavier the blend of WRRF effluent and desalination plant discharge is, the more energy will be needed to achieve the same level of dispersion of the pollutants in the wastewater effluent and the TDS in the desalination plant concentrate (Jirka, 2010; Miller, 2011; Ladewig and Asquith, 2012). Because the original WRRF diffusers were designed to disperse an effluent lighter than seawater, the addition of concentrate to the wastewater discharge will cause the need to re-evaluate the ability of the existing diffusers to disperse the discharge blend (Ladewig and Asquith, 2012; Miller, 2011). If the existing diffuser system can no longer achieve the level of dispersion of dissolved solids and wastewater pollutants originally delivered and dilution defined in the discharge permit, the configuration of this system may need to be modified (i.e., by closing diffuser nozzles or by changing the diffuser configuration and the direction of the nozzles) to achieve both the original wastewater pollutant dispersal levels as well as the dispersal of the additional dissolved solids contained in the wastewater-concentrate mix. Therefore, the impact of the concentrate discharge on the ability of the existing wastewater outfall to provide adequate dispersal of the mixed concentrate-wastewater plume should be evaluated by hydrodynamic modeling for the size-specific conditions of a given project.

Co-disposal will necessitate modification of the WRRF NPDES permit. Adequate mixing usually is defined as mixing that allows the concentrate salinity to be reduced to less than 10% of the ambient seawater salinity within the original mixing zone of the WRRF outfall while at the same time the dispersion of the wastewater pollutants is maintained at its original level defined in the wastewater discharge permit. Wastewater outfalls are usually assigned a certain mixing ratio and mixing zone in the WRRF discharge permits. After blending of the concentrate and WRRF effluent, the existing diffuser system should be able to provide the necessary mixing and dilution as defined in the WRRF NPDES permit. The concentrate-WRRF mixing studies for the West Basin Desalination Project (Jenkins, 2013) and the Santa Cruz SWRO Project (Jenkins and Wasyl, 2010) provide further insights into the issues associated with modeling the performance of WRRF outfalls for a blend of wastewater plant effluent and desalination plant concentrate.

Often, seawater desalination plants are operated at a constant production rate; as a result, they generate concentrate discharge with little or no diurnal flow variation. On the other hand, the availability of WRRF effluent for the dilution of the desalination plant concentrate typically follows a distinctive diurnal variation pattern.

Adequate protection of marine life requires a certain minimum concentrate dilution ratio in the mixing zone to be maintained at all times. However, during periods of low wastewater effluent flows (i.e., at night), the amount of concentrate disposed by the desalination plant (and therefore, the plant production capacity) may be limited by the lack of secondary effluent for blending. Intermittent operation of desalination plants or their operation at a capacity lower than design levels may occur in practice, and such operation typically does not create dilution challenges. However, usually desalination plant discharge permits require the plant operator to monitor salinity at all times, including periods of plant shutdown and reduced freshwater production.

To address this concern, the desalination plant operational regime and capacity may need to be altered to match the wastewater effluent availability patterns, or a diurnal concentrate storage facility may need to be constructed at the desalination plant.

In 2008, the Florida Legislature enacted a statute (Title XXIX, Chapter 403, Section 086) prohibiting the construction of new ocean outfalls for domestic wastewater discharge and the expansion of existing ocean outfalls for this purpose. This statute effectively bans the co-disposal of desalination plant concentrate with domestic wastewater in Florida for any new desalination plants.

3.5 Co-disposal with Power Plant Cooling Water

3.5.1 Description

At present, co-disposal of desalination plant discharge and power plant cooling discharge is mainly practiced at seawater desalination plants co-sited with large coastal power plants with open intakes. A recent study completed by the WateReuse Research Foundation (WRRF, 2013) shows that co-disposal by desalination and power plants is gaining popularity worldwide. Co-location with an active coastal power plant may be cost beneficial because it allows the use of both the existing intake and outfall infrastructure and the warm water from the power plant. If the power plant's operation is discontinued, the cost advantage of this concentrate disposal method will depend on the condition and size of the existing power plant intake and outfall infrastructure. Because the intake and outfall usually contribute between 20 to 30% to the total desalination plant construction cost, the use of these facilities could yield significant cost savings even if the power plant is no longer operational or is decommissioned, as long as the intake and outfall of the power plant are in good working condition.

Figure 3.2 shows a typical configuration of a desalination plant co-located with a power plant in which the discharge of the power plant is used both as a source of saline water for the desalination plant and as dilution water for concentrate mixing and co-disposal. As shown in Figure 3.2, under typical operational conditions, saline water enters the power plant intake facilities and, after screening, is pumped through the power plant condensers to cool them and thereby to remove the waste heat generated during the electricity generation process (Voutchkov, 2004). Typically, the cooling water discharged from the condensers is 5 to 10°C warmer than the source ocean water, which could be beneficial for the desalination process because warmer saline water has a lower viscosity and therefore a lower osmotic pressure and energy for salt separation. However, warmer water temperatures also tend to increase microbial growth rates, which may have an impact on microbial fouling and consequently on RO treatment performance.

Co-location of SWRO desalination plants with existing once-through cooling coastal power plants yields four key benefits: (1) the construction of a separate desalination plant outfall structure is avoided, thereby reducing the overall cost of the desalinated water; (2) the environmental impact of the salinity of the desalination plant discharge is reduced as a result of the mixing and dilution of the membrane concentrate with the power plant discharge, which has ambient seawater salinity; (3) because a portion of the discharge water is converted into potable water, the power plant thermal discharge load is decreased, which lessens some of the negative effect of the power plant thermal plume on the aquatic environment; and (4) the mixing of the desalination plant and the power plant discharges may result in the accelerated dissipation of both the salinity and the thermal load.

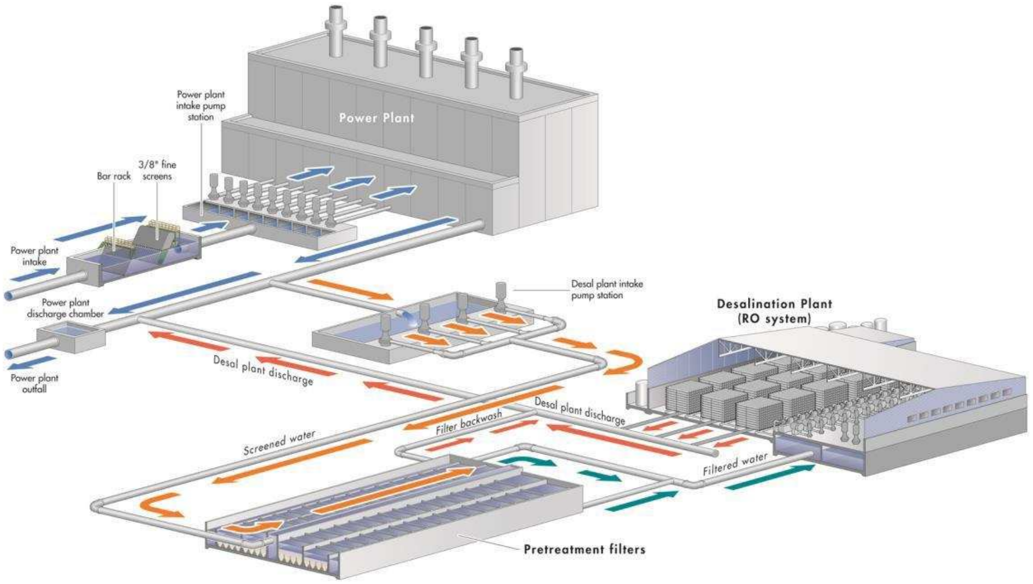


Figure 3.2. Configuration of a Coastal Desalination Plant Co-Located with a Power Plant.

The hydrodynamic modeling of the thermal plume mixed with concentrate for the Huntington Beach and Carlsbad projects (Jenkins and Wasyl, 2001; Jenkins and Wasyl, 2005a) shows that the thermal plume footprint is reduced by approximately 50% and that the thermal plume is dissipated more quickly because the heavier concentrate pushes the warm water down towards the ocean bottom; the warm water is mixed with the entire depth of the water column rather than with the first 3 to 5 ft of seawater on the surface of the ocean. The propagation of the thermal plume towards the bottom of the ocean exposes the same thermal load to a much larger mixing water volume (the entire water column depth of 25 to 35 ft rather than the first 3 to 5 ft only), which in turn accelerates the dissipation of the thermal load.

The warmer water also accelerates the mixing of the heavy saline concentrate. Without the warm water, the heavy concentrate tends to travel downwards and settle at the bottom in a layer with a depth of several feet; this layer then slowly dissipates in the ambient seawater near the bottom. The warm water reduces the weight of the concentrate; rather than travelling downwards, the concentrate stays within the water column and gets mixed more quickly, with the entire water column rather than with the bottom water layer only. Mixing of the concentrate with the ambient seawater requires energy. With co-location, the mixing energy comes from the thermal energy of the warm water. With stand-alone discharges, the mixing energy comes from pumping or gravity discharge of the concentrate through the outfall diffusers, where the static energy is converted into kinetic mixing energy. Modeling of stand-alone and mixed discharges of concentrate and cooling water from power plants (Jenkins and Wasyl, 2001; Jenkins and Wasyl, 2005a) shows that the mixed discharge could be diluted to the same salinity (+10% of the ambient seawater) within an approximately two times smaller mixing zone than that needed for the concentrate alone.

As a result of the co-location, the desalination plant unit power costs could be further decreased by avoiding the use of the power grid and the associated fees for power transmission to the desalination plant. Typically, the electricity tariff (unit power cost) structure includes two components: fees for power production and fees for power grid transmission. Often, the power transmission grid portion of the tariff is 30 to 50% of the total unit power cost. By connecting the desalination plant directly to the power plant electricity generation equipment, the grid transmission portion of the power fees could be substantially reduced or completely avoided, thereby further reducing the overall seawater desalination cost. However, if a power plant is not base-loaded [such as the Tampa Electric Company (TECO) power plant, which hosts the Tampa Bay SWRO desalination plant], it is exceedingly rare that it would operate 24 h a day, 365 days a year. Consequently, the reliability of the power supply from a sole-source power supplier must be carefully weighed as such a power supply construct may cause the desalination plant to be offline whenever the power station is offline. In practice, however, when power plants are in hot standby (which many peaker power plants often are), they operate at a certain minimal energy production level termed “spinning reserve” to allow the power plant to increase its production capacity on short notice. If the power plant is a peaker facility that only operates seasonally, in the “off-season,” the desalination plant would need either to rely on power supplied from the grid or to use the black-start power generators of the power plant to receive the necessary electricity. As a final note, utility regulators may not consider allowing a sole-source power supply contract.

Co-location of power and desalination plants may also have advantages for the power plant host. In addition to the benefit of generating revenue by leasing power plant property to the desalination plant, the power plant host also gains a new customer with a very favorable power-use profile: a steady and continuous power demand and a high power load factor. This continuous high-quality power demand allows the power plant host to operate its electricity generation units at an optimal regime, which in turn reduces the overall costs of power generation.

Under a typical co-location configuration, the desalination plant uses the power plant discharge water as both the source water for desalination and the dilution water for the desalination plant concentrate. An example of a co-location configuration where the power plant discharge is used only for dilution of the concentrate is the 32-MGD (120,000-m^3/day) Carboneras Seawater Desalination Plant in Spain. Plant concentrate is discharged to the cooling water canal of a nearby coastal power generation plant and thereby diluted to an environmentally safe level before its return to the sea. The Carboneras Seawater Desalination Plant has a separate open intake independent from the intake and discharge of the power plant.

Sharing intake infrastructure has environmental benefits because it avoids the need for new intake construction in the ocean and at the seashore area near the desalination plant. The construction of a separate new open intake structure and pipeline for the desalination plant could cause a measurable disturbance of the benthic marine organisms on the ocean floor.

Another clear environmental benefit of the co-location of power generation stations and desalination plants is the overall reduction of entrainment, impingement, and entrapment of marine organisms as compared to the construction of two separate open intake structures – one for the power plant and one for the desalination plant. This benefit stems from the fact that the total biomass of the impacted marine organisms is typically proportional to the volume of the intake seawater. By using the same intake seawater twice (first for cooling and then for desalination), the net intake inflow of seawater and marine organisms is minimized.

The length and configuration of the desalination plant concentrate discharge outfall are closely related to the discharge salinity. Usually, the lower the discharge salinity, the shorter the outfall and the less sophisticated the discharge diffuser configuration needed to achieve environmentally safe concentrate discharge. Blending the desalination plant concentrate with the lower-salinity power plant cooling water often reduces the overall salinity of the ocean discharge to within the range of natural variability of the seawater at the end of the discharge pipe, thereby completely alleviating the need for complex and costly discharge diffuser structures.

The power plant thermal discharge is lighter than the ambient ocean water because of its elevated temperature, and therefore, it tends to float on the ocean surface. The heavier saline discharge from the desalination plant draws the lighter water downwards and thereby engages the entire depth of the ocean water column into the heat and salinity dissipation process. As a result, the time for the dissipation of both discharges shortens significantly, and the area of their impact is reduced.

It should be pointed out that seawater density is a function of both temperature and salinity. Whereas seawater density increases with salinity, it decreases with an increase in temperature. A close to ideal condition for the co-location of desalination and power plants is a configuration where the increase in density of the blend of desalination plant concentrate and power plant cooling water (as compared to the salinity of the ambient water) is compensated by the decrease in density of the blend because of its higher-than-ambient temperature.

For example, in the case of the Carlsbad Desalination Project (CDP), illustrated in Figure 3.3, the average annual ambient seawater temperature in the open ocean near the power plant is 18°C and the seawater salinity is 33,500 mg/L. The seawater density at this temperature and salinity is 1024.12 kg/m^3. The desalination plant concentrate salinity is 67,000 mg/L. If this concentrate is not blended with the warmer and lighter cooling water from the power plant and instead is discharged directly into the ocean at 18°C, the density of the concentrate will be 1050.03 kg/m^3. Because the concentrate will have a significantly higher density than the ambient ocean water, after discharge it will quickly sink to the ocean floor and expose the bottom marine habitat to a significantly higher salinity that may have a detrimental effect on aquatic life.

In the case of the co-located discharge, the concentration of the desalination plant concentrate will be reduced from 67,000 mg/L to 36,200 mg/L as a result of the blending with the cooling water, which has ambient salinity. In addition, the blend will typically have a temperature that is 8°C higher than the ambient seawater temperature (i.e., 26°C vs. 18°C). As a result of the co-location and mixing of the two discharges, rather than sinking down towards the ocean floor, the concentrate will actually float and quickly mix and dissipate within the water column as it moves upwards towards the ocean surface.

For comparison, the discharge of concentrate through diffusers has to occur at very high velocity [7-13 fps (2-4 m/s)] to achieve adequate mixing, which requires a significant energy expenditure associated with the pumping of the concentrate discharge (see Figure 3.4).

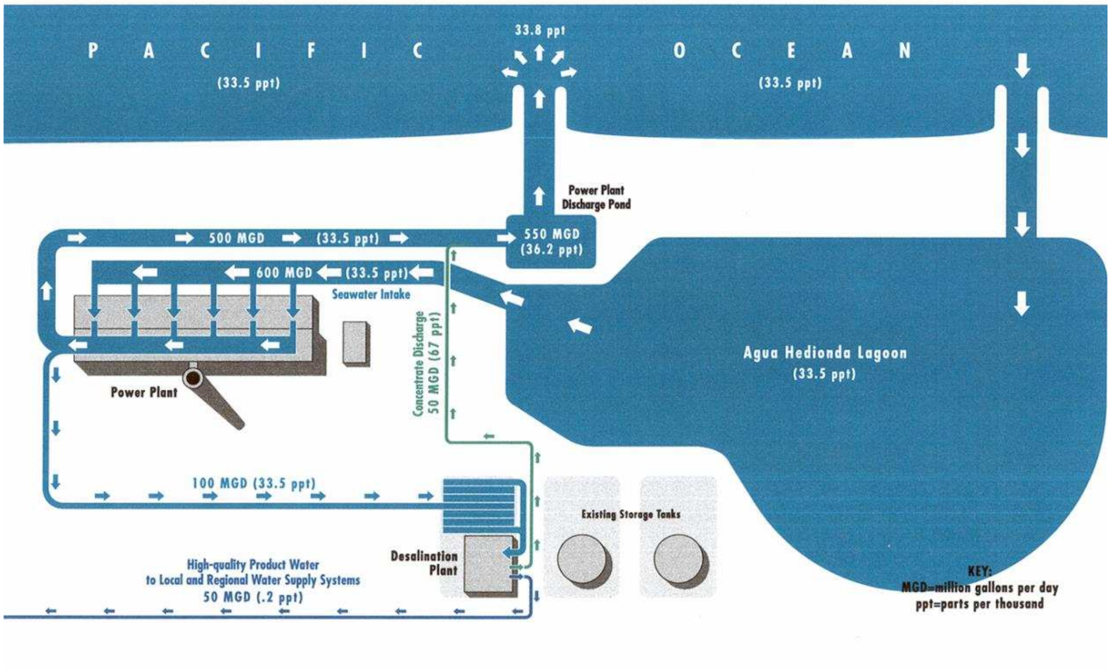


Figure 3.3. General Schematic of the Carlsbad Desalination Plant.

Historically, coastal power plants have used once-through cooling water systems, which require large volumes of intake water. In October 2010, a California policy (Use of Coastal and Estuarine Waters for Power Plant Cooling) became effective to establish technology-based standards to implement the Clean Water Act (CWA) Section 316(b) and to reduce the harmful effects associated with cooling water intake structures on marine and estuarine life. Over time, the discharge permittees' NPDES permits will be reissued or modified to conform to the policy. Changes in power plant sub-system design and operation will take time to implement, including time for the resolution of policies being contested as well as practical site-specific implementation constraints. More generally, once-through cooling phase-out tracks include the following (CEC, 2015):

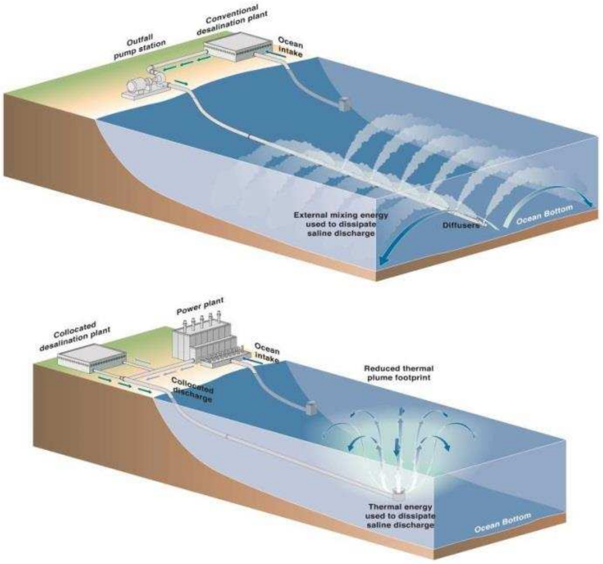


Figure 3.4. Comparison of the Concentrate Mixing Patterns of Conventional (top) and Co-Located (bottom) Desalination Plants.

1. Reduction of intake flow rate to a level that can be attained with a closed-cycle evaporative cooling system. A minimum of 93% reduction is required to the design intake flow rate.
2. If compliance via track 1 is not feasible, the impingement mortality and entrainment for a facility must be reduced to 90% of track 1 reductions using operational or structural controls, or both.
3. Alternatively, a plant can comply by shutting down.

Moving from once-through cooling to closed-cycle evaporative cooling systems will significantly reduce the intake and discharge volumes and in turn affect the feasibility and benefits of co-disposal (see Section 3.5.2).

3.5.2 Potential Environmental Impacts and Discharge Feasibility

The potential environmental impacts and discharge feasibility associated with co-located desalination facilities are similar to those of open ocean outfalls. Depending on the site-specific conditions, for power plant outfalls equipped with diffusers, the plant's outfall-diffuser structure may need to be modified to accommodate the heavier concentrate discharge.

The environmental impacts attributed to the desalination plant operations may increase if the power plant operation is discontinued because the desalination plant would no longer benefit from the mixing effect of its concentrate with the warm and buoyant power plant cooling water. In this situation, source seawater may need to be collected to provide pre-dilution of the concentrate to an environmentally safe salinity level prior to its discharge, or the discharge outfall may need to be modified to provide an adequate level of mixing. Collection of dilution water may result in impingement and entrainment of marine organisms. The volume of source water needed for dilution, however, is typically less than that needed for power plant cooling water when the power plant is operating. The environmental impact associated with a smaller source water intake volume is smaller; however, with the power plant no longer operating, the environmental impact of impingement and entrainment will be attributed to the desalination plant rather than to the power plant.

This augmentation of discharge water with source water is allowed in the United States [40 CFR 125.3(f)] under certain conditions. The NPDES permits of the Carlsbad SWRO Desalination Plant in California and the Tampa Seawater Desalination Plant in Florida, for example, allow the collection of additional source seawater from the power plant intake (RWQCB, 2011; FDEP, 2013) when the power plant is shut down temporarily or permanently, or (in the case of the Tampa project) conditionally when the discharge-water temperature from the power plant reaches 38°C.

Chapter 4

Other Seawater Residual Management Options

4.1 Introduction

Chapter 3 discussed discharge of SWRO concentrate to surface waters. Other management options (i.e., discharge to sanitary sewer, deep well injection (DWI), land application, and evaporation), which are presently used in brackish concentrate management (see Chapter 1), are not usually feasible for the disposal of SWRO concentrate because of the high salinity and typically high volume of SWRO concentrate. Further, the availability of these options is limited at coastal locations because of factors such as climate, hydrogeological conditions, and land availability. Some of the options, however, may be used for the disposal of other SWRO desalination plant residuals. This chapter discusses the applicability of these options to SWRO residuals.

4.2 Discharge to Sanitary Sewer

4.2.1 Description

Discharge to the nearby wastewater collection system is the second most widely used method for the disposal of concentrate from U.S. municipal brackish desalination plants (Mickley, 2006). This indirect wastewater plant outfall discharge method, however, is only suitable for very small volumes of concentrate into large-capacity wastewater treatment facilities, mainly because of the potential negative impacts of the concentrate's high TDS content on the operations of the receiving WRRF. Discharge of residuals to a WRRF may also affect the WRRF's ability to meet its discharge permit requirements. Discharge to the sanitary sewer in most countries is regulated by the requirements applicable to industrial discharges of the utility or municipality that is responsible for wastewater collection system management.

4.2.2 Potential Environmental Impacts

The discharge of desalination plant residuals (such as backwash water, spent cleaning solution, and membrane flush water) to the sanitary sewer could potentially have environmental impacts very similar to those of the co-discharge of concentrate and WRRF effluent (see Section 3.4.2). Regulations that apply to this method are usually local utility ordinances and codes that define requirements for the disposal of industrial and municipal waste into the wastewater collection system.

4.2.3 Effect on WRRF Operations

The feasibility of this disposal method is limited by the hydraulic capacity of the wastewater collection system and by the treatment capacity of the WRRF receiving the discharge. A detailed analysis of the potential impacts of concentrate discharges on WRRF treatment processes is provided elsewhere (Rimmer et al., 2008).

Typically, a WRRF's biological treatment process is inhibited by high salinity when the plant's influent TDS concentration exceeds 3000 mg/L (Voutchkov, 2012). Therefore, before directing desalination plant residuals to the sanitary sewer, the increase in the WRRF influent salinity must be assessed, and its effect on the plant's biological treatment system and permit compliance should be investigated.

Increasingly, regulatory agencies are limiting discharge constituents including TDS and chlorides; local wastewater collection system discharge-related codes should be consulted to identify discharge limits. The TDS limit of discharge to sanitary sewers is very site specific. In the case of Carlsbad, CA, for example, the limit is 1000 mg/L. TDS discharge into the local sewer was an issue of concern in the initial phases of the Tampa SWRO project; the issue was related to the discharge of CIP scavenger tank waste to a WRRF with a very small capacity compared to the volume of the discharge – 0.4 MGD versus 5 MGD (1500 m^3/day vs. 18,900 m^3/day). Because the CIP discharge had an approximately 40 times higher TDS concentration than the WRRF influent (20,000 mg/L vs. 500 mg/L), despite its small volume, the CIP water increased the feed salinity to the WRRF activated sludge system from 500 mg/L to approximately 1900 mg/L, which resulted in the upset of the biological treatment process in the activated sludge tanks.

4.2.4 Effect on Water Reused for Irrigation

If the effluent from the WRRF is used for water reuse, the amount of residuals that can be accepted by the WRRF is limited not only by the residual salinity but also by the content of sodium, chlorides, and boron in the blend because of the tolerance limits of crops and plants for these constituents. All of these compounds could have a profound negative impact on the reclaimed water quality, especially if the effluent is used for irrigation. Treatment processes of a typical municipal WRRF, such as sedimentation, activated sludge treatment, and sand filtration, do not remove a measurable amount of these constituents.

4.2.5 Application to SWRO Residuals

Because of the significantly higher salinity and concentration of constituents in SWRO concentrate, its discharge to the sanitary sewer would be possible only for very small SWRO facilities and large WRRF s and thus is unlikely to be used. Disposal of other SWRO residuals that have much smaller volumes, including backwash water, spent cleaning solution, and membrane flush water, to the sanitary sewer is frequently done. In Florida, large WRRF discharges to the ocean or saline canals and other surface bodies have recently been prohibited, making this option less feasible.

4.3 Deep Well Injection and Shallow Coastal Well Disposal

4.3.1 Description

The DWI disposal method involves the injection of desalination plant concentrate into a high-salinity aquifer that is confined deep underground and adequately separated from freshwater or brackish water aquifers. The depth of such wells usually varies between 1600 and 4900 ft (500 and 1500 m). DWI is used for the disposal of concentrate from all sizes of brackish water desalination plants where the suitable hydro-geological aquifer characteristics have been found. Desired aquifer characteristics include an aquifer that is structurally isolated from overlying drinking water aquifers, has sufficient capacity to accept concentrate over the lifetime of the desalination plant, and has sufficient permeability and porosity for an acceptable individual well injection rate, yet low enough permeability and porosity to avoid excessive migration. Assuming that the injected water will not be recovered for future use, DWI is the only disposal option where the concentrate water is not reintroduced to the water cycle (surface water, groundwater, or air) and made available for future use.

The high cost of DWI is an additional limitation in terms of feasibility. So far, no known plants exist that use DWI for seawater concentrate disposal. However, shallow exfiltration beach well systems have been used for seawater concentrate disposal. Compared to DWI, beach well disposal consists of concentrate discharge into a relatively shallow unconfined coastal aquifer that ultimately conveys this discharge into the open ocean through the bottom sediments. Discharge beach wells are mainly used for small and medium seawater desalination plants. Shallow coastal well injection has found a practical use at the 0.3-MGD (1250-m^3/day) desalination plant in Sand City, CA.

4.3.2 Potential Environmental Impacts

Well injection of concentrate in the United States is regulated by an underground injection control (UIC) program. The two major concerns associated with deep injection wells are (1) leakage and migration of injected fluid from the well or injection aquifer and (2) plugging of the aquifer. The second concern may be considered more of an operational concern. Contamination of above-lying aquifers can be due to TDS or any of the constituents of the injection fluid. Injection of waste can be considered safe if the waste never migrates out of the well and out of the injection zone into other aquifers. The leakage and migration concerns are also associated with injection in earthquake sensitive regions and with overpressure causing fracture and earthquakes. Fracturing of the confining layers that isolate the injection aquifer from overlying aquifers can lead to leakage and contamination of the shallower aquifers. Injection pressures need to be less than fracturing pressures. At present, there are no regulations specific to SWRO concentrate disposal in the United States and abroad; the existing federal and state regulations for liquid underground aquifer injections apply to this disposal method. The state of California has issued a permit for the disposal of concentrate from the 0.6 MGD capacity (2500 m^3/day) Sand City Desalination Plant. However, this permit limits the salinity of the concentrate to the salinity of the ambient ocean water.

The Sand City coastal desalination plant includes four brackish water feed wells, a shallow coastal concentrate disposal well, and the associated pipelines and components. Of the four wells that are used to pump brackish coastal water to the plant, two are in use at any given time. These wells are more than 60 ft (18 m) deep and located 200 ft (61 m) from the surf line and more than 2500 ft (760 m) from the plant. The discharge permit regulates flow, pH, and salinity. Because the salinity of the intake coastal wells used for this project has increased over time, the TDS disposal permit limit imposed on the project’s coastal well has in effect reduced plant production capacity to approximately 50% of its design flow (i.e., 0.3 MGD or 1250 m^3/day).

4.3.3 Application to SWRO Residuals

It is unlikely that SWRO concentrate would be disposed of via DWI because of the availability of coastal surface water discharge options and the difficulty in finding suitable deep, confined aquifers. However, as previously mentioned, disposal by shallow beach well systems is a possible option for smaller seawater desalination plants.

4.4 Evaporation Ponds

4.4.1 Description

Evaporation ponds are shallow, lined earthen basins in which concentrate evaporates naturally as a result of solar irradiation. As freshwater evaporates from the ponds, the minerals in the concentrate are precipitated as salt crystals, which are either harvested periodically and disposed of off-site or left in place on the retirement of the pond and use of a new pond. The general feasibility of evaporation ponds depends on climate and specifically the annual net evaporation rate. Evaporation ponds are land intensive; the highest net evaporation rates, found in southwestern states, are less than 4 gpm/acre. Thus, the evaporation of 1 MGD (694 gpm) of concentrate would require more than 170 acres of evaporation surface. Because of this and the frequently high unit costs for land and pond liners, ponds are used only for small volumes of brackish municipal concentrate and are mostly restricted to southern U.S. states (see Table 1.3).

Several approaches have been studied to date to enhance the evaporation rates from concentrate disposal ponds, including spray evaporation, pond aeration, and the addition of dye to elevate pond water temperature. Although such enhancements can significantly reduce land requirements or capital costs, the ponds are still restricted by climate and land availability and are impractical in the United States for the disposal of large volumes of SWRO plant concentrate.

4.4.2 Potential Environmental Impacts

State groundwater quality regulations in the United States require evaporation ponds to be constructed with impervious synthetic or clay liners for the protection of underlying aquifers. Typically, the concentrate is not contaminated with hazardous materials, and a single-layer liner is adequate for groundwater protection. However, if the concentrate contains any significant contaminant loading, then a double-lined pond may need to be constructed.

If the ponds are not lined or the pond liner is damaged, a portion of the concentrate may percolate to the water aquifer beneath the pond and deteriorate its water quality. Therefore, evaporation pond systems, especially those using geo-membrane liners, should be equipped with underground leak-detection systems that lie beneath the liner. Alternatively, pond leakage can be monitored via a groundwater-monitoring well system with at least three monitoring wells: one installed up-gradient to the groundwater flow, one down-gradient, and one in the middle of the pond system. Monitoring must be conducted monthly.

Pond closure plans are typically required as part of permitting to address the environmental impacts associated with closure. Closure usually involves removal or decontamination of the waste and all system components and the assurance of the maintenance of the pond cover. In some states, waste may be left in the pond on closure. The pond cover integrity and effectiveness must be maintained to address the effects of settling, subsidence, erosion, or other events and to prevent run-on and run-off from eroding or otherwise damaging the final cover. Typically, groundwater monitoring is required.

Other environmental concerns associated with evaporation ponds are odor control and mist conveyance, when ponds are located near population areas.

4.4.3 Application to SWRO Residuals

In general, the use of evaporation ponds for SWRO residuals is not practical in the United States. Evaporation ponds are land intensive even with enhanced evaporation techniques, and level coastal land is typically of high value, which results in high land costs. The higher humidity typically associated with coastal regions results in low and possibly negative net evaporation rates. An example of a SWRO project with very successful evaporation pond disposal practices is the 2.6-MGD (10,000-m^3/day) desalination plant in Eilat, Israel (Ravizky and Nadav, 2007).

4.5 High Recovery and Zero Liquid Discharge Concentrate Disposal Systems

4.5.1 Description

High recovery (HR) and zero liquid discharge (ZLD) systems are considered processing options in most industries, but in the municipal desalination industry, the use of HR systems (including ZLD processes) generally refers to the additional processing of concentrate from an initial BWRO, electrodialysis reversal, or NF brackish water desalination process. There are no known HR SWRO municipal desalination systems in the United States; however, there have been studies addressing salt and other by-product removal from SWRO concentrate, thus involving HR SWRO systems (Davis, 2006).

HR processing is widely used in several industries but, primarily because of high costs, has found limited application in inland U.S. municipal systems (one ZLD system in California and a few HR NF systems in Florida).

The residuals from HR processing may be brine, solids, or a mixture of the two. The same concentrate management options exist as for conventional recovery concentrate, although the brine disposal options may be less attractive because of the high salinity.

4.5.2 Potential Environmental Impacts

The potential environmental impacts are those related to the final process residuals and those associated with the additional processing equipment. The high brine and solid constituent concentrations may result in a hazardous waste, although this should be the exception. On a unit volume basis, the high constituent levels mean larger salt loads, which will have greater impacts on receiving waters (surface water, ground water, aquifer water) and on WRRF facilities than those of conventional recovery concentrate.

Thermal evaporative processing steps have significant energy requirements, which are usually an order of magnitude higher than those of RO processes and thus have a high carbon footprint.

4.5.3 Application to SWRO Residuals

To date, HR processing has made little inroads into municipal brackish water desalination primarily because of its high cost (Mickley, 2008). HR processing is much less likely to be considered for SWRO concentrate than for brackish concentrate for several reasons:

- high capital and operating costs associated with the additional processing required
- absence of a need to reduce concentrate volumes and preserve source water supplies (that exists in many inland locations)
- lack of a need to consider other disposal options as ocean discharge offers economical and environmentally benign disposal

4.6 Beneficial Use of Concentrate

4.6.1 Land Application of Concentrate – Description

Land application of concentrate is one of the five conventional disposal options that account for more than 98% of all U.S. municipal desalination plants. As discussed in Chapter 1, as of 2010, land application accounts for 7% of the cases but none of the SWRO cases. Land application is clearly not an option for SWRO concentrate because of the high salinity of the concentrate, which would require an excessive amount of blending water to reach a lower suitable TDS level. Although unlikely, in theory, land application could be an option for some other desalination plant residuals that are significantly free of disinfectant, cleaning chemicals, etc. and that would meet state-specific groundwater requirements.

4.6.1.1 Potential Environmental Impacts

Most crops and landscape vegetation have limited tolerance levels for salinity and specific water constituents, and salt buildup in soils is an additional concern. The concerns are the same as those discussed in Section 4.2.4 with respect to water reuse for irrigation.

4.6.1.2 Applicability to SWRO Residuals

Because of the effects of salinity and concentrated constituents on crops and landscape vegetation, land application of brackish water concentrate is limited to small concentrate volumes where little if any dilution is necessary. In addition, land application is dependent on groundwater protection standards, which vary by state. Because of the significantly higher salinity and concentration of constituents in SWRO concentrate, its use for land application is unlikely.

4.6.2 Other Beneficial Uses of Concentrate

Beneficial use of concentrate was the subject of a previous WateReuse Research Foundation report (Jordahl, 2006), in which several potential beneficial uses of concentrate were identified. Several were highlighted, including the following:

- oil well field injection
- Calera’s proprietary MAP (Mineralization via Aqueous Precipitation) and ABLE (Alkalinity Based on Low Energy) carbon-capture processes
- solar ponds
- aquaculture
- wetlands creation and restoration
- treatment of wetlands
- stormwater or wastewater blending

- subsurface storage
- feedstock or sodium hypochlorite generation
- cooling tower water
- dust control and deicing

Although Table 1.2 lists beneficial uses as a category under concentrate management options (see Chapter 1), most beneficial uses are not proven on a large scale for concentrate, are rarely available, and usually do not represent a final disposal method for concentrate (Mickley et al., 2013). While of limited applicability to SWRO systems, for BWRO systems, because of the challenges of finding cost-effective and environmentally sustainable concentrate solutions, beneficial uses should be considered at the planning phase of all inland desalination plants.

4.6.2.1 Potential Environmental Impacts

Potential impacts are dependent on the specific beneficial use. Because of the unlikely use of SWRO concentrate (see next section), the potential environmental impacts are not discussed for the several potential (but unlikely) beneficial uses. At present there are no regulations specific to such concentrate disposal methods in the United States.

4.6.2.2. Applicability to SWRO Residuals

The higher salinity and generally higher volume of SWRO concentrate further limits many of the potential beneficial applications of the concentrate.

4.6.3 Salt Recovery from Concentrate

Several studies involving both brackish water and seawater have demonstrated that technically, it is possible to recover one or more individual salts and minerals of value from concentrate by the selective precipitation and processing of the precipitate. This general process is discussed in various reports (Bellona, 2015; Carollo Engineers, 2009; Svensson, 2005; Davis, 2006; Jordahl, 2006; Mickley, 2008; Voutchkov, 2012; Mickley et al., 2013). These references list salts of value and applications for various salts and discuss general processing schemes to recover the salts. However, this process has not been demonstrated and proven economically viable for SWRO facilities. To date, there are no known SWRO desalination plants that have incorporated salt recovery technologies at the commercial scale. However, China’s largest desalination plant, the Tianjin SDIC seawater multi-effect distillation plant [53 MGD (200 ML/d)], produces table salt via sending concentrate to evaporation ponds (IDE, 2015).

4.6.3.1 Potential Environmental Impacts

The environmental concerns with salt recovery are the same as those discussed in Section 4.4.2 for HR processes. At present there are no state or federal regulations specific to the mining of various minerals from SWRO concentrate because of the lack of full-scale installations.

4.6.3.2 Application to SWRO Residuals

At this time, the industrial production of most salt materials by traditional technologies is significantly less costly than production from the concentrate of a desalination plant. Therefore, although it is environmentally attractive, the large-scale beneficial reuse of minerals produced from desalination plant concentrate is unlikely to gain significant ground in the near future. Salt recovery is not anticipated to play a major role in SWRO concentrate management in the near term; however, it represents an important push toward a more sustainable resource and concentrate management and is likely to be a concept of increasing consideration.

Chapter 5

Regulations and Permitting Practices in the United States

5.1 Introduction

One of the key environmental impact assessment-related activities for a given desalination project is to identify all applicable regulatory requirements associated with project planning, design, construction, and operation, and to develop a plan to obtain project permits and licenses stipulating such regulatory requirements (i.e., the project permitting plan).

The number and type of permits as well as the permit requirements and the regulatory agencies responsible for issuing and enforcing such permits vary significantly from project to project, country to country, state to state, and even on a regional- or local-agency level. Therefore, the permitting process and plans are always project specific.

The Guidelines for Implementing Seawater and Brackish Water Desalination Facilities developed by the Water Research Foundation in cooperation with the WateReuse Research Foundation, the U.S. Bureau of Reclamation, and the California Department of Water Resources (WRF, 2010) provide a general overview of permitting and regulatory requirements and challenges in the United States. Texas and California have state-specific general guidelines for desalination project environmental planning, review, and permitting (R.W. Beck, 2004; CDWR, 2008). These guidelines, however, are not legally binding regulations or regulatory guidelines.

As mentioned in Chapter 1, at the conceptual or preliminary design level of a desalination plant, significant details of all permits required for the desalination plant are identified, including the right of way, land acquisition, pilot system, intake system, construction, and operation permits, as well as the discharge permit. The focus of this report is only on the permits associated with the disposal of the concentrate generated by SWRO plants.

This chapter discusses four broad topics:

1. The federal regulatory framework, which defines the general approach taken by U.S. states in regulating discharge from SWRO desalination plants
2. Within this framework, the events and information involved in the setting of discharge permit limits
3. The environmental and regulatory issues associated with the regulation of SWRO concentrate discharges
4. Studies to develop data for discharge permit applications

5.2. General Overview of U.S. Federal Regulatory Framework

5.2.1 Federal Regulatory Programs Affecting SWRO Concentrate Disposal

Wastewaters are categorized under the CWA as either industrial or domestic. Desalination plant discharges are thus classified as industrial waste despite the fact that these discharges are distinctively different from most industrial treatment facility discharges. Several regulatory programs in the United States address the disposal of desalination plant discharges: (1) the CWA; (2) the UIC Program, with ordinances that protect groundwater; and (3) the Resource Recovery and Conservation Act, which regulates solid waste residuals. It should be noted that at the time of development of these primary regulations, there were only a few, very small seawater desalination plants in the United States. Thus, there was no appreciable consideration of the potential impacts or requirements specific to this form of discharge. Even today, this continues as a factor, as there are very limited precedents for states for the development of a cohesive framework for desalination discharge permitting.

The U.S. EPA is obligated to delegate the authority to operate many federal environmental programs to states that request delegation and that meet the stipulated qualifications and conditions. Most of the delegatable programs are now operated by the states. States that have not been granted complete authority are not excluded from the permitting process but generally work closely with their regional U.S. EPA office in the application evaluation process. The U.S. EPA must obtain state certifications prior to issuing permits. This process allows non-delegated states to have a voice in if, when, and where a permittee can dispose of or discharge waste.

Disposal by surface water discharge requires an NPDES permit. Besides numeric limits for specific contaminants and WET, NPDES permits for ocean discharge typically contain receiving water quality provisions developed to comply with anti-degradation regulations and/or policies that require the plant discharge to be within 10% of the ambient levels of naturally occurring contaminants and to prevent the impairment of the receiving water quality in terms of color, odor, and visual appearance.

Because most existing desalination plants are located in California, Florida, and Texas, these states have the most experience and the most advanced regulatory frameworks for the permitting of such projects. All three of the primary states of focus in the United States (California, Florida, and Texas) are delegated to operate the NPDES program in their state. It should be pointed out, however, that none of these key states at present has legally binding, desalination-project-specific regulations or publicly available regulatory guidelines. State regulators issue desalination permits for projects based on their prior experience with similar projects.

Discharge to a WRRF's wastewater collection system generally requires a permit issued by the local sewer agency or wastewater management utility to assure that the discharge meets its local sewer use ordinance and will not cause issues with the NPDES discharge permits. Salinity or TDS is often a pollutant of concern to local wastewater treatment agencies in California, Florida, and Texas because of the frequent use of wastewater effluent for reuse and the need to meet federal and state water quality criteria.

Concentrate disposal by land application (percolation ponds, rapid infiltration basins, landscape and crop irrigation, etc.) has to comply with federal and state regulations to protect groundwater, public health, and crops and vegetation. Land application also requires a permit from state agencies.

Concentrate disposal by DWI is regulated by the U.S. EPA or the respective delegated state agency under the UIC program of the Safe Drinking Water Act. The related construction, monitoring, and other permits are issued and enforced by the U.S. EPA regional or state agency that has jurisdiction over the desalination plant location.

The Resource Recovery and Conservation Act regulates the disposal of solid waste generated by desalination plants, such as precipitated salts and sludge. If a given plant generates solids that contain arsenic or other pollutants above levels that classify them as a hazardous waste and if such sludge does not pass the toxic characteristic leaching procedure test, than such sludge will be considered a hazardous waste and must be handled and disposed of accordingly.

It should be pointed out that sludge generated from typical seawater desalination plants with open intakes is usually nonhazardous and can be disposed of to a sanitary landfill without further treatment. One exception is the sludge generated by saline water pretreatment with diatomaceous media filters (such as those used at the Tampa Bay Desalination Plant), because the diatomaceous media is considered a hazardous material in the United States. In comparison, sludge from brackish water sources sometimes contains high levels of naturally occurring or anthropogenic toxic compounds such as arsenic and cyanide, which may require its disposal to a hazardous waste landfill.

5.2.2 Federal Framework for Ocean Discharge

The CWA's federal framework for discharge to the ocean is the same as that for discharge to inland waterways. States may choose to implement guidelines in different ways and to have more stringent regulations than required by the federal minimum requirements. In California, discharge to the open ocean is subject to different regulations (the California Ocean Plan) than discharge to inland waterways, estuaries, and bays. In Florida, discharge to the ocean and to estuaries is under the same regulation (state regulations are discussed in Chapter 7).

Water quality goals are defined by water quality standards (U.S. EPA, 2010). The CWA and implementing regulations require states to develop and, from time to time, to revise water quality standards. The U.S. EPA's Water Quality Standard Regulation 131.11(a) requires states to adopt water quality criteria using sound scientific rationale and to include sufficient constituents and parameters (concentrations, pH, etc.) to protect the designated use. State standards may be more stringent than those required by the CWA (CWA Section 510). Water quality standards comprise three parts:

- designated uses
- numeric and/or narrative water quality standards
- anti-degradation policy related requirements

Numeric criteria are developed for aquatic life and for human health; there may be other criteria such as for wildlife or sediment, as well as biocriteria. Narrative criteria are developed by states where numeric criteria cannot be established or to supplement numeric criteria.

In addition to the three required components of water quality standards, states may, at their discretion, include policies that generally affect how the standards are applied or implemented. Examples of such policies include:

- mixing zone policies,
- critical low flows at which standards must be achieved, and
- the availability of variances.

CWA Section 301(b)(1)(C) requires that NPDES permits include any effluent limitations necessary to meet water quality standards. Where technology-based effluent limitations do not exist or alone will not achieve the water quality standards, CWA and its implementing regulations [40 CFR 125.3(a)] require the development of water-quality-based effluent limitations (WQBELs). Technology-based effluent limitations do not exist for municipal desalination facilities, and thus, discharge limitations are based on WQBELs.

Effluent limitations (the WQBELs) and other conditions in NPDES permits may be based on a parameter-specific approach or on a WET testing approach to implementing water quality standards.

A third approach to implement water quality standards, using biocriteria or bioassessment, is not directly accomplished through NPDES permit effluent limitations but can lead to the effluent limitation of a specific parameter or of WET (U.S. EPA, 2010).

In summary, the CWA and other federal regulations provide the framework for permitting ocean discharges but task the states with developing and implementing regulatory and permitting details. The general concerns and regulatory constraints include the following:

- regulation based on the compatibility of the concentrate with the receiving water (salinity and individual constituents)
- receiving water quality standards based on its use classification
- meeting discharge standards that may be defined by:
    - numeric limits for specific constituents and parameters
    - the narrative standards of the specific constituents and parameters
    - WET test requirements
    - meeting biological diversity parameters
    - total maximum daily loads
    - requirements related to the anti-degradation rule

For ocean discharge, however, total maximum daily loads and the anti-degradation rule are not often applied except for bays and estuaries or areas of exceptional pollution (e.g., Santa Monica Bay, which has a total maximum daily load for bacteria).

For a more detailed discussion of the federal regulatory framework for surface water discharge, the reader is referred to Mickley et al., 2013, Chapter 6.

5.3 Salinity and WET Requirements for Surface Discharges

Although regulations do not spell this out explicitly, project-specific acute and chronic WET limits or requirements in combination with the mixing zone requirements ultimately regulate the salinity of the discharge. For example, Florida and Texas do not have numeric salinity limits in their regulations. However, these states regulate desalination plant salinity impacts on the marine environment by chronic and sometimes acute WET limits. For example, the Huntington Beach Desalination Plant does not have a salinity limit in its NPDES permit but has a chronic toxicity limit that defines the size of its mixing zone and ultimately the mixing or dilution ratio between the ambient water volume and the volume of the concentrate.

At present, countries worldwide do not have numeric standards or limits for salinity content in the concentrate discharge; the discharge limit for this water quality parameter is established based on the site-specific conditions of a given project (Einav et al., 2002; Sadhwani et al., 2005; Mauguin and Corsin, 2005). The pertinent federal and state laws in the United States indirectly regulate the salinity of desalination plant concentrate discharges by establishing WET objectives. WET is a more comprehensive measure of the environmental impact of concentrate than a salinity limit because WET water quality objectives also account for the potential synergistic environmental impacts of the concentrate's salinity with other constituents in the concentrate.

According to current regulations in the United States, except for California, if a desalination plant's discharge meets all water quality objectives defined in the applicable federal and state regulations as well as acute and chronic WET objectives, then the proposed discharge does not present a threat to aquatic life, regardless of the actual salinity level of this discharge or the increase above ambient salinity that this discharge may cause, because WET testing accounts for the salinity-related environmental impacts of concentrate.

In California, where the latest amendment of the California Ocean Plan introduced a non-site-specific salinity limit of a 2-ppt increment over ambient salinity, WET testing will remain a key permitting requirement. Even if a desalination project complies with the maximum salinity limit, such compliance would not eliminate the need for this project to also comply with the project WET limits. The California amendment is discussed in greater detail in Chapter 7.

The numeric limit poses some questionable situations. If a given project's discharge salinity passes the maximum salinity limit of 2 ppt above ambient salinity but fails the WET acute and/or chronic toxicity limits, the project will be considered noncompliant with permit requirements. Compliance with a maximum-salinity-type limit does not guarantee that the discharge will not have a toxic impact on the environment, because a number of marine organisms are sensitive not only to salinity but also to the ion makeup and other constituents of the discharge. However, if the concentrate passes the WET test but the discharge salinity is higher than 2 ppt of the ambient ocean water's salinity, it is unlikely that such salinity would result in negative impacts on the environment.

Another challenge associated with implementing the 2-ppt salinity limit involves the definition of ambient salinity. The ambient salinity is defined as the mean monthly natural salinity determined by averaging 20 years of historical salinity data in the proximity of the proposed discharge location and at the depth of the proposed discharge, when feasible. When historical data is not available, natural background salinity is to be determined by measuring salinity at the depth of the proposed discharge for three years, on a weekly basis, prior to the desalination facility discharging concentrate. This requirement can significantly delay the implementation of SWRO facilities.

Except for California, no U.S. state or environmental regulation worldwide (including the CWA) imposes or contains a specific numeric salinity limit, but all regulations contain WET limits. The addition of a maximum salinity limit to desalination project permit requirements introduces only a burden in terms of compliance costs and delay to the regulatory process because the WET compliance requirements already reflect the potential negative effect of elevated salinity on the ambient aquatic life.

The California amendment does allow an owner or operator to submit a proposal to the regional water board for approval of an alternative salinity limitation for receiving water (other than 2 ppt) to be met no further than 100 m horizontally from the discharge. To determine whether the facility-specific alternative receiving water limitation is adequately protective of beneficial uses, the owner or operator must establish baseline biological conditions at the discharge location over a 12-month period prior to commencing concentrate discharge, must conduct various chronic WET tests, and must get approval from the regional water board.

5.4 Determination of Effluent Limitations for Ocean Discharge

The determination of effluent limitations for individual constituents, of parameters such as salinity, and of toxicity involves the consideration and analysis of several different types of information.

Figure 5.1 illustrates the different events and types of information typically required in determining discharge or effluent limitations for ocean-discharge NPDES permits. As discussed previously, federal and U.S. EPA documents provide this framework but generally leave specific policy and implementation requirements up to the states. Consequently, state regulations and policies can affect most, if not all, of the events and information items represented in Figure 5.1.

The boxes highlighted in blue in Figure 5.1 represent efforts or actions required to develop the information (white boxes) typically necessary to calculate the dilution allowance that is then used to calculate effluent limitations (the green box).

Pilot tests typically serve multiple purposes such as providing performance data for making decisions on system equipment and treatment options and providing information and samples for the characterization of concentrate properties. The samples provided by the pilot tests are analyzed for constituent makeup and concentrations as well as for toxicity (via WET tests).

Together the information from these efforts provides discharge properties and performance data (Box 1). Receiving water samples are also taken to determine the ambient water quality parameters (Box 2). If data on receiving water is not available, it must be generated; this step may be a schedule driver.

A dilution allowance or regulatory mixing zone is typically required for salinity and may be required for water quality constituents or parameters that do not meet water quality standards at the end-of-pipe. Within the mixing zone, water quality standards can be exceeded; because of the mixing, they will be met at the boundary of the mixing zone. Mixing zone policy and physical descriptions and limitations are set by state regulations and can vary by state (Box 3). Each state defines water quality standards applicable to the particular receiving water in question (Box 4).

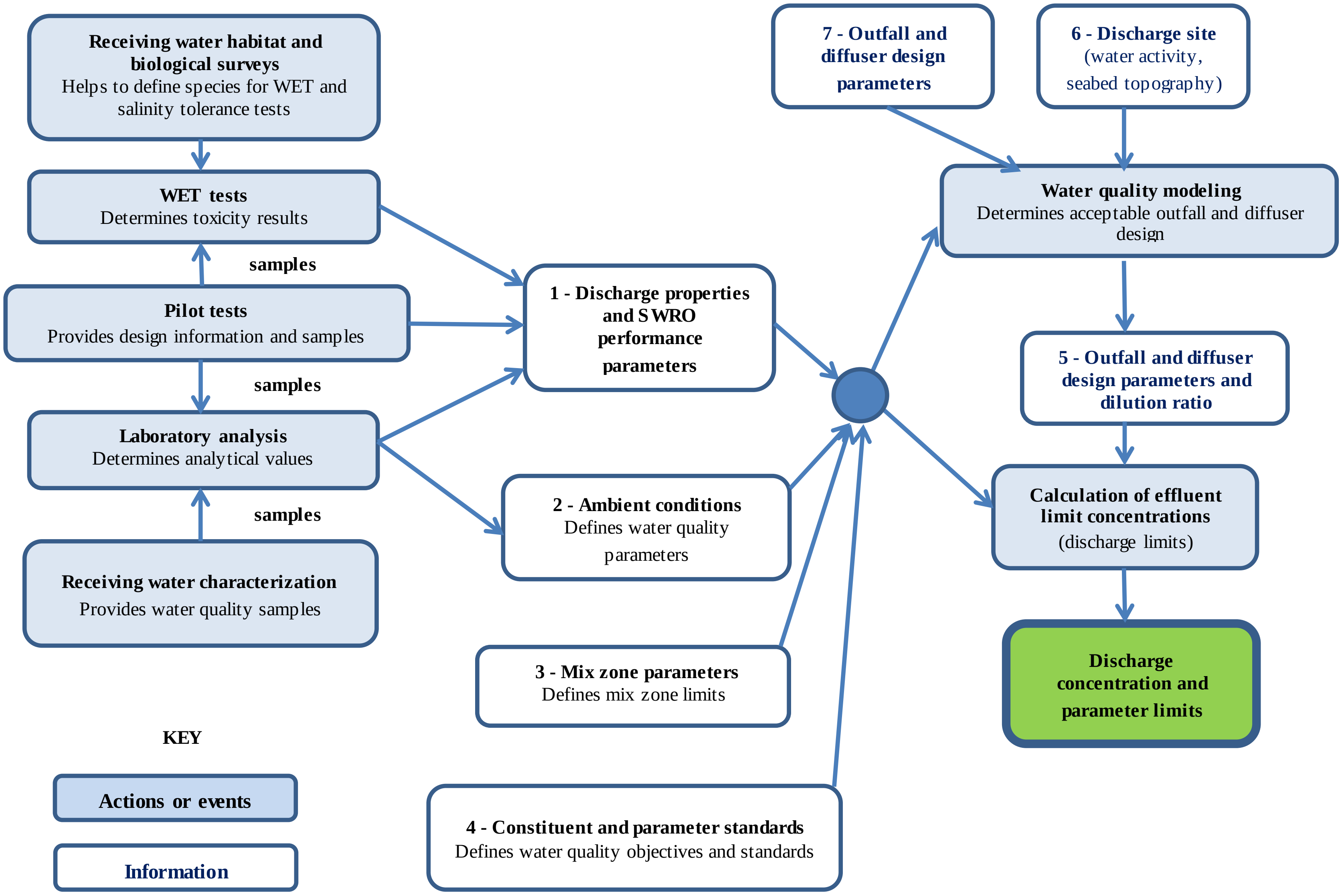


Figure 5.1. Events and Information Typically Required for the Determination of Numerical Discharge (effluent) Limits.

5.4.1 Regulatory Mixing Zones

For a desalination plant not to cause a material impact on the marine environment that receives its discharge, the higher-salinity concentrate discharge has to be mixed with the receiving waters and diluted to generally within 10% of ambient salinity levels as soon as possible and within as short a distance from the discharge as practical.

The distance from the point of discharge to the boundary at which the discharge salinity is diluted to 10% of the ambient salinity defines the actual "physical mixing zone." The size of the physical mixing zone depends on the ambient conditions, which can cause accelerated mixing (winds, waves, tidal movement, currents), and on the mixing energy introduced with the discharge of the concentrate, which in turn depends on the velocity, size, depth, and configuration of the discharge (i.e., the number and location of the outfall diffusers and the exit velocity at the diffusers).

The "regulatory mixing zone" is the zone around the discharge where the discharge could exhibit toxicity towards aquatic life inhabiting the zone and where the mix of concentrate and ambient seawater is allowed to have a concentration higher than the maximum concentration allowed at the boundary of the zone.

The concentrate discharge outfall has to be designed such that the physical mixing zone achieved by the outfall design is equal to or smaller than the allowable regulatory mixing zone. For example, at the Carlsbad SWRO plant, the regulatory mixing zone is 1000 ft. The use of the existing power plant outfall allows the physical mixing zone to be between 100 and 300 ft, that is, to be well within the regulatory mixing zone.

The maximum concentration allowed at the boundary of the regulatory mixing zone varies from state to state, country to country, and project to project. In some states such as Florida and Texas, the maximum salinity allowed at the boundary of the mixing zone is defined as 10% above the ambient salinity. In the latest California Ocean Plan, which became law on May 6, 2015, such maximum salinity is defined as 2 ppt above the ambient ocean water salinity.

Regulatory bodies of all U.S. states, including California, allow the maximum salinity limit for the regulatory mixing zone to also be established for the site-specific conditions of a project. The maximum limit is based on the level of dilution that is required for marine species inhabiting the area or for predetermined standard test species (defined by the respective regulatory agency) not to exhibit chronic toxicity. To determine the salinity threshold at which no chronic toxicity is exhibited, most regulatory agencies usually require standard chronic WET testing of at least one marine plant, one fish, and one crustacean. In countries such as Australia, the test marine organisms are determined based on their sensitivity to salinity at the embryonic phase and their presence in the discharge zone. In the case of the Carlsbad SWRO project, the site-specific maximum salinity limit was determined based on the long-term exposure (six months) of 19 marine species inhabiting the discharge area to a range of salinities between 36 and 48 ppt. Rather than using mortality as the criterion for impact and for establishing the salinity threshold, the threshold was based on the salinity concentration at which the marine organisms exhibited signs of stress (e.g., loss of weight or discoloration). In this case, the limit, based on chronic WET testing, was determined to be a salinity of 48 ppt. However, the maximum salinity at which marine species did not exhibit stress was found to be 46 ppt, and the regulatory agency that defined the salinity permit limit decided to use a safety margin and defined the maximum salinity limit at the boundary of the mixing zone as 44 ppt and the average salinity as 40 ppt. Using the new California Ocean Plan criteria, the limit would be the average ambient salinity (33.5 ppt) plus 2 ppt, or 35.5 ppt, which is obviously very conservative when compared to the actual level that marine species associated with this project can tolerate (46 ppt).

Applying the regulatory requirements in Florida and Texas, the limit would have been 33.5 ppt plus 10% (3.35 ppt), or 36.85 ppt. It should be pointed out that these states also allow limits to be established based on site-specific salinity studies, so it is likely that the limit would be closer to 46 ppt.

The examples illustrate the fact that the size of the regulatory mixing zone is mainly driven by the sensitivity of the marine species inhabiting the discharge area. However, because the actual species and the regulator-determined test species can vary from location to location, this size can vary significantly from one project to another.

5.4.2 Mixing Zone Definitions

The U.S. EPA defines two regulatory mixing zones, as shown in Figure 5.2. The term "acute mixing zone" is referred to as the "zone of initial dilution" (ZID). More specifically (U.S. EPA, 2015) states:

> In the zone immediately surrounding the outfall, both the acute and the chronic criteria may be exceeded, but the acute criterion is met at the edge of this zone, which is often referred to as the acute mixing zone or the zone of initial dilution. The acute mixing zone is sized to prevent lethality to passing organisms in order to protect the designated use of the waterbody as a whole.
>
> In the larger mixing zone, which is often called the chronic mixing zone, the chronic criterion may be exceeded, but the acute criterion is met. The chronic criterion is met at the edge of the chronic mixing zone. The chronic mixing zone is sized to protect the designated use of the waterbody as a whole.

The California Ocean Plan (SWRCB, 2012) and the California Desalination Amendment to the plan (SWRCB, 2015a) both use the term "initial dilution" to correspond to the largest mixing zone of the U.S. EPA figure. Here, initial dilution does not mean the ZID. The definition of initial dilution from Appendix I of the Ocean Plan (SWQCB, 2012) is as follows:

> Initial dilution is the process which results in the rapid and irreversible turbulent mixing of wastewater with ocean water around the point of discharge.
>
> For a submerged buoyant discharge, characteristic of most municipal and industrial wastes that are released from the submarine outfalls, the momentum of the discharge and its initial buoyancy act together to produce turbulent mixing. Initial dilution in this case is completed

> when the diluting wastewater ceases to rise in the water column and first begins to spread horizontally.

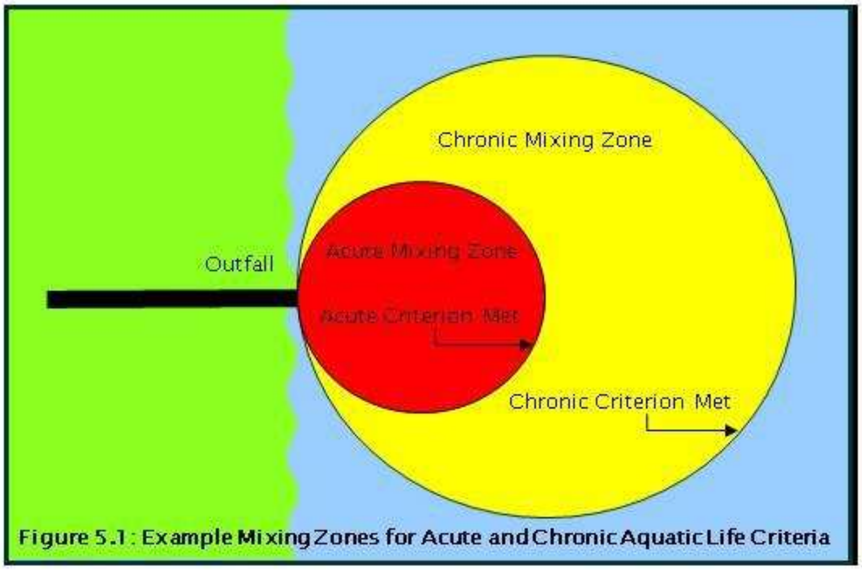


Figure 5.2. Example of Mixing Zones for Acute and Chronic Aquatic Life Criteria.
Source: U.S. EPA, 2015

> For shallow water submerged discharges, surface discharges, and non-buoyant discharges, characteristic of cooling water wastes and some individual discharges, turbulent mixing results primarily from the momentum of discharge. Initial dilution, in these cases, is considered to be completed when the momentum induced velocity of the discharge ceases to produce significant mixing of the water, or the dilution plume reaches a fixed distance from the discharge to be specified by the California Regional Board, whichever results in the lower estimate for initial dilution.

The California Desalination Amendment (SWRCB, 2015a), made into law on May 6, 2015, addresses only the regulatory mixing zone for salinity. This zone is entirely separate from the Ocean Plan regulatory mixing zones that address other pollutants and acute and chronic toxicity. There is no use of the term ZID in the amendment. Additional detail on the California Desalination Amendment is given in Section 7.2.1.2.

The previous discussion reflects the fact that there is room for confusion with respect to use of the term ZID. In this report, the U.S. EPA definition of ZID is used.

5.4.3 Water Quality Modeling

The effect of concentrate discharge on the receiving water is predicted through modeling the dispersion and mixing of the effluent in the receiving water (referred to as water quality modeling in several U.S. EPA documents). The goal of the modeling effort is to define an outfall and diffuser discharge system that provides sufficient dilution so that water quality standards can be met at the edge of an acceptable mixing zone. Different outfall and diffuser designs will give different mixing results. The modeling effort may be conducted for salinity and for each constituent and toxicity defined by the regulatory agency. Each acceptable mixing zone solution yields a dilution ratio defined as parts receiving water per parts discharged wastewater. It also defines an acceptable outfall and diffuser design (Box 5 in Figure 5.1). A design that provides a solution for each constituent and parameter of concern as well as for toxicity is chosen for implementation.

In addition to the information provided in Boxes 1 through 4, the modeling effort also requires

- a physical description (depths, seabed topography, currents, tides, etc.) of the shore and discharge area (Box 6), and
- a physical description of the outfall-diffuser system, to provide an estimate of the immediate dilution factor obtainable by the system (Box 7).

The modeling software then predicts the dispersion of the concentrate following the initial dilution offered by the diffuser system. Note that in some cases, a diffuser system may not be required, in which case the modeling software predicts the dispersion of the concentrate from the end of the discharge pipe or site.

5.4.4 Calculation of Dilution Ratios and Numeric Effluent Limitations

The dilution ratios resulting from the modeling effort are used in the calculation of effluent limit concentrations via a mass balance equation such as

$$C_e = C_o + D_m \times (C_o - C_s)$$

where

- C_e = effluent concentration limit
- C_o = water quality standard (objective) concentration to be met at the edge of the allowable mix zone
- C_s = background (ambient) seawater concentration
- D_m = dilution ratio expressed as parts seawater per part wastewater

Variants of the equation may be defined, such as in the California Ocean Plan's Desalination Amendment for acute toxicity, where the equation is

$$C_e = C_o + (0.1) \times D_m \times C_o$$

In summary, a modeling effort defines dilution ratios for salinity and for each constituent, parameter, and toxicity in question, as well as providing an acceptable outfall and diffuser system design. The dilution ratios thus found are used to calculate the discharge or effluent limitations. The information necessary for conducting the modeling effort includes the following:

- information defined in the state's regulatory policy and implementation documents (water quality standards, mixing zone definition and restrictions)

- information generated via pilot tests; characterization of the receiving water and discharge location
- outfall and diffuser system performance and design parameters

Some of the information depicted in Figure 5.1 (Boxes 3 and 4) is defined in state regulations. Most of the information is developed and supplied to the state by the desalination plant owner as part of the NPDES permit application. The state's permitting agency reviews the adequacy of the data and ultimately makes decisions on the effluent limitations based on acceptable data. Effluent limits are typically set as maximums, minimums, or averages over a set period of time (e.g., maximum daily, average monthly, average weekly, six-month median).

Chapter 6

Issues Associated with the Determination of Effluent Limitations

6.1 Introduction

Issues related to the permitting of SWRO concentrate discharge may be separated into two areas:

- environmental concerns that are the drivers for concentrate discharge permitting actions and permit limits
    - maintaining the receiving water quality within the salinity tolerance of aquatic species (i.e., the determination of the salinity tolerance of the marine organisms in the region of discharge)
    - avoiding the concentration of source water constituents to harmful levels
    - avoiding discharge that may cause discoloration of the receiving waterbody and that may lower the oxygen content in the area of the discharge
    - avoiding problematic shear and turbulence effects that are due to the diffuser discharge of concentrate
- issues associated with regulatory guidance and the process of providing information for the determination of discharge permit limitations
    - WET testing of the concentrate
    - modeling of concentrate dispersion and recirculation to the intake
    - protocols for analytical lab testing of high-salinity samples in general and for various compounds contained in concentrate such as metals, TSS, and organics
    - the status of state regulatory guidelines relevant to desalination plant discharges
    - classification of the concentrate as an industrial waste

Most of these issues are associated with an event or information depicted in Figure 5.1. The primary focus of this report is environmental issues and how these issues are dealt with in the permitting process. The following sections discuss these issues in detail. The other issues listed are identified to provide a broader characterization and understanding of the permitting process. Increased definition, clarity, and guidance in these issues would benefit the permitting process both for owners and operators providing information to regulatory groups and for the regulatory groups assigning the permit limitations.

6.2 General Environmental Issues

One of the key limiting factors in the construction of new desalination plants is the availability of suitable conditions and locations for the disposal of the high-salinity concentrate. This liquid stream contains most of the minerals and contaminants of the source water and pretreatment additives in concentrated form. If chemical pretreatment is used, such as coagulants, antiscalants, polymers, or disinfectants, some or all of these chemicals may reach or may be disposed along with the plant discharge concentrate. As discussed in Chapter 2, the discharge may also contain smaller volumes of other desalination plant waste streams such as spent filter backwash water and the spent flush water generated during membrane CIP. As indicated in Chapter 2, the quantity of the concentrate is a function of the plant capacity (flow) and recovery, which in turn is highly dependent on the TDS concentration of the source water. Concentrate quality is determined by the content of minerals and other contaminants in the saline source water. Chapter 2 discusses concentrate water quantity and quality in greater detail.

Because the most prevalent method of concentrate disposal at seawater desalination plants is surface water discharge, the focus here is on the environmental impacts of desalination plant discharges to surface waters. Key environmental issues and considerations associated with concentrate disposal to surface waters include:

- salinity increase beyond the tolerance thresholds of the aquatic species in the area of the discharge,
- concentration of source water constituents (e.g., metals, nutrients, radioactive ions) to harmful levels, and
- discharge discoloration and low oxygen content.

As stated in Chapter 1, these are all long-time recognized environmental impact issues that are addressed as part of discharge permits globally. A more recent issue, the impact on marine organisms that is due to shear and turbulence associated with the high velocity diffuser jets discharging the concentrate into the receiving water, is a relatively new issue that has not been widely addressed in discharge permits. The recently (2015) adopted California Desalination Amendment (SWRCB, 2015a), which is part of the updated California Ocean Plan, recognizes this issue and requires the owner or operator to

- estimate the mortality of all forms of marine life that occurs as a result of water conveyance, in-plant turbulence or mixing, and waste discharge, and to
- complete a mitigation project or participate in a fee-based mitigation program, if available.

We are not aware of this issue being addressed in any other state or global permitting efforts, and the reader is referred to the literature for additional information on this subject (Jenkins, 2013).

The following sections discuss each of the three key environmental issues listed previously.

6.3 Salinity Tolerance of Aquatic Species

The main environmental impact of concentrate on aquatic life in the vicinity of desalination plant discharge has typically been associated with the salinity of this discharge and the ability of the native species to tolerate this salinity.

There is a sizable gap in the knowledge base concerning the effects of salinity on marine organisms. Because of this, general guidelines have been used in the past (such as the

"10% rule" – 10% above ambient salinity) when considering permit limits on salinity. Use of such guidelines is now being questioned. The salinity tolerance of marine organisms is an area of increasing importance when establishing meaningful salinity limitations for concentrate discharges.

The maximum TDS concentration that can be tolerated by marine organisms living in the outfall area of a desalination plant is defined as the salinity tolerance threshold and depends on the type of aquatic organisms inhabiting the area of the discharge and the period of time during which these organisms are exposed to elevated salinity (Mickley, 2006). These conditions are very site specific for the area of each desalination outfall; therefore, a general rule of thumb for determining a salinity tolerance threshold is practically impossible to develop. A complication is that many species have differing tolerances to salinity at different life stages (e.g., juvenile stages may be less tolerant of changes). This consideration may be an issue if discharge is proposed at a site that is a known breeding or nursery ground. The exposure issue is also complicated by the fact that many mobile organisms exhibit avoidance behavior when confronted with a local unsuitable environment.

Marine organisms have varying sensitivities to elevated salinity. Some organisms are "osmotic conformers," that is, they have no mechanism to control osmosis, and therefore, their cells conform to the salinity of their environment. A large increase in salinity in the surrounding marine environment (such as an increase that is due to concentrate discharge) causes water to leave the cells of these organisms, which could lead to cell dehydration and ultimately to cell death. Marine organisms that can naturally control the salt content and hence the osmotic potential within their cells despite variations in external salinity are known as "osmotic regulators." Most marine fish, reptiles, birds, and mammals are osmotic regulators and employ a variety of mechanisms to control cellular osmosis. Salinity tolerances of marine organisms vary, but few shellfish (scallops, clams, oysters, mussels, or crabs) or reef-building corals are able to tolerate very high salinities.

Many marine organisms are naturally adapted to changes in seawater salinity. These changes occur seasonally and are mostly driven by evaporation from the ocean surface, by rain and snow deposition and runoff events, and by surface water discharges. The natural range of salinity fluctuations in the surface waters receiving concentrate from a given desalination plant could be determined based on information from sampling stations located in the vicinity of the discharge and operated by national, state, or local agencies and by research centers responsible for surface water quality monitoring. In open ocean waters, the typical range of natural salinity fluctuation is at least 10% of the average annual ambient seawater salinity concentration. The "10% increment above ambient ocean salinity" threshold is a conservative measure of aquatic life tolerance to elevated salinity. The actual salinity tolerance of most marine organisms is usually significantly higher than this level and often exceeds 40 ppt (Cotruvo et al., 2010; Hammond et al., 1998). For example, gobies, which are one of the most common species inhabiting California coastal waters, are tolerant to relatively high salinity concentrations and are well known to inhabit the Salton Sea of California, which currently has an ambient salinity of 45 ppt. However, other common organisms such as abalone and sea urchins have lower salinity tolerances.

The nature, magnitude, and significance of elevated concentrate salinity impacts mainly depend on the type of marine organisms inhabiting the discharge area and the length of time of their exposure. A salinity tolerance study implemented in 2005 as part of the environmental impact review of the 50-MGD (189,000-m^3/day) Carlsbad seawater desalination project, and completed based on the testing of more than two dozen marine species frequently encountered along the California coast, indicates that (based on WET tests) these marine species can safely tolerate a salinity of 40 ppt (19.4% above ambient salinity; Poseidon Resources, 2007).

It is also important to note that subsequent chronic toxicity bioassay testing using standard top smelt test organisms (*Atherinops affinis*) and completed in conformance with the NPDES permit requirements for the Carlsbad Desalination Project (CDP) identified the following: (1) the no-observed-effect concentration of the test occurred at 42 ppt of concentrate salinity; (2) the lowest-observed-effect concentration was found to be 44 ppt; (3) the plant was well below the applicable toxicity limit for a salinity of 46 ppt or lower; and (4) the no-observed-effect time for a 60 ppt concentration was 2 h, and the lowest-observed-effect time for a 60 ppt concentration was 4 h. This means that for a short period of time, the species can be exposed to a salinity as high as 60 ppt without any observed effect (Poseidon Resources, 2007).

A site investigation of a number of existing full-scale seawater desalination plants operating in the Caribbean that was completed by scientists from the University of South Florida and the South Florida Water Management District (Hammond et al., 1998) has concluded that salinity levels from 45 ppt to 57 ppt have not caused statistically significant changes in the aquatic environment in the area of the discharge.

6.4 Concentration of Source Water Constituents to Harmful Levels

As indicated previously, salinity-related toxicity to aquatic life is the prime source of the environmental impacts associated with surface water discharges. However, besides salinity, the RO membrane separation process also removes more than 90% of most other constituents in the source water and generally concentrates these constituents in the discharge between 1.5 and 2.0 times, depending on the desalination plant recovery. Therefore, some contaminants in the saline source water (e.g., heavy metals, arsenic, cyanide, nitrates, toxins) that are regulated because of their potentially harmful impacts on the environment may be concentrated to levels that exceed acceptable regulatory thresholds.

To assess the potential environmental impacts of regulated water constituents, concentrate water quality should be tested for such constituents, and the actual levels of the constituents should be compared to pertinent numeric regulatory water quality standards. Practical experience shows that in most cases, the SWRO concentrate water quality meets the regulatory standards associated with most surface waters. However, depending on the site-specific conditions and on the discharge configuration and location, some source water constituents, other than TDS, could potentially exceed regulatory water quality standards.

For example, because metal content in ocean water is naturally low, compliance with numeric standards for toxic metals usually does not present a challenge. However, concentrate that is co-discharged with WRRF effluent may occasionally present a concern because WRRF effluent contains metal concentrations that may be higher than those in the ambient surface source water. Similar attention to the metal levels in power plant discharge should be given to the co-disposal of power plant cooling water and concentrate, especially if the power plant equipment leaches metals such as copper and nickel, which may then be concentrated in the desalination plant discharge.

If the desalination plant has a pretreatment system that uses coagulant (such as ferric sulfate or ferric chloride), the waste discharges from the source water pretreatment may contain elevated concentrations of iron and turbidity that must be accounted for when assessing their total discharge concentrations (see Chapter 2).

Radionuclide levels in ocean water often exceed effluent water quality regulatory standards, and SWRO plant concentrate is likely to contain elevated gross alpha radioactivity. This condition is not unusual in both Pacific and Atlantic Ocean waters and must be well documented with adequate water quality sampling to avoid potential regulatory challenges.

Toxins, such as domoic acid and saxitoxin, that are released by decaying algae during red tides and other algal bloom events could potentially be harmful to human health and/or the marine environment and are known to cause shellfish poisoning. Practical experience shows that even under severe algal bloom conditions, such toxins typically occur at levels that do not present a threat to human health through direct ingestion of the desalinated water or concentrate. These toxins could, however, cause shellfish poisoning because they concentrate in shellfish tissue at levels that are several hundred times higher than the toxin level in the ambient seawater, at which level they exceed the human health toxicity threshold. For comparison, SWRO plants concentrate algal toxins only 1.5 to two times, and at such concentrations, these toxins are below the human toxicity threshold.

The federal alert level for domoic acid or saxotoxin toxicity is 80 µg/100 g of shellfish tissue, and the detection limit of the paralytic shellfish poisoning bioassay is approximately 40 µg/100 g (CDPH, 2013). Such threshold levels are expressed in units of "content of the toxin in shellfish" because this is the most common path of human exposure to the toxins – that is, ingestion of shellfish with a high content of toxins related to algal bloom. If ingesting 100 g of shellfish tissue is considered equivalent to ingesting 100 g of water, then the shellfish limit can be prorated to 800 µg/1000 g of water or 800 µg/L.

It should be pointed out that the measurements of saxitoxin and domoic acid completed as a part of the permitting process for the Carlsbad, West Basin, and Santa Cruz desalination projects indicated levels of these toxins in the source seawater during a 50-year algal bloom in 2005 in a range of 2 to 20 µg/L, which is an order of magnitude lower than the toxicity threshold listed previously. The reason why the contents of saxitoxin and domoic acid are regulated in shellfish tissue is because shellfish can concentrate these toxins several hundred times in their tissues, which can make the ingestion of such shellfish harmful to human health.

If a constituent or parameter level in the discharge concentrate exceeds regulatory water quality standards, a mixing zone may be requested for the constituent or parameter. As an alternative, the desalination treatment process or operation may be modified to avoid the exceedance.

6.5 Discharge Discoloration and Low Oxygen Content

Typically, concentrate from desalination plants with open surface water (ocean, river) intakes has the same color, odor, oxygen content, and transparency as the source water from which it was produced, and an increase or decrease in salinity will not change its physical characteristics or aesthetic impact on the environment. Usually, there is no relation between the level of salinity and the biological or chemical oxygen demand of the desalination plant concentrate from open intakes. Therefore, concentrate generated by desalination plants with open intakes typically does not pose significant environmental challenges in terms of color and oxygen content. In fact, in some cases, such plant discharge may have a higher content of oxygen than the surface waters to which it is discharged and may actually improve the quality of the receiving waterbody in terms of DO content.

Acids and scale inhibitors are often added to the desalination plant source water to facilitate the pretreatment and salt separation processes. With the exception of the hydrogen (hydronium) ion from acids, these additives are typically rejected by the RO membranes and collect in the concentrate. However, such source water conditioning compounds are applied at very low concentrations, and their content does not significantly alter the water quality and quantity of the concentrate. The environmental implications of the use of such additives are usually well evaluated and tested before their use, and only additives that are proven harmless to the environment and approved by pertinent regulatory agencies are actually applied in seawater treatment. All chemical additives used at desalination plants are typically of high-grade purity and are approved for human consumption. All chemicals approved for the production of drinking water and used in the desalination process are biodegradable, and they usually have toxicity levels several hundred times higher than the levels at which they are applied, so they typically do not trigger acute or chronic toxicity.

One condition that may cause a reduction and ultimately a depletion of the naturally high level of oxygen in the concentrate from desalination plants with open intakes is the overdosing of the reducing chemical (i.e., sodium bisulfite or sulfur dioxide) that is added to remove chlorine from the saline water fed to the desalination plant RO membrane system; this chlorine resulted from the disinfection of the raw water.

Typically, a reducing chemical is applied at a dosage proportional to the chlorine content in the source water such that the total chlorine residual in the water is reduced to less than 0.05 mg/L; this is done to protect the RO membranes from oxidation. However, sometimes, because of operator error or a monitoring instrument malfunction, the concentration of sodium bisulfite may exceed the dosage needed for the removal of the chlorine in the RO system feed water. In such cases, the excess content of reducing chemical that is left after dechlorination will react with the oxygen in the source water and reduce its content. As a result, both the desalination plant concentrate and the product water could have DO levels lower than those of the saline source water.

This potential environmental challenge is usually addressed by the installation of multiple instruments for monitoring of chlorine content and oxidation-reduction potential (ORP) of the water being treated with reducing chemical and of the concentrate: typically, two ORP meters and one chlorine residual analyzer are installed in series on the pipeline feeding the RO system with source water. The ORP of the source water is an indirect indication of its oxygen content. In addition, the ORP is measured in the desalination plant source water and concentrate. If the ORP of the water being treated with reducing chemical decreases below 10% of the ORP of the source water, than the dosage of the reducing chemical is decreased.

One of the concerns raised during the approvals for the plants in Australia (including Perth and Adelaide) was not just the risk of low DO in the discharge (e.g., through overdosing with reducing chemicals) but also the possibility that the plume would sink if not dispersed adequately and result in low DO levels for benthic organisms as they consume oxygen that is not replaced. Although monitoring has demonstrated that this has not occurred, it was considered and addressed through the approval process.

Concerns for the potential creation of zones of apoxia in the discharge zone, induced by concentrate discharge, were also raised during the permitting process of the Tampa Bay, Huntington Beach, and Carlsbad SWRO desalination projects. These concerns were addressed by measurement of the DO concentrations of the discharges generated by the pilot testing plants operated for these projects and by the hydrodynamic modeling of the distribution of DO in the water column in the areas of the plants' discharges. Direct measurements of the DO levels of the concentrates generated by the pilot plants indicated that the DO concentration of the discharge was usually higher than that of the ambient seawater and that, therefore, the discharges of desalination plants with open intakes usually increase rather than decrease the DO levels in the area of the discharge. The additional oxygen in the water typically originates from the backwash water disposed along with the concentrate, which may be nearly saturated with air because filter backwashing procedures usually include intensive air washing of the filtration media. Similar to all other gases, oxygen is not rejected or removed from the source water by the SWRO membranes. Therefore, usually the DO of the plant concentrate is similar to that of the ambient source seawater used in desalination. When the SWRO system concentrate is blended with the high-oxygen-content backwash water, the overall DO of the concentrate increases slightly. Long-term monitoring of the concentration of DO and marine aquatic life in the vicinity of the discharge from the Tampa SWRO desalination plant as a part of the biological monitoring survey for this plant (McConnell, 2009) confirms this observation.

It should be pointed out, however, that the observations presented previously are valid only for desalination plants with open ocean intakes. Pilot testing experience at the Dana Point Desalination Plant in California, which uses slant intake wells for source water collection, shows the opposite observation (Bell et al., 2011). Because the seawater collected by the well intake usually contains a lower concentration of DO than the ambient seawater, the concentrate of this plant also has a lower DO concentration, sometimes at levels of 0.0 to 2.0 mg/L, which are below the U.S. EPA DO discharge limit of 5 mg/L. Under such low DO conditions, the desalination plants using well intakes could trigger or exacerbate apoxia conditions in the discharge area. Therefore, such discharges may require re-aeration prior to concentrate disposal.

One condition that could cause the concentrate from a surface water source to be discolored is when it is blended with untreated spent filter backwash water from the desalination plant pretreatment facilities, especially if such backwash water contains an iron-based coagulant (ferric hydroxide). Because ferric hydroxide has a red color, when it is blended with the colorless concentrate, it will discolor the desalination plant discharge and may degrade the quality of the receiving surface waters. If such a discharge is directed to a groundwater aquifer via DWI, it may degrade the aquifer water quality and over time decrease the well discharge capacity.

A commonly applied solution to such environmental challenges is the treatment of spent filter backwash water in solids-handling facilities, including lamella sedimentation with a subsequent dewatering of the sludge collected in the sedimentation tanks by mechanical dewatering equipment (centrifuges or belt filter presses). The dewatered sludge, which typically contains more than 95% of the coagulant, is usually disposed of in a landfill in solid form. At smaller desalination plants, the spent filter backwash water and other pretreatment conditioning chemicals are discharged to the nearby sanitary sewer for further treatment in a WRRF. Most membrane-pretreatment-based systems do not use a coagulant and therefore, are not challenged with the discharge discoloration issue.

6.6 Concentrate Discharge Permit-Related Issues

In addition to the environmental issues discussed previously, there are several issues related to concentrate discharge that impact the permitting of desalination plants. These issues include:

- the scope of the WET testing performed to develop the data for permit applications;
- protocols for the modeling of the discharge, receiving water, and discharge system;
- the selection of an analytical laboratory to produce numerical data for permit applications and for permit monitoring requirements; and
- the experience and the existing and future policies of the regulatory agencies involved with the permitting of the desalination projects.

Although these issues are not the main focus of this report, they are issues that reflect the level of understanding and study associated with the permitting process. Definition of the states' and countries' positions on these issues characterizes their permitting basis.

6.6.1 WET Testing

WET testing is an important and integral part of the process to determine the impacts of discharge on marine life, and from global experience, the role of WET tests has been a successful one. However, there are several issues associated with WET tests that could benefit from either study or further definition. These mostly have to do with the requirements and protocols used when conducting WET tests:

- which organisms to use in the test
- the number of different organisms to use in the test
- the dilution water to use in the test (i.e., use of actual seawater versus artificial seawater)
- whether to do chronic and/or acute toxicity tests
- the appropriate length of time to run the test (whether acute, chronic, or both)
- how to acclimate species for testing; adaptation of the test organisms to the test salinity prior to testing depends on the age and type of the organisms
- the lack of standards for high-salinity WET testing
- the lack of protocols specific to the various life stages of the test species
- challenges in obtaining lab testing protocols for local species relevant to the discharge site

6.6.2 Testing Issues Not Addressed by WET Tests

Issues not addressed by the WET tests include:

- the adaptation of organisms in the region of discharge to natural salinity variations and/or continuous concentrate discharge,

- the ability of organisms to move away from the discharge area, and
- naturally occurring changes in aquatic habitat that are due to heavy storms or other natural calamities that occur periodically in nature.

6.6.3 Modeling of Dispersion and Recirculation to Intake Area

The determination of the receiving water movement or physical activity is important when estimating how the discharge will move and disperse in the receiving water and was discussed in Section 6.2.3. Issues associated with modeling include:

- determining which models to use,
- understanding how to use the simulation results in setting the dilution requirements,
- understanding how to calibrate and validate the models, and
- the experience (or lack of experience) of the regulatory agencies involved in the project permitting with the model selected by the project proponent.

6.6.4 Analytical Laboratory Testing

Lab testing is required to assign values to water quality parameters: both concentrations and physical parameters. This occurs when characterizing the receiving water, the concentrate (for pilot tests, for monitoring), and other system residuals.

A key issue with analytical testing is that some standard test procedures (e.g., the methods of analysis of the concentrations of TSS, copper, nickel, and radionuclides) were originally developed for lower-salinity freshwater and wastewater and are not suited to higher-salinity waters. Because of this, they can lead to incorrect results.

6.6.5 Limited Available Information on Existing Projects

At present, there are very few medium and large SWRO desalination projects in the United States, and therefore, most regulatory agencies lack experience and precedents to use to support their project review process and regulatory decisions. The lack of available discharge monitoring information can complicate tasks associated with planning and performing studies and can complicate decision making in general. An information vacuum can also allow project stakeholders who are against the implementation of a desalination plant (e.g., to control growth) to create a false sense of anxiety and uncertainty in the general public and among the regulators involved in the environmental review of the project, and thereby to unreasonably delay or halt project implementation.

Issues that many projects face are:

- the need for pilot testing to prove already-proven membrane separation technologies,
- the need to complete WET testing of proprietary chemicals (i.e., coagulants, antiscalants, membrane cleaning solutions) before the exact types of the most suitable chemicals are known,
- the lack of local precedents, and
- limited published discharge information on existing desalination plants.

6.6.6 Status of Regulatory Policy and Guidelines

As indicated previously, at present there are no federal regulatory guidelines for the implementation and permitting of desalination projects. This regulatory vacuum has hindered the implementation of many desalination projects in the United States, especially those in California and Florida. The development of federal desalination guidelines similar to the U.S. EPA Water Reuse Guidelines (U.S. EPA, 2012) would significantly benefit the advancement and implementation of desalination projects in the United States and provide an independent source of information to all stakeholders in future desalination projects. Similar to the Water Reuse Guidelines, the desalination guidelines could share the successes and lessons learned from other projects and could allow the streamlining of the data that need to be collected and of the studies that need to be conducted to complete the environmental review of desalination projects more expeditiously. At present, the United States is the only country in the world where the permitting of medium and large desalination projects takes much longer (three to 10 years) than their construction (two to three years).

One general issue is the classification of municipal desalination concentrate as an industrial waste. Concentrate discharges are permitted on a case-by-case basis, and thus, the classification should not unduly affect the permitting process, as the same environmental impact concerns need be raised with any waste.

The concern, however, is with the public perception of industrial waste as being toxic and perhaps hazardous. Public comment on impending permits is part of the permit approval process, and although this classification may help to support the definition and addressing of environmental impact, definition misconceptions and a lack of understanding have arguably disrupted and hindered the permitting process of a number of desalination projects in the United States.

The other part of this issue is that an improved understanding of the nature of concentrate, along with the benefits of research studies, will lead to a more effective and timely consideration of the environmental impacts and issuance of permits.

6.7 Studies to Develop Data for Discharge Permit Applications

6.7.1 Salinity Dispersion Modeling

The main purpose of the evaluation of the rate of concentrate dispersion from the point of discharge is to establish the size of the mixing zone required to dissipate the discharge salinity plume down to within 10% or less of the ambient water's TDS level and to determine the TDS concentrations at the surface, midlevel, and bottom of the water column in the mixing zone.

The TDS concentrations of the saline plume at these three levels are then compared to the salinity tolerances of the aquatic organisms inhabiting the surface (mostly plankton), the water column (predominantly invertebrates), and the bottom sediments of the receiving waterbody to determine the impact of the salinity of the concentrate discharge on these organisms.

The discharge salinity field in the mixing zone and the mixing zone boundaries are established using hydrodynamic modeling. The results from this modeling can be used to determine the most suitable location, design configuration, and size of the discharge outfall and diffusers if a new outfall is needed or to assess the feasibility of using the outfall facilities of an existing WRRF or power plant.

The model selected to identify the boundaries of the desalination plant discharge should be used to define the concentrate plume dissipation boundaries under a variety of outfall and diffuser configurations and operational conditions.

Evaluation of the concentrate dispersion and recirculation at large desalination plants usually requires a sophisticated discharge plume analysis and is completed using various computational fluid dynamics software packages tailor-made for a given application (Bleninger and Jirka, 2008; Cotruvo et al., 2010). The models most widely used in salinity plume analysis are CORMIX and Visual Plumes. Both models allow the depiction of the concentrate plume's dissipation under a variety of outfall and diffuser configurations and operational conditions. These models have been developed for and approved by the U.S. EPA for mixing zone analysis and the establishment of total maximum discharge limits. However, CORMIX and Visual Plumes are near-field models that do not account for the far-field mixing and advective processes associated with shoaling waves and coastal current systems. Therefore, discharge modeling is often extended beyond the near-field ZID using computational fluid dynamics software packages.

6.7.2 Discharge WET Study

WET testing is an important component of the comprehensive evaluation of the effect of the concentrate discharge on aquatic life. The completion of both acute and chronic toxicity testing is recommended at the salinity levels that may occur in the discharge under a worst-case combination of conditions. Use of at least one species endogenous to the targeted discharge is desirable.

In the case of concentrate discharge through an existing WRRF outfall, testing of at least one species of the echinoderms taxa (i.e., urchins, starfish, sand dollars, or serpent stars) is recommended, using a worst-case-scenario blend of concentrate and wastewater effluent (typically, the maximum wastewater effluent flow discharge combined with an average concentrate flow).

In the United States and Australia, the discharge permit (license) issued by the government regulatory agency in charge of surface discharges will typically include limitations or requirements based on WET test results: either a maximum TDS limit or dilution requirements. In the United States, WET bioassay testing is required, performed according to U.S.-EPA-approved protocols by certified laboratories, to assess the acute, chronic, and bio-accumulative toxicity to the receiving water biota. The bioassays use approved, pollutant-sensitive species.

Some BWRO plants in the United States have produced concentrates that fail WET limit tests. Most of such cases in Florida were associated with high calcium levels, and some were complicated by toxicity from high fluoride levels (Mickley, 2006). Toxicity caused by high levels of major ions is a correctable chemical imbalance, as opposed to toxic contamination by heavy metals or pesticides (Mickley, 2000). For this reason, Florida has exceptions for ion imbalance toxicity (i.e., major ion toxicity) when it is the only toxicity present in a concentrate. This toxicity occurs when major ion ratios in the concentrate differ significantly from those found in seawater or in dilutions or concentrations of seawater. Thus, the toxicity does not occur in SWRO concentrate but may occur when SWRO concentrate is blended with other non-seawater waters (see discussion in Section 3.4.2).

6.7.3 Concentrate Water Quality Characterization Study

Concentrate water quality is dependent on the source water quality, pre-treatment of the source water, and performance of the membrane treatment process. At early stages in the consideration of a desalination plant, projections of concentrate water quality are made using RO treatment simulation programs. Meaningful projections require good ambient seawater quality characterization; source water quality is a major consideration in the feasibility determination of desalination plants. As a project moves forward, accurate concentrate water quality characterization typically requires pilot plant study.

A concentrate water quality study involves the collection of concentrate samples from a pilot desalination plant and the laboratory analysis of these samples for the discharge water quality parameters established by pertinent regulatory agencies with jurisdiction over concentrate disposal. At a minimum, it is recommended that concentrate samples be collected under near-average source water quality conditions (i.e., annual average salinity, temperature, and turbidity) as well as at extreme conditions such as heavy rain events, algal blooms, dredging near the intake area, seasonal agricultural runoff events, and very low and high source water temperatures and salinities, which are typically seasonally dependent.

The pilot plant used to generate the concentrate samples should utilize the specific pretreatment(s) proposed and be operated at the same recovery, flux, and product water quality targets as would the planned full-scale desalination plant to collect representative samples. If possible, the same type of RO membrane elements should be used as well.

The concentrate water quality data collected from the sampling events should be compared against the numeric limits of the applicable regulatory requirements. Key parameters that should be given attention when assessing concentrate compliance with applicable numeric effluent discharge water quality standards are the quantity of TDS, metals, turbidity, and radionuclides. In addition, the concentrate toxicity needs to be evaluated via WET tests.

One important issue with all concentrate water quality analyses is that most of the laboratory analysis guidelines worldwide are developed for testing freshwater rather than for testing a high-salinity concentrate. The elevated salt content of the concentrate samples can interfere with the standard analytical procedures and can often produce erroneous results. Therefore, concentrate analysis must be completed by an analytical laboratory experienced with and properly equipped for brackish water and seawater analyses. The same recommendation applies to the laboratory retained to complete the WET testing and source water quality characterization; it must use techniques designed for saline water.

If pilot testing is not possible for a given project, the mineral content of the concentrate can be projected by characterizing the desalination plant’s source water quality at the operational conditions described previously and analyzing this data with software that projects RO membrane performance, available from all key manufacturers of membrane elements (e.g., Hydranautics, Toray, Dow-Filmtec). This software calculates the content of key ions in the concentrate based on the content of the same ions in the source water, the type of RO elements, and the main design criteria of the RO desalination system, such as recovery, membrane flux, and membrane age. It should be pointed out, however, that this concentrate water quality characterization method is less desirable than pilot testing, because the currently available membrane performance projection software does not have provisions to calculate the concentrations of most of the regulated metals, organics, and pathogens in the discharge.

6.7.4 Salinity Tolerance Evaluation Study

Determining the tolerance of aquatic organisms to the actual concentrate of the desalination plant may be beneficial because it could reduce the complexity of the plant's outfall structure, especially if the discharge area is inhabited by salinity-tolerant species.

Such studies are important because permit discharge limits should be based on scientific data. The new California salinity limit of 2 ppt above ambient level at the edge of the salinity mixing zone may be overly constraining and not reflective of the site-specific conditions and salinity tolerance of the flora and fauna in the discharge area. Salinity tolerance evaluations (STEs) are needed to define site-specific conditions.

A novel method to identify the salinity tolerance of the aquatic life in the area of a desalination plant's discharge was developed at the Carlsbad seawater desalination demonstration plant in California. This method includes the following four key steps: (1) determination of the test salinity range, (2) identification of site-specific test species inhabiting the discharge area, (3) a biometrics test at the average discharge salinity, and (4) salinity tolerance tests at varying levels of concentrate dilution.

6.7.4.1 Determining Test Salinity Range

The first step of the STE method is to define the minimum and maximum TDS concentrations that are projected to occur in the area of the discharge after the startup of desalination plant operations. This salinity range should be established by taking under consideration the effect of mixing and associated dilution in the area of the discharge as a result of the site-specific natural hydrodynamic forces in the receiving waterbody (currents, winds, tidal movements, temperature differences, etc.) as well as the mixing energy introduced by the desalination plant's discharge diffuser system. If the desalination plant's concentrate is diluted with another discharge (i.e., cooling water from a power plant or effluent from a WRRF) prior to its exit from the outfall into the surface waterbody, this additional dilution should also be accounted for when establishing the salinity range in which the salinity tolerance of the aquatic species will be assessed.

Because of the complexity of the various factors that impact the mixing and dilution of desalination plant concentrate with ambient surface water, especially for medium and large projects [i.e., projects with a discharge volume of 2.5 MGD (10,000 m^3/day) or higher], the actual salinity range that will occur in the area of the discharge should be determined based on hydrodynamic modeling (Jenkins and Wasyl, 2001; Einav and Lokiec, 2003).

At a minimum, the salinity test concentrations should range from that at the middle of the water column and the middle of the salinity mixing zone to the maximum bottom salinity concentration at the edge of the mixing zone (Jenkins and Wasyl, 2001).

6.7.4.2 Identifying Test Species

The second step of the STE method is to identify the most sensitive, site-specific species that are indicative of the salinity tolerance of the aquatic flora and fauna in the area of the desalination plant discharge. These species are used in the biometrics and salinity tolerance tests. At least three species should be selected for the tests: one representative of the fish population in the area, one of the invertebrate population, and one of the macro-algal population (e.g., kelp or red algae), if such species are present and occur in significant numbers (Chapman et al., 1995; California State Water Resources Control Board, 1996; Graham, 2004).

The selection of the specific test species should be completed by an expert aquatic biologist who is very familiar with the site-specific flora and fauna in the area of the desalination plant discharge. The test species should be selected based on (1) presence and abundance in the area, (2) environmental sensitivity (i.e., endangered or protected marine species are first priority), (3) sensitivity to salinity in the range projected to occur in the discharge, and (4) significance in terms of commercial and recreational harvesting or fishing.

In cases where environmentally sensitive species are also endangered or protected, it may be hard to use them as test species, and it is unlikely that testing protocols would be developed for such species. In this case, test species representative of the protected species (e.g., of the same genus) might be used.

Habitat characterization studies leading to the identification of sensitive, site-specific species for the selection of test species (as represented in Figure 5.1) also serve more generally to identify the environmental sensitivity of the proposed discharge area.

6.7.4.3 Biometrics Test

The purpose of the biometrics test is to track how well the indicative test species can handle long-term steady-state exposure to the elevated average discharge salinity that would occur in the middle of the mixing zone once the desalination plant is in operation. The biometrics test should be completed in a large aquarium (test tank) in which the desalination plant concentrate is blended with ambient water from the receiving surface waterbody (ocean, river, etc.) to obtain a salinity not to be exceeded in the middle of the mixing zone in the ocean for at least 95% of the time. This salinity level should be maintained in the aquarium for the duration of the biometrics test.

In addition, a second aquarium (control tank) containing the same size, number of, and type of test aquatic organisms should be employed; this tank should be filled with ambient water from the receiving waterbody, collected from the area of the discharge. The control tank should be operated in parallel with the test tank; observations from this tank will serve as a baseline for comparison and statistical analysis.

Once the salinity in the aquariums is set to the target level, they are populated with the selected test species, and key biometric parameters (e.g., appearance, willingness to feed, activity, and gonad production) of these species are monitored frequently (a minimum of every two days) by an expert marine biologist over a prolonged period of time (a minimum of three months; preferably five or more months). Percentage weight gain or loss and fertilization for one or more of the test and control organisms should be measured as well. At the end of the test, the qualitative and quantitative biometric parameters of the aquatic species in the test and control tanks should be compared to determine if the species exhibit statistically significant differences – especially in terms of weight gain or loss and fertilization capabilities.

6.7.4.4 Salinity Tolerance Test

The main purpose of the salinity tolerance test is to establish if the selected test species will survive the extreme salinity conditions that may occur within the mixing zone and on the edge of the mixing zone and if these test organisms will be able to retain their capacity to reproduce after exposure to these conditions for the length of time that is expected to occur during full-scale plant operation under worst-case-scenario conditions. The test species should be exposed to several blends of concentrate and ambient receiving surface water that may occur within the range of the discharge salinities. The low end of the range should be the average salinity in the mixing zone (mid-depth), and the high end should be the maximum salinity at the boundary of the mixing zone (near the seabed). In general, discharge salinity is expected to decrease with an increase of the distance from the point of concentrate discharge and to increase with depth. The rate of the decrease of the concentrate salinity from the point of discharge depends on the hydrodynamic conditions in the vicinity of the discharge.

Similar to the biometrics test, this experiment requires two sets of aquariums for each salinity concentration – a series of test tanks (one tank for each test salinity level) and a series of control tanks. The duration of the salinity tolerance test should be determined by the length of occurrence of the worst-case discharge salinity scenario. This duration should be established based on the results from the hydrodynamic modeling of the desalination plant discharge.

Usually, extreme salinity discharge conditions are not expected to continue for more than one to two weeks. However, if this is likely in specific circumstances, then the length of the study should be extended accordingly. Starting from the low end of the salinity concentrations, individual test tanks should be set using salinity increments of 1 to 2 ppt until the maximum test salinity concentration is reached.

Chapter 7

U.S. State-Specific Discharge Regulations

7.1 Introduction

As discussed in Section 5.2, federal regulations generally establish the minimum requirements for NPDES discharge permits. However, states have some latitude in determining how to implement U.S. EPA guidance. Consequently, the regulation of surface water discharge varies significantly from state to state. Examples of NPDES regulation varying from state to state include the following:

- the automatic inclusion of mixing zones in initial permit feasibility determinations (e.g., Texas) as opposed to mixing zones being granted on a case-by-case basis (e.g., Florida and California)
- the definition of mixing zone parameters
- the automatic inclusion of WET tests for municipal membrane concentrate (e.g., Florida) versus inclusion on a case-by-case basis (e.g., Texas)
- different water quality standards (although all must be at least as stringent as the federal guidelines)
- different degrees of implementation of total maximum discharge limit development

In this chapter, regulations from California, Florida, and Texas are discussed along with case studies of permitting associated with the Carlsbad (under construction) and Huntington Beach (not yet constructed) desalination plants in California and the Tampa Bay Desalination Plant in Florida.

7.2 State-Specific Discharge Regulations

7.2.1 California

7.2.1.1 Regulatory Bodies Involved in Permitting

The state of California is delegated to oversee the NPDES program. The California State Water Resources Control Board (SWRCB) is one of six branches of the California Environmental Protection Agency. The SWRCB's mission is to preserve, enhance, and restore the quality of California's water resources and to ensure their proper allocation and efficient use for the benefit of present and future generations. Issuance of NPDES permits is by the nine Regional Water Quality Control Boards (RWQCBs).

The California regulatory system that comes into play when municipal desalination facilities are planned, developed, and implemented is complicated. Considering all the permits required for the plant, there are many different agencies and groups that are involved in permitting. Only a few actually issue permits, but the others are involved in granting approvals.

The California Coastal Commission (CCC) is a state agency that has quasi-judicial regulatory oversight over land use and public access in the California coastal zone within 5 miles of the shore; their main mission is "To protect, conserve, restore, and enhance the environment of the California coastline." In partnership with coastal cities and counties, the CCC plans and regulates the use of land and water in the coastal zone. For SWRO desalination, the CCC is the main regulatory agency in California and has a strong position in reviewing and approving permits relating to desalination facilities. On review and approval of all major permits, it may issue a coastal development permit. In this role, the CCC held up the final approval and implementation of some NPDES permits until after the promulgation of the latest version of the California Ocean Plan, which occurred in May 2015.

The CCC review process has resulted in measurable delays in the permitting of all medium and large SWRO desalination projects in the state. For example, the RWQCBs and other regulatory bodies completed their reviews and issued permits within a reasonable time of six to nine months for the 50-MGD (189,000-m^3/day) Carlsbad project, but it took the CCC more than three years to complete their review. As of yet, this agency has not issued a permit for the 50-MGD Huntington Beach Desalination Project (after more than 10 years of reviews). So far, besides the coastal development permit for the Carlsbad SWRO plant, the CCC has issued only one other permit for a full-scale SWRO facility in California – the 0.6-MGD (2300-m^3/day) Sand City Desalination Project.

The CCC does not have numeric standards that allow it to directly quantify environmental impacts and measure their compliance; instead, the CCC uses general policies and precedents during the permitting process that in most cases result in a significant increase in desalination project permitting time and project costs.

The main issues that have prolonged the permitting process of all medium and large desalination projects in California are associated with the desire of the CCC to:

- push the SWRO project proponents towards the use of subsurface intakes;
- discourage low-cost desalination solutions such as the co-location of desalination plants with power plants or other facilities with onshore outfalls because of their impact on the coastal environment, mainly the impingement and entrainment of marine species by the plant intakes;
- require extensive mitigation measures for the impingement and entrainment impacts of desalination plants with open intakes; and
- make compulsory the development of complex carbon footprint mitigation plans for all medium and large desalination projects in California.

The Ocean Unit of the SWRCB is responsible for the development and updating of statewide water quality control plans, policies, and standards involving marine waters. This includes the California Ocean Plan, the California Thermal Plan, and the development of sediment quality objectives in bays and estuaries. The unit is also responsible for providing scientific support to the regional water boards and inter-agency coordination regarding marine pollution and resource management issues.

Because several new desalination facilities have been planned along the California coast to augment existing water supplies, desalination facilities and concentrate disposal were identified as Issue Number 4 in the 2011-2013 Triennial Review Workplan of the California SWRCB.

As a result, the regulatory bodies have been actively researching both intake and discharge issues and developing new regulatory policies and implementation standards as part of a desalination amendment. The SWRCB staff released the proposed Desalination Amendment and Draft Staff Report in July 2014. Part of the reason for the update of the Ocean Plan and the addition of the Desalination Amendment is to give direction to the RWQCBs regarding the requirements for the permitting of new, expanded, and conditionally permitted desalination facilities, thus simplifying the cumbersome permitting process. The SWRCB promulgated the Ocean Plan amendment in May 2015 (SWRCB, 2015a). The implemented amendment includes components that:

- clarify the SWRCB's authority over desalination facility intakes and discharges;
- provide direction to the regional water boards regarding the determination required by California Water Code Section 13142.5, Subdivision (b) [hereafter 13142.5(b)];
- include implementation provisions for a statewide narrative receiving water limitation for salinity, and an option for dischargers to apply for a facility-specific receiving water limitation; and
- include monitoring and reporting requirements.

As part of the development of the amendment, the SWRCB staff completed four studies to gather scientific data and get technical input and scientific recommendations on key desalination issues. The four studies, which included three expert panels and a salinity toxicity study, were as follows:

- Expert Panel II on Intake Impacts and Mitigation
- Expert Panel III on Intake Impacts and Mitigation
- Salinity Toxicity Studies
- Expert Panel I on Impacts and Effects of Brine Discharges

The third and fourth studies in the list affect brine discharge.

Salinity Toxicity Studies: Researchers at the Marine Pollution Studies Laboratory at Granite Canyon determined the tolerance of Ocean Plan test species to various concentrations of hyper-saline brine. Toxicity tests followed U.S. EPA methods. The results of the tests were used to calculate a no-observed-effect concentration, a lowest-observed-effect concentration, and a median lethal or median effects concentration for each test protocol and endpoint. Toxicity tests were also conducted using brine effluent samples from a desalination facility.

Expert Panel I on Impacts and Effects of Brine Discharges: The SWRCB contracted with the Southern California Coastal Water Research Project to establish a panel of experts in the fields of oceanography, plume modeling, ecotoxicology, and marine ecology to answer the following questions related to brine discharge:

- What are the potential environmental impacts?
- What disposal strategies will minimize impacts from brine discharges?
- What models should be applied to predict how brine plumes will behave?
- Can cumulative water quality effects associated with multiple brine plumes be evaluated with models?
- What are appropriate monitoring strategies for brine discharges?

As a result of this effort, changes were made in brine discharge regulations.

The expert panel's report (Jenkins et al., 2012), however, was not a consensus document and raised important research issues that should be taken into consideration in developing a policy on regulating the salinity of discharges. Review of the report by independent consultants (SWRCB, 2015b) also reflected varying opinions on the issues discussed in the report. In spite of this situation, it appears the SWRCB pushed for a simple formula and adopted a position that was not necessarily recommended by the researchers.

7.2.1.2 California Ocean Plan

In May 2015, the State Water Quality Control Board of California promulgated an updated California Ocean Plan that contains additional requirements specifically targeting desalination projects. This latest California Ocean Plan (SWRCB, 2014a) contains a separate section entitled "Implementation Provisions for Desalination Facilities" that introduces a host of new regulatory requirements and constraints associated with the development of seawater desalination plants in the state. It is interesting to note that these requirements are explicitly referenced to apply only to seawater desalination facilities and that other plants, such as brackish water or water reclamation plants, are not governed by its requirements. The key new requirements include several significant constraints on the development of new seawater desalination projects:

- The compulsory use of subsurface intakes for the collection of source seawater for desalination plants to minimize impingement and entrainment of marine organisms. Open ocean intakes are allowed only if the use of subsurface intakes is not found feasible. Because currently available subsurface (well and infiltration gallery) intake technologies limit the size of desalination plants to within 10 to 20 MGD (37,850-75,700 m^3/day), such a measure indirectly limits the size of future desalination plants in California to small and medium and practically precludes the development of large facilities (more than 25 MGD or 95,000 m^3/day) that can bring a significant economy of scale to the costs of desalinated water.

- A requirement for impingement and entrainment mitigation measures in cases where open ocean intake is used. The Ocean Plan prescribes a specific method for the determination of the mitigation measures that is known to yield the most conservative requirements for the size and complexity of the mitigation measures. Such measures are expected to add 5 to 15% in additional construction, operation, and maintenance costs to new desalination projects.

- The discouragement of the co-location of desalination plants and power generation stations, which is intended to phase out the use of the open intakes and discharges of existing power plants along the Pacific Ocean shore and to require the reconsideration of the operation of existing co-located desalination plants when the power plants with which they are co-located permanently close their operation. Such a measure eliminates the most cost-effective desalination plant configuration, where the construction costs of the desalination plants are reduced by 10 to 20% by using the intakes and outfalls of existing power plants.

- A requirement for the co-disposal of desalination plant and WRRF discharges, whenever possible and practical, to avoid the construction of new ocean outfalls and to avoid the use of existing power plant outfalls. Such a requirement also limits the size of future desalination plants to small and medium capacity because WRRF s have a limited existing discharge capacity and because the mixing of the two discharges may require modifications of the WRRF outfalls to accommodate the heavier desalination plant concentrate. Such modifications may be difficult or practically impossible to implement because WRRF operation might need to be discontinued for a significant period of time while outfall modifications are completed. In addition, the wider reuse of wastewater effluent, which is encouraged by the state, will leave very limited volumes for concentrate dilution, which will indirectly marginalize desalination and reduce the size of future seawater desalination plants.

- A requirement for the desalination project proponents to assess the mortality of marine organisms caused by the operation of the outfall because of the high velocity of the outfall discharge and the physical damage such discharge can cause to marine larvae and adult marine organisms inhabiting the outfall. Although such damage has not been observed or documented for wastewater discharges, where diffusers could destroy marine organisms because of the same forces and mechanisms, the regulations have stipulated that such damage be assessed for seawater desalination plant discharges in an obvious attempt to minimize and discourage the development of new desalination projects.

- A requirement that, if loss of marine organisms is found that is due to damage caused by the operation of the desalination plant outfall, the proponent of the desalination plant mitigate such loss via complex and costly mitigation measures. It is interesting to note that WRRF s and water reclamation facilities are not required to determine and mitigate discharge damages caused by their operations.

- A requirement that the desalination plant discharge salinity at the edge of the mixing zone be lower than or equal to 2 ppt above the ambient water salinity. However, such requirement could be relaxed (i.e., the salinity discharge limits could be increased) if the project proponent completes site-specific studies proving that a higher salinity limit is warranted.

The additional California Ocean Plan requirements listed previously are likely to significantly hinder the development and implementation of new desalination plants in California and are unique in terms of the severity of the constraints they impose on the projects.

In California, there are many large water reclamation plants that discharge their highly concentrated waste streams into the Pacific Ocean. Although the newest version of the California Ocean Plan addresses concerns associated with SWRO concentrate discharge, it does not address similar concerns associated with the discharge of highly environmentally damaging substances such as endocrine disruptors (e.g., pharmaceuticals, personal care products, contraceptives) from water reclamation plants. As water reuse in the state is promoted and maximized, the concentration of endocrine disruptors discharged in the marine environment will increase. Many of these compounds are biologically damaging and therefore dangerous to aquatic life. The focus in the California Ocean Plan update given to SWRO concentrate discharge and the non-focus on WRRF discharge is difficult to understand. It appears that desalination projects are being made more complicated to permit and that water reclamation projects are promoted by less stringent permitting requirements not based on actual or relative environmental damage. If this is an intentional state policy to promote water reuse and suppress the development of desalination, it is unique worldwide. No other state or county worldwide has a similar "double standard" regarding environmental regulations.

7.2.1.2 Regulations Governing Concentrate Management in California

California policy regarding mixing zones was discussed in Section 5.4.2. Present regulations via the *California Ocean Plan* (CSWCRCB, 2012) establish a daily maximum acute toxicity receiving water quality objective of 0.3 acute toxicity units (TU_a). Requirement III.C.4(b) of the *California Ocean Plan* designates that this objective of 0.3 TU_a applies to ocean waters outside the acute toxicity mixing zone.

Despite the fact that environmental impacts associated with concentrate salinity are indirectly regulated through site-specific acute and chronic WET objectives, the discharge permits for some of the existing seawater desalination plants in the United States also contain specific numeric salinity limits (see Table 7.1).

The Carlsbad Project NPDES discharge permit, for example, contains an effluent limitation for chronic toxicity at the edge of the ZID in combination with numeric limitations for average daily and average hourly TDS (salinity) concentrations of 40 ppt and 44 ppt, respectively. These salinity limits were established based on a site-specific salinity tolerance study and on chronic and acute toxicity testing completed for this project (City of Carlsbad, 2005). The referenced limits are applicable to the point of discharge and are reflective and protective of the acute toxicity effect of the proposed discharge.

The 50-MGD (189,000-m^3/day) Huntington Beach SWRO Project's NPDES permit also contains a limit for chronic toxicity but does not contain numeric limits for salinity. Instead, the potential acute toxicity effect of the discharge is limited by a ratio of the daily discharge flow from the desalination plant and the power plant intake cooling water flow, which provides dilution to the concentrate. This dilution ratio requirement effectively provides a limit to the salinity discharge from the desalination plant of 40 ppt and is derived from a site-specific analysis of the conditions of the discharge at this project.

7.2.1.3 Key Permits and Permitting Agencies

At present in California, five permits and approvals associated with concentrate discharge from a host of regulatory agencies at different levels are typically required to implement a desalination project. The key permit for a desalination plant discharge is the NPDES permit issued by a RWQCB, presently with some oversight by the CCC. The main permits and approvals include:

- a Coastal Development Permit,
- an NPDES or Waste Discharge Permit (under the federal CWA),
- a State Lands Commission Permit,
- a Certification of Environmental Impact Assessment, and
- approvals from the National Coast Guard and the National Marine Fisheries Service.

In addition, the desalination project has to obtain approvals from various local jurisdictions such as the fire department, city and county planning departments, etc.

Table 7.1. Examples of Desalination Plant Discharge Limits.

Desalination Plant	Total Flow [MGD (ML/d)]	TDS (Average) (ppt)	TDS (Max.) (ppt)	Acute Toxicity (TU$_a$)	Chronic Toxicity (TU$_c$)	Dilution Ratio
Carlsbad 50 MGD (189 ML/d); 33.5 ppt TDS source; 67.0 ppt TDS conc.	54/60.3 (204/228)	40 (daily) (19.4% above ambient)	44 (max. hourly) (31.3% above ambient)	0.765	16.5	mixing zone 15.1:1
Huntington Beach 50 MGD (189 ML/d); 33.5 ppt TDS source; 67.0 ppt TDS conc.	56.59 (214) (conv. pretreat)	none	none	none	8.5	mixing zone 7.5:1; min. dilution 2.24:1
Tampa 25 MGD (95 ML/d); 26 ppt TDS source; 43 ppt TDS conc.	22.8 (86) (conv. pretreat)	35.8 (38% above ambient)	35.8 (38% above ambient)	none	none	dilution 28.1 (20:1 min.)

Notes: 1 part per thousand (ppt) = 1000 mg/L; TU$_a$ = acute toxicity unit; TU$_c$ = chronic toxicity unit; max. = maximum; min. = minimum; conv. = conventional; conc. = concentration

7.2.2 Florida

7.2.2.1 Regulatory Bodies Involved in Permitting

Florida is delegated to oversee the NPDES program. The Florida Department of Environmental Protection (FDEP) has jurisdiction over public water supplies, including desalination plants, that are producing potable water, and NPDES permits are issued by the six district offices.

As in California, in addition to permitting through the FDEP, other agencies may have either regulatory jurisdiction or review and commenting authority over desalination plants. Although no specific permits may be necessary from these agencies, it is important to consider their jurisdiction and authority during the initial planning stages of a desalination plant, such as site selection. Permit decisions related to brine discharge, however, are made by the FDEP without the possibility of permits being held up by the prerequisite approvals of other agencies, as is the case in California with the CCC.

7.2.2.2 Existing Regulations Governing Concentrate Management

Chapter 403, Florida Statues, encourages the development of alternative water supplies using desalination technology, and pursuant to Chapter 403, Florida Statues, the FDEP promulgated rules regulating desalination plants and the management of desalination brine. Found in Chapter 62, Florida Administrative Code, these rules address the following issues related to desalination plants:

- the permitting process (Rule 62-4)
- brine and concentrate discharge to surface waters (Rule 62-4-200)
- discharge quality and toxicity requirements (Rule 62-4-244)
- guidelines for the testing of receiving waters (Rule 62-246)
- surface waters and water quality standards (Rules 62-301, 302)
- groundwater classes, standards, and exemptions (Rule 62-520)
- underground injection control (Rule 62-528)
- drinking water standards, monitoring, and reporting (Rule 62-550)
- reclaimed water blending and land application (Rule 62-650)
- industrial wastewater facilities (Rule 62-660)
- the effective ban on co-discharge with wastewater discharges (Florida Statutes, Title XXIX, Chapter 403, Section 086)

The FDEP has also created a streamlined authorization process for small utilities that use a desalination process that presents minimal environmental risk.

To provide further incentives for the use of desalination and other alternative water supplies, the Florida Legislature passed Senate Bill (SB) 364, which creates longer duration consumptive use permits for alternative water supplies. The bill requires the issuance of a permit duration of at least 30, and possibly as long as 37, years for such facilities.

The Florida Legislature has thus taken steps to support and promote the use of desalination technology as an alternative water source with certain permitting incentives (FELB, 2013).

7.2.2.3 Key Permits and Permitting Agencies

The key permit is the NPDES permit issued by the six regional district offices of the FDEP.

7.2.3 Texas

7.2.3.1 Regulatory Bodies Involved in Permitting

Texas is delegated to oversee part of the NPDES program. The permit appropriate for discharging desalination brine, called the Texas Pollutant Discharge Elimination System (TPDES) permit, is issued by the Texas Commission on Environmental Quality (TCEQ).

7.2.3.2 Existing Regulations Governing Concentrate Management

Water quality standards and criteria for TPDES (NPDES) permits are found in Title 30 of Texas Administrative Code entitled Environmental Quality. Section 307 addresses surface water quality standards, and Section 308 addresses criteria and standards for an NPDES. A guidance document entitled “Procedure to Implement Texas Surface Water Quality

Standards" was updated in February 2014. The document has yet to be approved by the U.S. EPA, and thus, at present guidance is found in the 2010 document of the same name.

There are no numeric criteria for SWRO brine discharge. The guidance document (p 180) provides narrative such as

> Tidal waters will be protected from the adverse effects of excessively high or excessively low salinities (compared to the normal salinity range of the receiving water). The absence of numerical criteria will not preclude evaluations and regulatory actions to protect estuarine salinity.

Texas Administrative Code Section 307.4(g) applies to salinity:

> (1) Concentrations and the relative ratios of dissolved minerals such as chloride, sulfate, and total dissolved solids must be maintained such that existing, designated, presumed, and attainable uses are not impaired.
>
> (2) Criteria for chloride, sulfate, and total dissolved solids for classified freshwater segments are specified in Appendix A of §307.10 of this title.
>
> (3) Salinity gradients in estuaries must be maintained to support attainable estuarine dependent aquatic life uses. Numerical salinity criteria for Texas estuaries have not been established because of the high natural variability of salinity in estuarine systems, and because long-term studies by state agencies to assess estuarine salinities are still ongoing. Absence of numerical criteria must not preclude evaluations and regulatory actions based on estuarine salinity, and careful consideration must be given to all activities that may detrimentally affect salinity gradients.

Some effort has been made to address BWRO discharge permitting but not SWRO discharge permitting: working with a Texas Water Development Board project team, TCEQ created a new staff guidance document, detailing the streamlined process to use computer modeling in lieu of on-site pilot studies for BWRO treatment for secondary contaminants from a groundwater source. However, because the computer models do not model for biological contaminants, sources deemed to be groundwater under the influence of surface water are excluded from this process.

7.2.3.3 Key Permits and Permitting Agencies

TPDES (NPDES) permits are issued by TCEQ.

Chapter 8

U.S. State Permitting Case Studies

8.1 Carlsbad Case Study

8.1.1 Facility Description

The facility, presently under construction and to be completed in 2016, is located in southern California. It is called the Carlsbad Desalination Project (CDP) and is on a 6.8 acre parcel within the site of the Encina Power Station (EPS). The EPS steam generators are cooled by a once-through seawater flow system. The warm cooling water from all condensers is directed to a common discharge tunnel and lagoon leading to the ocean. The desalination facility taps into this discharge tunnel both for desalination plant feed water and for discharging high-salinity concentrate downstream of the intake area. A total of 100 MGD (378,500 m^3/day) of EPS cooling water effluent will be diverted to the CDP as source water for treatment.

An average daily flow of 50 MGD (189,000 m^3/day) of potable freshwater will be produced by the CDP. Treatment processes at the CDP will consist of conventional granular media pretreatment, RO desalination, and product water disinfection and stabilization. The facility will have 13 RO trains (racks) operating in parallel at the facility with a combined installed maximum capacity of 54 MGD (204,000 m^3/day). Under normal operating conditions, one RO unit at a time is expected to be offline for membrane cleaning or maintenance.

The 50 MGD (189,000 m^3/day) of potable freshwater produced by the CDP will be delivered to San Diego County Water Authority's Twin Oaks WWTP for distribution to the regional water distribution system for San Diego County water agencies. The production of 50 MGD (189,000 m^3/day) of potable freshwater would result in the generation of an average of 54 MGD (maximum flow estimated to be 60.3 MGD or 228,000 m^3/day) of combined filter backwash water and concentrated saline wastewater that would be discharged back into the EPS cooling water discharge channel for discharge to the Pacific Ocean.

The granular media filtration step will use ferric chloride or ferric sulfate to enhance the removal of particulate matter. These added chemicals will be backwashed, collected in a sedimentation basin (clarifier), removed as waste sludge, and disposed of at a landfill. The RO process will generate membrane backwash cleaning solutions, which will be collected in a separate tank, neutralized for pH value, and discharged to the sanitary sewer system. The backwash supernatant from the granular media filtration pretreatment will be directed to the EPS discharge channel, or it will be partially recirculated to the plant inlet.

Figure 3.3 shows a schematic of the Carlsbad Desalination Plant and its co-located configuration with the power plant. This was the first large SWRO desalination project permitted in California, and the permitting process for this project established a precedent for the permitting of all SWRO desalination projects in California. The permitting process included a detailed source water quality and concentrate characterization, followed by a salinity tolerance study for the marine species specific to the discharge area and a hydrodynamic concentrate dispersal study to determine the level of mixing of the concentrate and ambient seawater that has to be achieved in the ZID of the concentrate. The results of the hydrodynamic concentrate dispersal study, the salinity tolerance study, and the WET testing of the discharge-ambient-water mix at the mixing ratio determined by hydrodynamic modeling were used by the regulatory agencies to determine a project-specific mixing ratio and maximum TDS discharge requirements for the project, which were incorporated in the plant's NPDES discharge permit.

This permitting process is not unique to the Carlsbad SWRO Desalination Project. The same permitting activities were implemented for the Huntington Beach SWRO Desalination Project in California, the West Basin Desalination Project in California, and the Tampa Bay SWRO Project in Florida. Practically identical permitting processes were applied for all large desalination projects in Australia and Europe as well.

The most recent amendment of the California Ocean Plan has introduced a "blanket" non-site-specific limit of 2.0 ppt for a daily maximum salinity increment over the natural background ocean water salinity (determined from historical data) at the edge of the mixing zone. Because such a prescriptive "one-size-fits-all" limit is overly restrictive and is not reflective of the site-specific aquatic environment in the area of a plant discharge, it is very likely that proponents of large desalination projects in the future will pursue the opportunity included in the California Ocean Plan and similar regulations in other states to establish a site-specific limit for the conditions of their respective projects.

Most likely, the blanket maximum salinity limit in the California Ocean Plant will be used only for smaller desalination projects, where investment in site-specific studies is not economically viable and where the salinity impacts are minimal and achievement of the prescriptive limit will be possible without a significant cost burden to the project.

8.1.2 Receiving Water Characterization

The blend of power plant cooling water and desalination plant concentrate is discharged into a small lagoon from which it is directed to an open channel extending approximately 700 ft offshore (see Figure 8.1).

The discharge area of the Carlsbad SWRO Desalination Project is an "underwater desert" with a very limited presence of marine organisms. As indicated in the comprehensive marine tolerance study completed for the permitting of this project (Voutchkov, 2012), all marine species inhabiting the discharge area (e.g., sea urchins, sea stars, abalone, red rock crab, sand dollars) are tolerant to the salinity of the discharge.

8.1.3 Description of Discharge Streams

The discharge consists of concentrate and backwash (clarifier supernatant) from the granular media filtration step. More than 94% of the total plant discharge will be concentrate and 4 to 6% will be spent pretreatment backwash water. Membrane backwash cleaning solutions will be sent to the sanitary sewer. Waste sludge from the granular media filtration step and spent filter cartridges will go to the landfill.

Figure 8.1. Carlsbad Desalination Plant Showing Discharge Location.

Plant concentrate is projected to have a salinity of 60 to 68 ppt; it will be diluted down to 40 ppt or less by either using cooling water from the EPS or (if and when power station operation is discontinued) using raw intake seawater. The plant's spent filter backwash has a salinity identical to that of the source seawater.

The provision to use raw intake seawater for dilution during stand-alone operations of the desalination plant was found to be less costly and environmentally intrusive than the modification of the existing outfall structure or construction of a new outfall. The use of intake source water for dilution was allowed under the existing desalination plant NPDES permit.

8.1.4 Description of Plant Outfall

The facility will discharge an average of 54 MGD (204,000 m^3/day) of RO concentrate and filter backwash to the Pacific Ocean via the EPS discharge channel. The EPS discharge channel is owned and operated by Cabrillo Power I LLC, the owner and operator of the EPS. Prior to discharging into the receiving water, the facility's discharge will combine with EPS effluent in the discharge channel. EPS cooling water flow averages approximately 576 MGD (2,180,000 m^3/day) and exceeds 304 MGD (1,151,000 m^3/day) more than 99% of the time. Because the CDP is expected to use 100 MGD (378,500 m^3/day) of the EPS cooling water as source water, the 54-MGD (204,000-m^3/day) average discharge from the CDP is expected to combine with an approximate average discharge flow of 476 MGD or 1,802,000 m^3/day (and greater than 204 MGD or 772,000 m^3/day for 99% of the time) from the EPS prior to discharge into the Pacific Ocean. Water collected from one end of the power plant discharge canal will be conveyed to the desalination plant to produce freshwater, and the concentrate from the desalination plant will be returned into the same discharge canal, approximately 810 ft (270 m) downstream from the point of intake. The desalination plant concentrate, containing approximately two times the salinity of the source seawater (68 ppt vs. 33.5 ppt), will be blended with the remaining cooling water discharge of the power plant and conveyed to the ocean for disposal.

The salinity range of the mixed discharge from the CDP and the power plant will be between 35 and 40 ppt. The average salinity in the middle of the salinity mixing zone is projected to be 36.2 ppt. Therefore, the biometrics test was completed for this average salinity, and the test range for the salinity tolerance test was 37 ppt to 40 ppt in 1 ppt increments. Both tests were executed by a marine biologist very familiar with the local flora and fauna in the area of the future desalination plant discharge (Le Page, 2004).

The current EPS NPDES permit (Order No. 2000-03) assigns an initial dilution of 15.5:1 for the existing EPS discharge. The combined CDP and EPS effluent is expected to be denser and to sink through the water column, increasing the amount of mixing that occurs as a result of the lack of buoyancy. Based on modeling performed by the discharger, average day conditions from 1980 through 2000 project an initial dilution of 70:1. The modeling results further indicate that initial dilutions under the conditions of the worst-case month, for any single month of the year, at the edge of the salinity mixing zone, will exceed 20:1. The worst-case month dilution is typically used as the dilution applied for WQBELs by the regional water board. Theoretical extremes for heated and unheated flow resulted in more conservative dilution factors (12:1 and 7.1:1, respectively); however, the application of these values is not practical and considered overly stringent because these scenarios are based on theoretical extremes that have not been demonstrated to occur and have a probability of occurrence of less than 0.01%.

The discharger has demonstrated to a high degree of certainty, through a comprehensive data collection and modeling effort, that the applicable worst-case month dilution will be approximately 20:1. However, because the modeling effort is based on a theoretical temperature and salinity of the combined CDP and EPS effluent, the more conservative dilution credit of 15.5:1 shall continue to be applied for this outfall at the edge of the mixing zone. The permit may be reopened by the regional water board to re-evaluate the initial dilution at the outfall when actual CDP and EPS effluent data is available.

During initial startup operations and immediately before or after certain on-site maintenance operations, it may be necessary to temporarily return all or a portion of the filtered pretreated seawater back into the EPS effluent channel instead of routing the filtered seawater flow to the RO units. Also, during such startup periods or periods when it is not feasible to deliver product water to the regional potable water system, it may be necessary to temporarily discharge product water from the RO process back into the EPS effluent channel.

During such temporary periods, the discharger is required to conduct additional monitoring, and the maximum allowable flows returned to the ocean shall not exceed 120.6 MGD (456,000 m^3/day). The flow and salinity of the additional CDP effluent under operating conditions when either pretreatment process water or RO product water is directed back into the EPS effluent channel would be identical to the flow and salinity of the source water directed to the CDP during such temporary periods. Therefore, no water quality impacts would occur as a result of such temporary process water diversions.

8.1.5 Key Discharge Permits and Permit Requirements

The key discharge permit for this facility is the plant NPDES discharge permit, which pertains to the disposal of concentrate and other waste streams from the desalination plant. The permitting process for this project continued for more than five years and involved the development and certification of a project Environmental Impact Report (EIR) as well as the submittal of the NPDES permit application and permit review through seven sets of requests for additional information, mainly by the CCC.

To support the EIR review and permitting process, the project proponent, Poseidon Resources, completed the following activities:

1. Collected monthly samples of intake source seawater for a period of two years (2002-2004) to analyze the seawater in terms of all parameters regulated by the CWA and included in the NPDES permitting process as well as all parameters of the Safe Drinking Water Act.
2. Completed a sanitary survey from 2004 to 2005 to identify and quantify all potential sources of pollution of the intake source water quality within a two-mile radius from the point of intake. This sanitary survey involved source water quality sampling and an inventory of potential point and non-point sources of pollution of the source water located within the two-mile radius.
3. Installed and operated a 27,000-gpd pilot SWRO plant for more than 5 years to generate concentrate and test the proposed key desalination technologies, including pretreatment, SWRO system, and post-treatment facilities. The plant was operated during a series of extremely high intensity (50-year repeatability) algal blooms that occurred along the California coast in the summer of 2005. Toxicity testing of the concentrate during this period showed that even in extreme algal bloom conditions, the plant discharge was safe for the aquatic life in the vicinity of the discharge.
4. Completed a detailed chemical characterization and analysis of the concentrate generated by the pilot plant as well as of all other waste streams, including the spent filter backwash water and spent clean-in-place (CIP) chemicals generated from the cleaning of the SWRO membranes. This information was needed to prepare the NPDES permit application.
5. Completed acute and chronic WET testing of several blends of concentrate and discharge water from the power plant to determine the impact of the desalination plant discharge on standard test marine organisms defined and approved by the San Diego RWQCB.
6. Completed hydrodynamic modeling of the desalination discharge dispersion for several operational conditions with varying power plant discharge blending flows and ambient seawater factors influencing the mixing of the concentrate and power plant discharge with the ambient seawater, including wave action, tides, wind, currents, and seasonal salinity variations.
7. On the basis of the results from the hydrodynamic modeling and the WET testing, completed a salinity tolerance study under the supervision of the SCRIPPS Institute of Oceanography and under the scope and conditions approved by the San Diego RWQCB. The salinity tolerance study was completed on species inhabiting the discharge area of the desalination plant and representing aquatic fauna sensitive to elevated salinity

impacts. The results of the study were used by the RWQCB to establish the site-specific average and maximum salinity limits for this project, which were conservatively established at levels of 40 and 42 ppt, respectively.

8. Completed a detailed 12-month impingement and entrainment study to assess the impact of desalination plant operation on the loss of marine life. The study was extended to capture conditions of the collection of source water both during power plant operation and during times when the power plant was down to determine the impingement and entrainment impacts of the desalination plant.

The studies listed previously were used in the preparation of the project EIR and NPDES application. The NPDES application process was commenced after the EIR was certified. The NPDES permit was issued after a six-month review process. However, the overall project implementation process was delayed by the series of requests for additional information by the CCC, which mainly pertained to such issues as the mitigation of the loss of marine life that is due to impingement and entrainment, the cost and energy use of the production of desalinated water, the carbon footprint of the desalination plant operations, and feasibility studies for the use of alternative intakes to minimize impingement and entrainment impacts. The CCC did not challenge the NPDES discharge permit conditions and was supportive of all the work completed to determine the salinity tolerance of the local flora and fauna.

The NPDES permit for the CDP was issued by the San Diego RWQCB. The NPDES permit, CA0109223, dated 2006, had an initial expiration date of 2011. The permit was amended in May 2009 to accommodate stand-alone operations of the desalination plant, which would occur when and if the EPS discontinued operation in the future; it was again amended in May 2010 to address the right of the project sponsor, Poseidon Resources, who is the owner of the project at present, to transfer ownership of the plant and permit obligations in the future to the San Diego County Water Authority. At present, the permit expires in May 2016. The RWQCB has reserved the right to reopen the permit after the new California Ocean Plan is promulgated (it was signed into law on May 6, 2015) or after the EPS permanently shuts down its operation. The numerical limitations and monitoring requirements from the NPDES permit are summarized in Table 8.1.

The numerical limits are for Discharge Point 001, which is the desalination plant discharge into the EPS discharge channel. In addition to the numerical limits, there are narrative discharge prohibitions, discharge specifications, and receiving water limitations (temperature, bacterial characteristics, chemical characteristics, physical characteristics, and biological characteristics). The monitoring and reporting requirements are contained in Attachment E of the NPDES permit. These requirements are for all regulated parameters and all parameters or constituents having performance goals.

Constituents that do not have reasonable potential or had inconclusive reasonable potential to cause environmental impacts are referred to as performance goal constituents and assigned the performance goals listed. Performance goal constituents are required to be monitored, but the results will be used for informational purposes only, not for compliance determination.

Table 8.1. Numerical Effluent Limitations and Performance Goals for CDP.

Effluent Limitations – Desalination Discharge

Parameter/Constituent	Units	MAX Daily	Average Monthly	Average Weekly	Instantaneous MIN	Instantaneous MAX
Maximum flow, median filtration	MGD		54			
TSS	mg/L		60			
pH	Standard units				6	9
Oil and grease	mg/L		25	40		75
Settleable solids	ml/L		1	1.5		3
Turbidity	NTU		75	100		225
Chronic toxicity	TU	16.5				

Effluent Limitation – Combined Discharge

Parameter	Units	Average Daily	Average Hourly
Salinity	ppt	40	44

Performance Goals based on the California Ocean Plan

Parameter/constituent	Units	MAX Daily	Average Monthly	Average Weekly	Instantaneous MIN	Instantaneous MAX	6-Month Median
10 metals	µg/L	X*				X*	X*
Cyanide	µg/L	66				165	16.5
Total residual chlorine	µg/L	132				990	33
Ammonia nitrogen	µg/L	39,600				99,000	9,900
Acute toxicity	TU	0.765					
Phenolic compounds (non-chlorinated)	µg/L	1980				4,950	495
Phenolic compounds (chlorinated)	µg/L	66				165	16.5
Endosulfan	µg/L	0.297				0.446	0.148
Endrin	µg/L	0.066				0.099	0.033
HCH	µg/L	0.132				0.198	0.066
Radioactivity**							
62 others (few metals, mostly organics)	µg/L		X*				

*The X entries all have different numerical limits – in total too numerous to list

**Not to exceed limits specified in Title 17, Division 1, Chapter 5, Subchapter 4, Group 3, Article 3, Section 30253 of the California Code of Regulations

Note: HCH = sum of alpha, beta, gamma (lindane), and delta isomers of hexachlorocyclohexane

8.1.6 Permit Support Study – Application of the STE Test for the CDP

The STE procedure described in detail in Section 6.7.4 of this report was applied to assess the discharge impact of the 50-MGD (189,000-m^3/day) CDP.

A list of the 20 marine species selected for the biometrics test for the CDP is presented in Table 8.2. The salinity tolerance test was completed using three local species that are known to have the highest susceptibility to stress caused by elevated salinity (Le Page, 2004): (1) the purple sea urchin *(Stronglyocentroutus purpuratus)*, Figure 8.2; (2) the sand dollar *(Dendraster excentricus)*, Figure 8.3; and (3) the red abalone *(Haliotis rufescens)*, Figure 8.4.

The biometrics test continued for a period of 5.5 months. The results of this test are summarized in Table 8.3 and indicate that all organisms remained healthy throughout the test period. No mortality was encountered, and all species showed normal activity and feeding behavior. The appearance of the individuals remained good with no changes in coloration or development of marks or lesions.

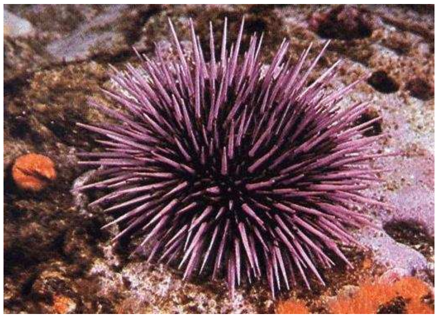


Figure 8.2. Purple Sea Urchin.

Figure 8.3. Sand Dollars.

Figure 8.4. Red Abalone.

Table 8.2. Marine Species Used for the Carlsbad Biometrics Test.

	Scientific Name	Common Name	Number of Individuals Per Species
1	*Paralichthys californicus*	California halibut	5 juveniles
2	*Paralabrax xlathratus*	Kelp bass	3 juveniles
3	*Paralabrax nebulifer*	Barred sand bass	3 juveniles
4	*Hypsoblennius gentilis*	Bay blenny	5
5	*Strongylocentrotus franciscanus*	Red sea urchin	4
6	*Strongylocentrotus purpuratus*	Purple sea urchin	14
7	*Pisaster ochraceus*	Ochre sea star	3
8	*Asterina minuata*	Bat star	3
9	*Parastichopus californicus*	Sea cucumber	2
10	*Cancer productus*	Red rock crab	2
11	*Crassadoma gigantea*	Giant rock scallop	3
12	*Haliotis fulgens*	Green abalone	3
13	*Megathura crenulata*	Giant keyhole limpet	3
14	*Lithopoma undosum*	Wavy turban snail	3
15	*Cypraea spadicea*	Chestnut cowrie	3
16	*Phragmatopoma californica*	Sand castle worm	1 colony
17	*Anthropleura elegantissuma*	Aggregating anemone	4
18	*Muricea fruticosa*	Brown gorgonian	1 colony
19	*Haliotis refescens*	Red abalone	5
20	*Dendraster excentricus*	Sand dollar	5

The duration of the salinity tolerance test for the CDP was 19 days. The results of this test are given in Table 8.4 and show that two of the three tested marine organisms – sand dollars and red abalones – had 100% survival in all test tanks and in the control tank. One individual in the purple sea urchin group died in each of the test tanks, and one died in the control tank.

Therefore, the adjusted survival rate for the purple sea urchins was also 100%. These test results confirm that the marine organisms in the discharge zone would have adequate salinity tolerance to the desalination plant discharge in the entire range of operations of the desalination plant (i.e., up to 40 ppt). All individuals of the three tested species behaved normally during the test, exhibiting active feeding and moving habits. The biometrics and salinity tolerance tests were completed in 110-gallon (420-liter) marine aquariums (Figure 8.5).

Table 8.3. Overall Condition of Biometrics Test Species.

Scientific Name	Common Name	Average Percentage of Weight Change (g)	Percentage of Weight Change (Control Group)	Sig.	Appearance and Feeding
Paralichthys californicus	California halibut	91.3	96.9	n/s	Strong
Paralabax clathratus	Kelp bass	114.3	104.8	n/s	Strong
Paralabrax nebulife	Bared sand bass	106.8	113.5	n/s	Strong
Hypsoblennium gentilis	Bay blenny	120.0	107.1	n/s	Strong
Strongylocentrotus franciscanus	Red sea urchin	2.8	2.4	n/s	Strong
Strongylocentrotus purpuratus	Purple sea urchin	7.9	7.2	n/s	Strong
Pisaster ochraceus	Ochre sea star	3.8	4.6	n/s	Strong
Asterina miniata	Bat star	2.8	3.1	n/s	Strong
Parastichopus californicus	Sea cucumber	-2.2	1.3	n/s	Strong
Haliotis fulgens	Green abalone	9.6	7.7	n/s	Strong
Megathura crenulata	Giant keyhole limpet	5.1	4.7	n/s	Strong
Lithopoma undosum	Wavy turban snail	3.9	2.4	n/s	Strong
Cypraea spadicea	Chestnut cowrie	0.6	1.0	n/s	Strong
Anthropleura elegantissima	Aggregating anemone	115.9	48.9	n/s	Strong
Haliotis refescens	Red abalone	9.2	7.8	n/s	Strong
Dendraster excentricus	Sand dollar	3.5	4.5	n/s	Strong

Notes: n/s = not significant; Sig. = statistical significance

Figure 8.5. CDP Test Tank.

Table 8.4. Results of CDP Salinity Tolerance Test.

Species Observed	Salinity (ppt)	Mortality	Elapsed Time to First Mortality (days)
Red abalones	33.5 (control tank)	0	N/A
Red abalones	37	0	N/A
Red abalones	38	0	N/A
Red abalones	39	0	N/A
Red abalones	40	0	N/A
Sand dollars	33.5 (control tank)	0	N/A
Sand dollars	37	0	N/A
Sand dollars	38	0	N/A
Sand dollars	39	0	N/A
Sand dollars	40	0	N/A
Purple sea urchins	33.5 (control tank)	1	1
Purple sea urchins	37	1	1
Purple sea urchins	38	1	4
Purple sea urchins	39	1	4
Purple sea urchins	40	1	6

Note: N/A = Not Applicable

In summary, the STE method applied to the CDP confirms that the elevated salinity in the vicinity of the plant discharge will not have a measurable impact on the marine organisms in this location and that these organisms can tolerate the maximum salinity of 40 ppt that could occur in the discharge area under extreme conditions.

Additional acute and chronic toxicity studies completed subsequently for this project using the U.S. EPA's standard WET test (Weber et al., 1998) have confirmed the validity of the STE method. WET testing using abalone *(Haliotis ruefescens)* shows that the chronic toxicity threshold of this species occurs at a TDS concentration of more than 40 ppt. An acute toxicity test completed using another standard WET species, the topsmelt *(Atherinops affinis)*, indicates that the salinity in the discharge can reach more than 50 ppt on a short-term basis (one day or less) without impacting this otherwise salinity-sensitive species.

8.2 Huntington Beach Desalination Plant

8.2.1 Facility Description

The Huntington Beach Desalination Facility in southern California is not yet under construction. It is planned to be built on a 12-acre parcel adjacent to the AES Huntington Beach Generating Station (HBGS; see Figure 8.6).

The permitted maximum plant discharge is 60.3 MGD (54 MGD or 204,000 m^3/day of concentrated seawater and 6.3 MGD or 24,000 m^3/day of filter backwash) to the Pacific Ocean. On August 25, 2006, the regional water board issued Order No. RB-2006-0034, NPDES No. CA80000403, which prescribed waste discharge requirements for discharges from the facility.

Similar to the CDP, this plant will receive its source water from either the HBGS's condenser cooling water discharge or directly from the HBGS's intake system. The desalination process will consist of source water screening, coagulation, filtration, pH adjustment, chlorination, de-chlorination, RO membrane separation, and product water chlorination and chemical conditioning. The facility will produce a 12-month average of 50 MGD (189,000 m^3/day) of potable water and 50 MGD (189,000 m^3/day) of concentrated seawater. RO cleaning solutions and first-rinse wastewater will be directed to a neutralization tank and then discharged to the local sewer. All subsequent RO membrane rinse wastewater (up to 0.29 MGD or 1100 m^3/day) will be conveyed to a 200,000 gal (757 m^3) wash water equalization tank prior to being metered into the facility's effluent outfall. The plant will utilize chlorine in the form of sodium hypochlorite to control and prevent microbial growth in the transmission pipelines and filter media. Chlorine may be injected before the influent to the filtration system. All chlorinated process water will be de-chlorinated if returned to the ocean. Chlorine will also be used to disinfect product water to meet the water quality standards of the Division of Drinking Water of the California SWRCB.

Figure 8.6. Huntington Beach Desalination Plant Site Schematic.

8.2.2 Receiving Water Characterization

The power plant outfall is nearly perpendicular to a relatively straight beach line, which extends for several miles. The ebb tide and flood tide directions are also nearly perpendicular to the beach line. The desalination and power plant use a common discharge outfall, which extends approximately 1500 ft (455 m) from the shore into an area with a sandy bottom, a very limited content of marine life, and no endangered species (see Figure 8.7). The species found in this discharge area are identical to those found in the vicinity of the CDP outfall. Therefore, the salinity tolerance study developed for the CDP was incorporated into the permitting process for the Huntington Beach project.

8.2.3 Description of Discharge Streams

The discharge stream will consist of concentrate, filter backwash (supernatant from the clarifier), and final rinse water from the cleaning cycle. Cleaning solutions and first-rinse water will be sent to the sanitary sewer. The concentrate is projected to have a salinity of 60 to 68 ppt. The salinity of the spent filter backwash water is the same as that of the source seawater (33.5 ppt). The cleaning solution from membrane rinsing varies in a range of 1000 to 20,000 mg/L.

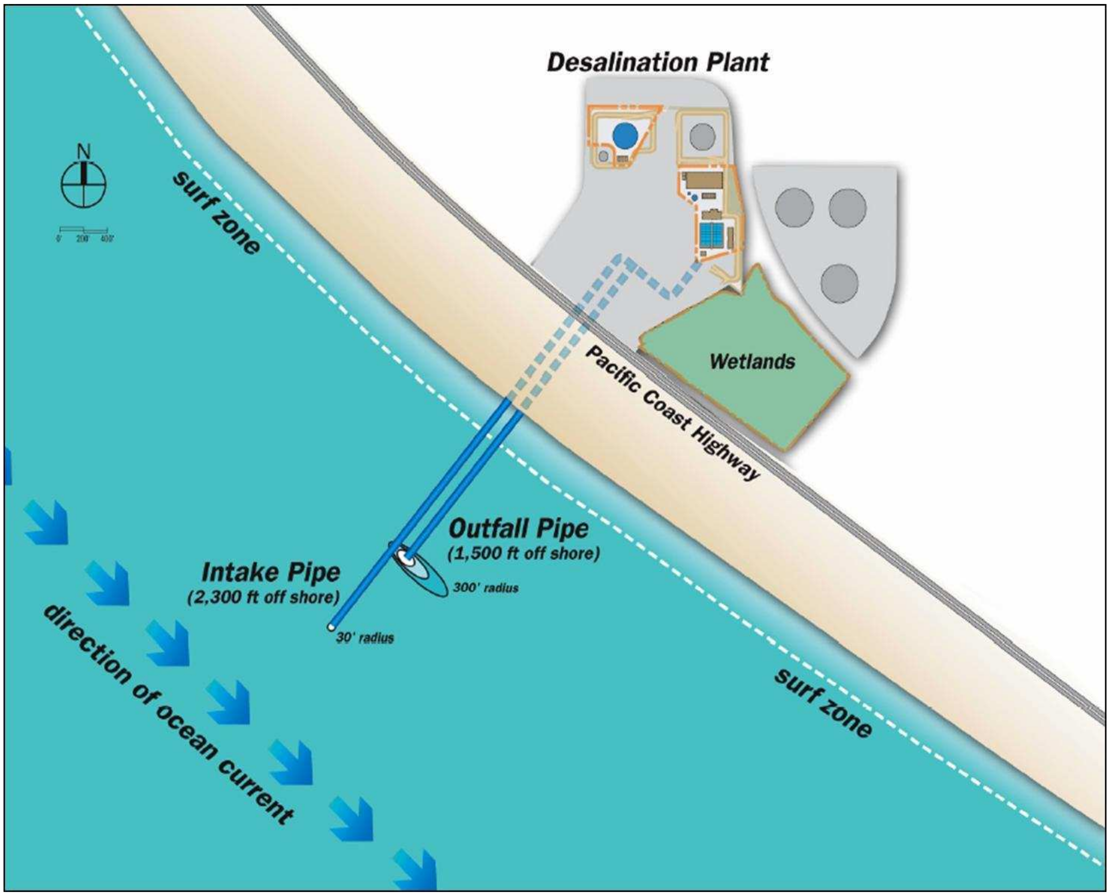


Figure 8.7. Configuration of the Intake and Outfall of the Huntington Beach Desalination Plant.

8.2.4 Description of Plant Outfall

The concentrated seawater with other process wastewater (on average 56.59 MGD or 214,000 m^3/day) will be discharged to the ocean through the existing HBGS outfall structure (see Figure 8.8).

The outfall consists of a single 21-ft (6.4-m) diameter, 1500-ft-long (455-m-long) discharge pipe (see Figure 8.4) and a vertical tower structure with a discharge depth of 20 ft (6.1 m) below the ocean bottom.

8.2.5 Key Discharge Permits and Permit Requirements

The NPDES permit discusses periods of power plant inactivity (such as during maintenance work or during a heat treatment antifouling measure) that may occur every six to eight weeks and may last from 6 to 8 h per occurrence. The desalination facility may not operate during this time but may operate at its maximum daily peak production capacity during other periods to make up for the lost production. During these times, the operation will also reach its maximum daily permitted concentrate seawater discharge.

If the HBGS were to temporarily cease operations of its once-through cooling water system (e.g., during HBGS maintenance shutdowns), or if it were to provide insufficient flows to satisfy the desalination facility's intake flow requirements, the facility would operate the

HBGS's seawater intake and outfall independently in a temporary stand-alone operational mode. This temporary stand-alone mode might occur in one of two situations: (1) when HBGS is temporarily shut down, or (2) when HBGS is operating but its discharge volumes are not sufficient to meet the facility's intake requirements. When operating in temporary stand-alone mode, the facility's intake flows will be maintained at approximately 126.7 MGD (480,000 m^3/day).

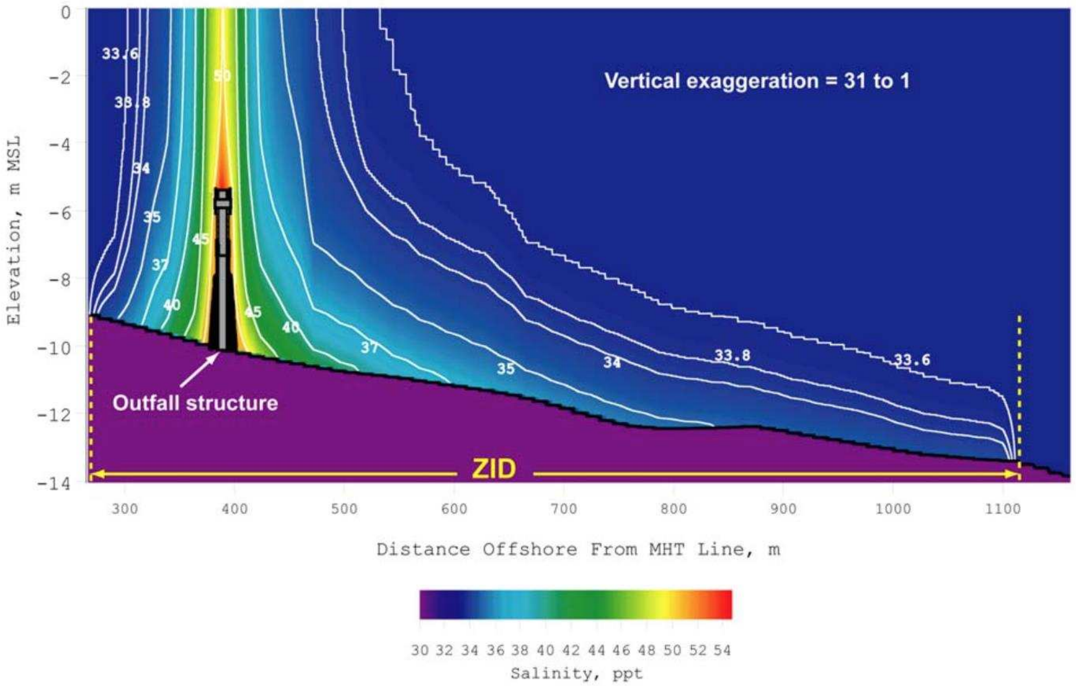


Figure 8.8. Outfall Structure and Distribution Of Discharge Salinity in a Worst-Case Scenario. (No Power Plant Cooling Water for Mixing and Minimum Mixing from Wind and Currents).

To ensure protection of the receiving water's beneficial uses and to limit the salinity concentrations in the receiving water, Order No. RS-2006-0034 limited the desalination facility's total outfall discharge under the co-located operations to a maximum of 44.7% of the intake flow [a total desalination discharge of 56.59 MGD (214,000 m^3/day) for a total HBGS discharge of 126.7 MGD (480,000 m^3/day)]. Under this requirement, the facility could achieve its production capacity whenever HBGS flows meet or exceed 126.7 MGD (480,000 m^3/day). If the HBGS does not direct 126.7 MGD (480,000 m^3/day) to the facility, the facility will operate the intake system in a temporary stand-alone mode to maintain a minimum intake flow of approximately 126.7 MGD (480,000 m^3/day), thereby ensuring that the facility's discharge remains at or less than 44.7% of the total intake volume.

Similar to the CDP, in addition to an NPDES discharge permit, the Huntington Beach project implementation requires the following other discharge-related permits and approvals:

- an intake and discharge lease from the California State Lands Commission
- a Coastal Development Permit from the CCC
- approvals from the U.S. Fish and Wildlife Service and the NOAA Fisheries
- approval from California Fish and Game in terms of confirmation that the intake and discharge areas do not contain threatened or endangered species

The effluent limitations are for Discharge Point 001, before the discharge is mixed with HBGS discharges. The effluent limits are calculated using a dilution factor of 7.5 and a wastewater flow of 56.59 MGD (214,000 m^3/day). In addition, there are narrative discharge prohibitions, discharge specifications, and receiving water limitations (temperature, physical characteristics, chemical characteristics, biological characteristics, and radioactivity) in the NPDES permit. Effluent monitoring and procedures for WET testing are in Attachment E of the permit. Monitoring and reporting are required on all parameters that have numerical limits, shown in Table 8.5, on about 100 organic chemicals and five other metals.

It is interesting to note that the Huntington Beach NPDES permit does not contain a numeric limit for salinity. However, the permit has a specified minimum volumetric ratio between the concentrate and the receiving seawater in the mixing zone of 2.24:1 (see Table 7.1), which corresponds to a mixed water salinity of 40 ppt. This indirectly incorporated salinity limit was based on the salinity tolerance study completed for the CDP and discussed in detail in a previous section of this chapter. The same salinity threshold was used for both projects because the marine species inhabiting the areas of the Huntington Beach and Carlsbad desalination plants are practically identical and are typical for southern California near-shore coastal waters. Similar marine organisms and a similar salinity threshold limit were also identified for the West Basin SWRO Project, which incorporated an independent salinity tolerance study for marine species inhabiting the outfall area of the project (Weston Solutions, 2013).

Table 8.5. Numerical Discharge Limitations for the Huntington Beach Desalination Facility.

Parameter/Constituent	Units	MAX Daily	Average Monthly	Average Weekly	Instantaneous MIN	Instantaneous MAX	6-Month Median
Maximum flow	MGD	56.59					
Oil and grease	mg/L		25	40		75	
Oil and grease	lb/day		11,800	18,900			
TSS	mg/L		60				
TSS	lb/day		28,300				
Settleable solids	ml/L		1	1.5		3	
Turbidity	NTU		75	100		225	
Arsenic	µg/L	250				660	46
Arsenic	lb/day	118					21
Cadmium	µg/L	34				85	8.5
Cadmium	lb/day	16					4
Chromium-6	µg/L	68				170	17
Chromium-6	lb/day	32					8
Copper	µg/L	87				240	11
Copper	lb/day	41					5
Lead	µg/L	68				170	17
Lead	lb/day	32					8
Mercury	µg/L	1.36				3.4	0.34
Mercury	lb/day	0.64					0.16
Nickel	µg/L	170				420	43
Nickel	lb/day	80					20
Silver	µg/L	23				58	4.8

Silver	lb/day	11				2.2
Zinc	µg/L	620			1600	110
Zinc	lb/day	290				52
Cyanide	µg/L	34			85	8.5
Cyanide	lb/day	16				4
Total chlorine residual	µg/L	68			510	17
Total chlorine residual	lb/day	32				8
Chronic toxicity	TU	8.5				
Ammonia nitrogen	µg/L	20,400			51,000	5100
Ammonia nitrogen	lb/day	960				2550
Phenolic compounds (non-chlorinated)	µg/L	1000	255		2600	250
Phenolic compounds (non-chlorinated)	lb/day	480	120			120
Chlorinated phenolics	µg/L	34	8.5		85	8.5
Chlorinated phenolics	lb/day	16	4			4
pH	Standard units			6	9	

8.2.6 Permitting Support Studies – Retrofitted Diffuser on the Discharge Outfall

In January 2005, Scott A. Jenkins Consulting provided a supplemental report to a 2004 modeling study they performed to simulate dilution and dispersion of the concentrate sea salts that would be added to the power plant's discharge stream. The recommended diffuser to consider was a velocity cap diffuser, which would provide four lateral diffuser ports with rectangular cross sections, producing four horizontal discharge jets. The study conclusion was that a diffuser would provide an increased dilution factor at the shoreline. However, the installation of a diffuser would increase the seabed salinity within 600 ft of the outfall because only half of the water column would be engaged in dilution and because the present discharge configuration ejects the concentrate seawater away from the seabed. The benthic area would consequently experience higher salinity in the near field. Therefore, the current outfall configuration allows a more rapid dilution of the concentrate sea salts and was found to be more appropriate than the installation of new diffusers.

8.3 Tampa Bay Desalination Plant

8.3.1 Facility Description

The co-location of a large-scale desalination plant with a power station was first used for the Tampa Bay Seawater Desalination Project and since then has been considered and used for numerous plants in the United States and worldwide. The intake and discharge of the Tampa Bay Seawater Desalination Plant are connected directly to the cooling water discharge outfalls of the Tampa Electric Company's (TECO's) Big Bend Power Station (Figure 8.9).

The TECO power generation station discharges up to 1400 MGD (5,300,000 m^3/day) of cooling water depending on the load and the generating units in operation. The desalination plant takes an average of 44 MGD (166,540 m^3/day) from the cooling water discharge to produce 25 MGD (95,000 m^3/day) of freshwater for drinking. The desalination plant concentrate is discharged to the TECO cooling water outfalls, downstream from the point of the desalination plant's seawater intake.

The source seawater is treated through fine screens, coagulation and flocculation chambers, sand media, and diatomaceous filters in series, as well as through the SWRO system with partial second pass. The spent filter backwash water from the desalination plant is processed through lamella settlers. The solids produced are dewatered using a belt filter press. Treated backwash water and concentrate are blended and disposed of through the power plant outfalls.

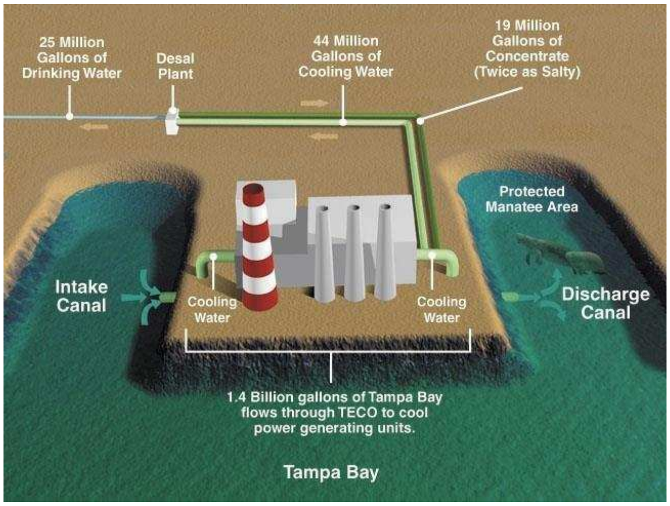


Figure 8.9. Tampa Bay SWRO Plant Co-Location Schematic Showing Daily Water Volumes.

8.3.2 Receiving Water Characterization

The combined power plant cooling water and concentrate from the desalination plant are discharged into a man-made open canal, which conveys the discharge to Hillsborough Bay. This bay is a sub-embayment of Tampa Bay on the west-central coast of Florida. The TECO power plant is near the mouth of Hillsborough Bay. Tidal action is the dominant force affecting water transport in lower Hillsborough Bay. With each tide reversal, more than 25 times as much water enters or leaves Hillsborough Bay and more than 200 times as much water enters or leaves Tampa Bay than is circulated through the power station (Levesque and Hammett, 1997). The canal has limited aquatic vegetation, and because of the relatively high temperature of the power plant discharge, the TECO discharge canal attracts manatees that bring their calves to the canal for the winter (Baysoundings, 2015; Save the Manatee Club, 2015).

8.3.3 Description of Discharge Stream

The discharge stream consists of concentrate, treated filter backwash (lamella clarifier supernatant) from the granular media filters, and membrane cleaning rinse water.

8.3.4 Description of Plant Outfall

The TECO power generation station discharges a maximum of 2.2 billion and an average of 1.4 billion gallons of cooling water per day (maximum and average of 8,327,000 and 5,300,000 m^3/day, respectively) depending on the load and the generating units in operation. From this cooling water, the desalination plant takes an average of 44 MGD (166,540 m^3/day) to produce 25 MGD (95,000 m^3/day) of freshwater for drinking. The desalination plant concentrate is discharged to the same TECO cooling water outfalls approximately 70 ft (21 m) downstream from the point of the desalination plant's seawater intake.

At full capacity, the RO process results in about 19 MGD (71,915 m^3/day) of 2.3-times-as-salty seawater, which is returned to the TECO plant's cooling water stream and blended with cooling water, achieving a blending ratio of up to 70:1. At this point, before entering and mixing with any bay water, the salinity is already only 1.0 to 1.5% higher, on average, than the ambient water salinity in Tampa Bay. This slight increase falls within Tampa Bay's normal, seasonal fluctuations in salinity. It should be pointed out that the Tampa Bay Desalination Plant's recovery rate is 57% and is slightly higher than the typical recovery rates of all other SWRO plants under construction and development in the United States, which have a typical recovery rate of 50%. The slightly higher recovery rate of this project is mainly due to the relatively lower average salinity of Tampa Bay (average of 26 ppt) compared with that in the Gulf of Mexico (38 ppt) or that along the Pacific coast of the United States (33.5 ppt).

The cooling water mixture moves through a discharge canal, blending with more seawater and diluting the discharge even further. By the time the discharged water reaches Tampa Bay, its salinity is nearly the same as the bay's salinity. And, the large volume of water that naturally flows in and out of Tampa Bay near Big Bend provides more dilution, preventing any long-term buildup of salinity in the bay.

At present, the desalination plant is operated in a hot standby mode for six months per year, and the remainder of the time, it operates at between 40 and 100% of its design freshwater production capacity. During hot standby mode, the plant runs only several days every week and produces water for service purposes only – to maintain the readiness of the desalination plant for full capacity production. The pretreatment system of the plant operates at all times, but during the hot standby period, no coagulants are added to the processed feed water except on days when service water is produced. Because of the continuous operation of the seawater pretreatment system, the plant has a continuous discharge to Tampa Bay.

8.3.5 Key Discharge Permits and Permit Requirements

Numerical effluent limitations from the Tampa Bay Desalination Plant NPDES Permit FL0186813-006 are shown in Table 8.6.

Most of the numerical limitations apply to the combined discharge. There are several monitoring sites for taking samples for reporting only.

Table 8.6. Numerical Discharge Limitations for the Tampa Bay Desalination Plant.

Effluent Limitations (Numerical)				**Monitoring Requirements**		
Parameter	**Unit**	**MAX/ MIN**	**Limit**	**Statistical Basis**	**Frequency of Analysis**	**Sample Type**
Chronic WET, 7-day IC25 *Mysidopsis bahia*	percent		100	single sample	quarterly	grab
Menidia beryllina	percent		100	single sample	quarterly	grab
RO facility discharge flow	MGD	MAX	22.8	daily maximum	continuous	recorder
Dilution ratio	ratio	MAX	N/A	single sample	continuous	calculated
		MIN	28	single sample	continuous	calculated
Time dilution ratio less than 28 h	hr	MAX	N/A	annual total	hourly	calculated
Oxygen (DO)	mg/L	MIN	Report	single sample (grab)	weekly	4 grabs/day
	mg/L	MIN	Report	single sample (24 h)	weekly	4 grabs/day
Chloride (as Cl)	mg/L	MAX	0	daily maximum	daily	calculated
Salinity	ppt	MAX	35.8	daily maximum	daily	calculated
Copper, total recoverable	µg/L	MAX	0	daily maximum	monthly	calculated
Iron, total recoverable	mg/L	MAX	0	daily maximum	monthly	calculated
Radium 226 + 228, total	pCi/L	MAX	5	daily maximum	monthly	calculated
Alpha, gross particle activity	pCi/L	MAX	15	daily maximum	monthly	calculated
pH		MIN	6.5	daily minimum	continuously	meter
		MAX	8.5	daily maximum	continuously	meter
Mercury	µg/L	MAX	0	daily maximum	monthly	calculated

Note: N/A = Not Applicable

8.3.6 Permit Compliance Observations

Long-term monitoring of the plant discharge indicates that the plant has been consistently and continuously in compliance with its NPDES permit requirements. Environmental monitoring of the desalination plant discharge has been ongoing since the plant first began operation in 2003 (McConnell, 2009). Since then, the plant operated at varying production levels until being taken offline for remediation in May 2005. The facility came back online in March 2007. The desalination plant discharges 19 MGD (72,000 m^3/day) of concentrate with a salinity of 54,000 to 62,000 mg/L when the product water is 25 MGD (95,000 m^3/day). The concentrate is blended with the remainder of the power plant cooling water prior to its disposal to Tampa Bay. Because of the large dilution volume of the cooling water, the blend of concentrate and cooling water has a salinity that is well within 2000 mg/L of the ambient bay water salinity.

Discharge bio-monitoring by the host community is a requirement under an Environmental Resource Permit that was issued by the local county environmental agency. The environmental monitoring program in the area of the desalination plant discharge is implemented by Tampa Bay Water, independent of the desalination plant operator. Overall objectives for the monitoring program are to detect and evaluate the effects of the discharge through comparison to a control area for time periods defined by facility operation (pre-operational, operational, and offline periods).

The plant discharge permit requires additional supplemental sampling to be performed as part of Tampa Bay Water's hydro-biological monitoring program. Water quality monitoring and benthic invertebrate monitoring include fixed and random sites and are focused on the areas most likely to be affected by the discharge. A control area considered representative of the ambient background bay water quality conditions is used for comparison. For fish and seagrass, data collected by other government agencies monitoring in the vicinity of the desalination facility are used to evaluate potential changes.

Evaluation of monitoring data from the period of 2002 to 2008 shows that even during periods of maximum water production, changes in salinity in the vicinity of the discharge were within or below the maximum thresholds (less than 2000 mg/L increase over background) predicted by the hydrodynamic model developed during the design and permitting phases of the plant. Review of monitoring data to date indicates that the plant operation does not have any observable adverse impacts on Tampa Bay's water quality and abundance or on the diversity of the biological resources near the facility discharge.

Benthic assemblages varied spatially in terms of dominant taxa, diversity, and community structure, but the salinity did not vary among monitoring strata, and the observed spatial heterogeneity of marine life distribution was found to be caused by variables not related to the discharge from the desalination facility (i.e., temperature and substrate). Patterns in fish community diversity in the vicinity of the facility were similar to those occurring elsewhere in Tampa Bay, and no differences between operational and non-operational periods were observed.

8.3.7 Permitting Support Studies

The key environmental studies completed for the permitting of the Tampa Bay SWRO desalination project included:

- a pilot study to generate concentrate, spent filter backwash, and spent membrane cleaning solutions, which were used for discharge water quality characterization;
- a one-year source water quality characterization study;
- a concentrate, spent filter backwash water, and cleaning solutions chemical characterization study for compliance with all parameters regulated by the CWA and the FDEP;
- a WET study of the concentrate and of various blends of concentrate and spent filter backwash water;
- a desktop salinity tolerance study for marine species inhabiting the area of the discharge;

- near- and far-field hydrodynamic modeling studies to determine the zone of initial mixing and dilution ratios near the area of the discharge and within Tampa Bay; and
- an environmental impact assessment of the desalination project, including the product water delivery pipeline and off-site drinking water storage tanks.

8.4 Analysis and Comparison of Permitting Practices in Key States

8.4.1 Similarities in the General Permitting Process and Permits

The framework for issuing discharge permits is set by federal regulations and begins with the submittal of a discharge application to the appropriate state regulatory agency (except for in the few states not delegated to oversee NPDES permits, in which case applications go to the regional U.S. EPA office). The California permitting process is a typical example of the general permitting process (SWRCB, 2014b):

- The discharger submits an application to the appropriate regional water board.
- The state or regional water board staff reviews the application for completeness and may request additional information.
- The staff determines if the discharge is to be permitted or prohibited. If a permit is needed and the application is complete, the staff prepares a draft and sends out a notice for a 30-day public comment period.
- The discharger must publish the public notice for one day in the largest circulated paper in the municipality or county and submit proof of posting or publication to the regional water board within 15 days after posting or publication.
- The regional water board holds a public hearing after the 30-day public comment period. The state or regional water board may adopt the permit as proposed, with modification, or not at all. A majority vote of the water board members is required to adopt the permit. The U.S. EPA has 30 days to object to the draft permit, and the objection must be satisfied before the permit becomes effective.
- The permit issuance process takes approximately six months but may take longer, depending on the nature of the discharge.

The general flow of events described previously is representative of permitting processes in Florida, Texas, and other states.

The specific form of state permits can differ, but at a minimum, all NPDES permits contain five general sections (U.S. EPA, 2015b):

1. *Cover Page*: Typically contains the name and location of the permittee, a statement authorizing the discharge, and the specific locations at which a discharge is authorized.
2. *Effluent Limits*: The primary mechanism for controlling discharges of pollutants to receiving waters. Permit writers spend a majority of their time deriving appropriate effluent limits based on applicable technology-based and water-quality-based standards.
3. *Monitoring and Reporting Requirements*: Used to characterize waste streams and receiving waters, evaluate wastewater treatment efficiency, and determine compliance with permit conditions.
4. *Special Conditions*: Conditions developed to supplement effluent limit guidelines. Examples include best management practices, additional monitoring activities, ambient stream surveys,

and toxicity reduction evaluations.

5. *Standard Conditions*: Pre-established conditions that apply to all NPDES permits and delineate the legal, administrative, and procedural requirements of the permit.

The permitting agencies determine permit effluent limits based on information provided by the permit applicant. The general decision process that state regulatory systems use follows the federal framework discussed in Chapter 5, including the events and information associated with the determination of numerical effluent limits as represented in Figure 5.1.

8.4.2 Differences among the State Permitting Processes and Permits

8.4.2.1 Differences in Effluent Limits

The latitude given to the states in how they conform to the general federal NPDES guidelines results in some policy and procedural differences among different states. Examples of this include the following:

- the automatic inclusion of mixing zones in the initial permit feasibility determination (e.g., Texas) as opposed to mixing zones being granted on a case-by-case basis (e.g., Florida and California)
- the definition of mixing zone parameters
- the automatic inclusion of WET tests for municipal membrane concentrate (e.g., Florida) versus WET tests on a case-by-case basis (e.g., Texas)
- different water quality standards (although all must be at least as stringent as the federal guidelines)
- different permit formats

Differences in permit effluent limits occur from such policy and procedural differences and also from the site-specific nature of the concentrate discharge and the receiving water. Both of these factors are evident when comparing the permit limits given in the permits of the Carlsbad, Huntington Beach, and Tampa Bay desalination plants, which were shown in Figures 8.1, 8.5, and 8.6.

8.4.2.2 Differences in Guidelines

There are also differences in the availability of regulatory guidelines for implementing SWRO desalination facilities. The Texas Water Development Board developed a generic guidance document clarifying the permitting agencies involved in the permitting of desalination projects in Texas; it is quite old (2004). The CCC prepared a position paper that presents its views on the permitting of desalination projects; it also is quite outdated (2004).

The Guidelines for Implementing Seawater and Brackish Water Desalination Facilities developed by the Water Research Foundation in cooperation with the WateReuse Research Foundation, the U.S. Bureau of Reclamation, and the California Department of Water Resources (WRF, 2010) provide a general overview of permitting and regulatory requirements and challenges in the United States. Texas and California have state-specific general guidelines for desalination project environmental planning, review, and permitting (R.W. Beck, 2004; CDWR, 2008).

These documents do not contain any specific technical details or engineering guidance (such as that found in the Ten State Standards or the U.S. EPA Water Reuse Guidelines) related to the scope and nature of environmental studies needed or any specific design and planning recommendations to complete a successful desalination project.

Thus, at present, there are no legally binding desalination-project-specific regulations or publically available regulatory guidelines specifically for desalination projects in the states of California, Florida, and Texas that are issued by the state agencies responsible for the environmental review and permitting of such projects. State regulators issue desalination project permits based on their prior experience with similar projects.

8.4.2.3 Differences in Complexity of the Regulatory Process

In most U.S. states, four to six agencies are involved in the regulatory process for permitting a SWRO desalination plant. In California, there are 24 agencies involved in an independent multi-agency review process that typically results in numerous conditions and permits that regulate the discharge and in other permits that may have different requirements in terms of the mitigation of environmental impacts. Such practices not only delay the permitting process but also put a significant burden on the project sponsor associated with project implementation, operations monitoring, and data reporting.

8.4.2.4 Differences in Salinity Limits

Generally, in the United States, salinity is regulated indirectly via WET tests. Although regulations do not explicitly spell this out, WET limits and requirements in conjunction with mixing zone requirements ultimately regulate the salinity of the discharge. This allows the maximum salinity limit of the regulatory mixing zone to also be established for the site-specific conditions of the project.

The maximum limit is based on the level of dilution required for marine species inhabiting the area (or for predetermined standard test species defined by the respective regulatory agency) not to exhibit chronic toxicity. The marine organisms selected for testing are identified based on a biological survey of the discharge area, usually completed during the initial environmental review phase of the project.

At present, there are no numerical salinity limits incorporated in the federal and state regulations (California is pending) that are developed independently of the site-specific WET tests. However, salinity limits for desalination concentrate discharge have become a focus of the updated California Ocean Plan, which incorporates a generic maximum incremental salinity of 2 ppt at the edge of the mixing zone.

A concern is that such a prescriptive “one-size-fits-all” limit is overly restrictive and not reflective of the site-specific aquatic environment in the area of the plant discharge. For instance, if the concentrate passes the WET test and the discharge salinity is higher than 2 ppt of the ambient ocean water salinity, it is unlikely that such salinity will result in negative impacts on the environment. From this perspective, the addition of a maximum salinity limit to the desalination project permit requirements may introduce an overly constraining burden in terms of compliance costs and delay to the regulatory process because the WET toxicity compliance requirements are already reflective of the potential negative effect of elevated salinity on the ambient aquatic life. Further, such a limit is not reflective of the site-specific conditions or of the salinity tolerance of the flora and fauna in the discharge area.

Chapter 9

Regulation and Permitting Practices Abroad

9.1 Introduction

There are substantial differences in the regulation and permitting of SWRO discharges in other countries. In this chapter, the practices in Australia, Spain, and Israel are reviewed for each of these countries via discussion of

- regulatory bodies,
- regulations, and
- permit support studies.

Case studies of SWRO facilities from the three countries are the subject of Chapter 10.

9.2 Australia

9.2.1 Regulatory Bodies Involved in Permitting

The Environmental Protection and Biodiversity Conservation Act (Australian Government, 1999) sets out a range of matters of national environmental significance (such as threatened species or ecological communities); where an activity impacts or has the potential to impact one or more of these matters, approval is required. This act is not specific to the activity of desalination, but if a proposal were to impact a matter on the list, the proposal would require assessment and approval under the act.

The Australian and New Zealand Environmental and Conservation Council (ANZECC) establishes guidelines that are then applied by the individual state jurisdictions as they see appropriate within their own legislation. Each of the five Australian states that have SWRO desalination plants (Western Australia, South Australia, Queensland, New South Wales, and Victoria) have state and local governing bodies (environmental protection agencies or authorities) that actually issue and enforce the plant discharge permits.

In addition to the issuing of licenses and permits for the discharge from the desalination plant, most states also have other approvals associated with the development of the desalination facility itself, which include consideration of environmental impacts, including those associated with the discharge of saline concentrate.

9.2.1.1 Queensland

The regulatory body involved in discharge consent approval in Queensland is the Department of Environment and Resource Management (DERM). Direct discharge of an RO concentrate to surface water in Queensland is regulated under the Environmental Protection Act 1994 and other subordinate legislation (Vargas et al., 2011). This act includes a requirement that certain activities that are environmentally relevant activities be licensed. Approval to operate an environmentally relevant activity is obtained through a development approval under the

Integrated Planning Act 1997 (QIPA, 1997) and is administered by DERM.

The role of DERM is to protect and improve the water environment in Queensland and to achieve a continuing overall improvement of coastal waters within the water quality objectives and environmental values for a specific location stated under the Environmental Protection (Water) Policy 1997 *QEPP, 2014)* , as well as ensuring that dischargers pay the cost of the consequences of their discharges.

Within its regulatory framework, DERM must ensure that the correct environmental and discharge standards are set and enforced. The discharge of effluent to a receiving water is acceptable providing the quality of the discharge complies with the conditions in the development approval set by DERM to prevent or minimize the negative impact to the receiving environment and providing the discharge of the seawater desalination plant consistently meets or exceeds the minimum requirements set under the Environmental Protection (Water) Policy 1997. At present, the only large SWRO desalination plant in Queensland is the 35-MGD (132,000-m^3/day) Gold Coast Desalination Facility.

9.2.1.2 Western Australia

The Western Australia Office of Environmental Protection Authority has primary responsibility for the development and enforcement of environmental legislation within Western Australia, and more specifically the Environmental Protection Act of 1986. The Western Australia Department of Environment and Conservation (DEC) has introduced environmental legislation that regulates the storage, transportation, and treatment of hazardous chemicals and waste that ultimately can reach surface waters. The DEC is also responsible for the implementation of the National Water Quality Management Strategy – the environmental quality management framework that contains environmental values and environmental quality objectives (EQOs) for use in Western Australia’s coastal water management. Compliance with the EQOs for a specific desalination project is judged using an assessment and the monitoring data of the discharge area, collected before and after the initiation of desalination plant operations. Western Australia has three large SWRO desalination plants: the 38-MGD (143,000-m^3/day) Perth I (Kwinana) Desalination Plant; the 74-MGD (280,000-m^3/day) Perth II Desalination Plant; and the 37-MGD (140,000-m^3/day) Cape Preston SWRO Desalination Plant.

9.2.1.3 South Australia

The South Australian Environment Protection Act of 1993 sets out that the activity of desalination is a prescribed activity of environmental significance that requires a license. The relevant water quality criteria are established through the Environment Protection (Water Quality) Policy of 2003. The actual permit is issued by the Environmental Protection Authority of South Australia. South Australia has only one large SWRO desalination facility: the 79-MGD (300,000-m^3/day) Adelaide Desalination Plant.

9.2.1.4 New South Wales

The Marine Water Quality Objectives for New South Wales Coastal Waters (NSW-DEC, 2000) provided the guiding principles used in the development of the discharge permit of the Sydney Water Desalination Plant. The state agency issuing the permit was the New South Wales Environment Protection Authority. The license is issued under Section 55 of the Protections of the Environment Operations Act 1997. New South Wales has one large desalination plant: the 66-MGD (250,000-m^3/day) Sydney Desalination Plant.

9.2.1.5 Victoria

At present, the state of Victoria has one large seawater desalination project: the 110-MGD (414,000-m^3/day) Wonthaggi Desalination Plant, which is the largest desalination plant in Australia and the third largest SWRO desalination plant in the world. The discharge permit of this plant was issued by the Department of Sustainability and the Environment under the Environmental Effects Act of 1978. Because ultimately the state owns the project in public-private partnership with Suez Environment, the Secretary to the Department of Sustainability and Environment (DSE) is the proponent of the project on behalf of the Minister for Water. Under the direction of the secretary, the Capital Projects Division of the DSE was responsible for the development and permitting of the project and the preparation of the environmental effects statement and discharge permit application.

9.2.1.6 Tasmania

At present, Tasmania does not have any medium or large desalination plants in operation or in planning or development. The regulatory agency that issues permits for wastewater discharge, including that from desalination plants, is the Environment Protection Authority of Tasmania. The Environmental Management and Pollution Control Act 1994 is the primary environmental protection and pollution control legislation in Tasmania. It is a performance-based style of legislation, with the fundamental basis being the prevention, reduction, and remediation of environmental harm.

9.2.2 Existing Regulations Governing Concentrate Management

ANZECC published the revised Australian and New Zealand guidelines for fresh and marine waters in 2000 (ANZECC, 2000). These guidelines are available on the internet (NWQMS, 2000).). The National Water Quality Management Strategy established by ANZECC forms the basis of water quality policy development for the states. The states have adopted the ANZECC guidelines in various ways. Within the states, different waterbodies have different specific water quality targets, similar to the system in the United States.

The ANZECC guidelines recognize a mixing zone at the discharge point and indicate that the water quality limits included in the guidelines are applicable to the boundary of the mixing zone. The extent and nature of the mixing zone are governed by the design parameters of the discharge structure and the hydrological conditions at the discharge area. Mixing zones in general are designed to manage the discharge of soluble, non-bio-accumulating substances. Reduced environmental benefits are accepted within the mixing zone as long as the values and uses of the broader ecosystem are not jeopardized. The ANZECC guidelines recommend a management philosophy of continual improvement, to reduce the size of the mixing zone over time.

The ANZECC guidelines consider toxicity testing as a key mechanism to assess the combined toxicity effects of all chemicals, the effect of interactions between chemicals, and the potential for ecological impacts. This approach is considered preferable to chemical- and component-specific evaluations of discharges because it accounts for the synergistic effects and the bio-available fraction of particular substances.

For various marine environments along Australia's coasts, the ANZECC guidelines contain default trigger values above which undesirable environmental impacts are very likely. Such trigger values for the states' large seawater desalination plants are listed in Table 9.1. Table 9.1 was compiled based on the ANZECC limits for "marine" and "estuarine and marine" environments (see Tables 3.3.2 to 3.3.9 of ANZECC, 2000.

The southeast Australia limits apply to the desalination plants in Sydney and the Victoria desalination plant. The tropical Australia limits apply to the Gold Coast SWRO desalination plant located in Queensland. The southwest Australia trigger values apply to the Perth I and II and Cape Preston SWRO desalination plants. The south-central Australia regulations apply to the Adelaide SWRO desalination plant.

The discharge from a given desalination plant must contain concentrations of contaminants that are lower than the applicable trigger values listed in Table 9.1. If the trigger value for a given parameter is exceeded at the boundary of the mixing zone, then the desalination plant has to treat (or in some cases, it is allowed to dilute) its discharge to meet the regulatory limit. Usually, dilution is allowed only for parameters that are inert and nonreactive such as salinity. The local government agencies involved in project permitting have the right to use more stringent trigger values for specific projects and circumstances.

It should be noted that the water quality targets indicated in Table 9.1 are not always the criteria that are actually used to determine the desalination plant discharge limits. Often, the states have their own requirements that differ from the ANZECC guidelines. For example, all states allow for a mixing zone, but they have different requirements for this zone. Therefore, the water quality limits incorporated in the permits of the desalination plant cases studied in Chapter 10 differ from the limits presented in Tables 9.1 and 9.2.

Usually, all desalination plant discharges comply with the limits listed in Table 9.1 and in their site-specific discharge permits without any additional treatment of the waste streams, except for turbidity. As seen from this table, the discharge turbidity limit is very low and can only be achieved if the spent filter backwash water, which is generated during seawater pretreatment, is processed on site (usually by lamella settling followed by mechanical dewatering of the sludge generated in the settlers).

In addition to the parameters listed in Table 9.1, the desalination plant needs to comply with the metal levels (triggers) presented in Table 9.2. Which value applies depends on how the discharge area is classified by the regulatory agency: High Ecological Protection Area, Medium Ecological Protection Area, or Low Ecological Protection Area. If a trigger is exceeded at the boundary of the mixing zone, then the plant must modify its operation to meet the respective regulatory requirement. These regulations also contain requirements for organic toxicants similar to those included in the U.S. EPA CWA.

Table 9.1. Australian Regulations Pertinent to Desalination – Key Discharge Permit Requirements.

Discharge Parameter	Southeast Australia	Tropical Australia	Southwest Australia	South-Central Australia
Chlorophyll a, inshore/offshore, µg/L	1	0.7–1.4/ 0.5–0.9	0.7/20 0.3/20	1
Total phosphorous, inshore/offshore, µg/L	25	15/10	20	100
Filterable reactive phosphate, µg/L	10	5	5	10
Total nitrogen, inshore/offshore, µg/L	120	100	230	1000
Nitrates, inshore/offshore, µg/L	5	2–8/1–4	5	50
Ammonia, inshore/offshore, µg/L	15	1–10/1–6	5	50
DO (percentage of saturation), lower/upper limit, %	90/110	90	90	90
pH, lower/upper limit	8.0/8.4	8.0/8.4	8.0/8.4	6.5/9.0
Turbidity, NTU	10	20	2	10

Note: Values are inshore/offshore.

It should be pointed out that based on ANZECC recommendations, each state has developed its own desalination project discharge permit requirements based on local site-specific data, type of receiving waterbody, and actual environmental conditions. For all desalination plants built to date, these limits are within 25% of the values listed in Tables 9.1 and 9.2.

Table 9.2. Australian Regulations Pertinent to Desalination − Metal Concentrations.

Permit Discharge Parameter	HEPA (protection of 99% of species)	MEPA (protection of 90% of species)	LEPA (protection of 80% of species)
Cadmium, µg/L	0.7	14	36
Chromium III, µg/L	7.7	48.6	90.6
Chromium IV, µg/L	0.14	20	85
Cobalt, µg/L	1	14	150
Copper, µg/L	0.3	3	8
Lead, µg/L	2.2	6.6	12
Mercury (inorganic), µg/L	0.1	0.7	1.4
Nickel, µg/L	7	200	560
Silver, µg/L	0.8	1.8	2.6
Vanadium, µg/L	50	160	280
Zinc, µg/L	7	23	43

Notes: HEPA = High Ecological Protection Area; MEPA = Medium Ecological Protection Area; LEPA = Low Ecological Protection Area

The ANZECC guidelines also contain specific requirements related to the observable impact of the desalination plant discharge on the aquatic flora and fauna. Such impact is assessed based on aquatic surveys of the discharge area before and after the commissioning of the desalination plant. The specific parameters of the health and biodiversity of the aquatic life measured before and during plant operations are the following:

- whole effluent toxicity
- chemical and biochemical changes in marine organisms
- whole-sediment laboratory toxicity assessment
- structure of macro invertebrates and/or fish populations and communities using rapid, broad-scale, or quantitative methods
- seagrass depth distribution
- imposex in marine gastropods [imposex is a disorder in sea snails caused by the toxic effects of certain marine pollutants; these pollutants cause female sea snails (marine gastropod mollusks) to develop male sex organs such as a penis and a vas deferens]
- frequency of algal blooms
- density of capitellids
- in-water light penetration
- filter-feeder densities
- sediment nutrient status
- coral reef trophic status
- habitat distributions
- assemblage distributions

It is interesting to point out that the Australian regulatory requirements do not require the project proponent to quantify and mitigate the impingement and entrainment of marine organisms by the desalination plant intakes. However, impingement and entrainment potential by the intakes is acknowledged in documents related to the project environmental review, and these effects are typically minimized by designing the intakes such that the through-screen velocity is between 0.33 and 0.5 fps (0.10-0.15 m/s).

9.2.3 Permitting Support Studies

Permitting support studies common for all large SWRO desalination projects in Australia are the following: at least one year of source water quality characterization and pilot testing of the proposed desalination system; numerical modeling of the desalination plant discharge to develop projections for mixing (the dilution factor) of the discharge at the boundary of the mixing zone; and discharge area flora and fauna surveys for one year before and after the commissioning of the desalination plant. There are a number of small SWRO desalination projects that have lesser requirements, such as no need to do pilot testing.

9.3 Spain

Spain has a long desalination history starting in 1969, with desalination as a source of urban water for dry and isolated remote locations like City of Ceuta in Northern Africa and the Canary Islands including Lanzarote, Fuerteventura, and Gran Canaria. In 2006, operating installed capacity in Spain was more than 530 MGD (2,000,000 m^3/day). In 2010, this capacity was 782 MGD (2,960,000 m^3/day), and the country had more than 750 desalination plants. The population of Spain in 2010 was 47 million (MARM, 2010).

Approximately 80% of Spain’s desalination capacity is concentrated in four regions: the Canary Islands (33%), Andalusia (23%), Murcia (13%), and the Region of Valencia (13%). The largest Spanish desalination plants are located along the Mediterranean coast (see Figure 9.1).

Seawater desalination in the Canary Islands is a prime source of the drinking water supply because of the scarcity of natural freshwater resources. On average, the Canary Islands rely on ocean desalination for one-fifth of their water supply, and the island of Lanzarote relies on desalination for more than 80% of its drinking water needs. The remaining 20% is provided by water reuse. The largest Spanish SWRO desalination plants are Torrevieja (Alicante), 63 MGD (240,000 m^3/day), and Barcelona, 53 MGD (200,000 m^3/day).

9.3.1 Regulatory Bodies Involved in Permitting

The Spanish Ministry of Environment and Rural and Marine Affairs (Minsterio de Medio Ambiente y Medio Rural y Marino), within the framework of the A.G.U.A. (Actuaciones para la Gestión y la Utilización del Agua) Program, develops and implements a long-term plan for the construction of new desalination facilities, which is updated every several years.

Basin Agencies (Confederaciones de Cuencas Hidrográficas) are in charge of planning, constructing, and operating major water infrastructure such as desalination plants and dams, as well as the following: developing basin plans; setting water quality targets, as well as monitoring and enforcing them; granting permits to use water, as well as inspecting water facilities for which permits were granted; undertaking hydrological studies; and providing advisory services to other entities at their request. Basin Agencies are headed by a president who is nominated by the cabinet at the proposal of the Minister of Environment and Rural and Marine Affairs.

Each agency has a board, a user assembly, and a council to ensure broad participation by various stakeholders in its decision-making process, both in planning and operations.

Figure 9.1. Location of the Largest SWRO Desalination Plants in Spain.

9.3.2 Existing Regulations Governing Concentrate Management

A cornerstone of the legal framework for water supply and sanitation is the 1985 Water Law (Ley de Aguas), modified in 2001 and most recently in 2005. Policy and regulation functions for water supply and sanitation are shared among various ministries. For example, the Ministry of Environment and Rural and Marine Affairs is in charge of water resources management, and the Ministry of Health is in charge of drinking water quality monitoring. In December 2010, Law 41/2010 was introduced to specifically address the protection of marine environment and set out regulations governing wastewater discharges, including concentrate from desalination plants. The regulations establish standards both at the point of discharge ("effluent standards") as well as at the boundary of the mixing zone ("ambient standards"). Spanish desalination regulations address environmental issues and concerns associated with project implementation at all phases of project development: (1) planning, (2) construction, and (3) operation.

9.3.2.1 Planning Phase

During the planning phase, the desalination project proponent is required to prepare an environmental impact assessment, which must include the following:

- a biological survey of the discharge area
- water quality characterization near the ocean surface and the bottom of the discharge area, including measurement of pH, TSS, DO, nitrates, total nitrogen, total phosphorus, and algal content (chlorophyll a)
- bathymetric and current surveys
- numeric modeling of concentrate plume dispersion
- an assessment of the biological significance and presence of endangered species in the discharge area; the Mediterranean coast of Spain is characterized by the existence of large seabeds of two salinity-sensitive seagrasses:
    - *Poseidonia oceanica* – a seagrass that grows in large beds along the coast and is sensitive to salinity exceeding 40,000 mg/L; the Poseidonia seagrass beds sometimes extend one to two miles offshore
    - *Cymodocea nodosa* – a seagrass that usually grows on a sandy or muddy bottom at up to 66 ft (20 m) in depth. Cymodocea forms thick, underwater lawns referred to as “sebadales” that are habitat for endangered marine species and are used for spawning by many aquatic organisms

9.3.2.2 Construction Phase

During the construction of the desalination plant, the project developer is required to complete the following activities:

- monitoring seawater quality to determine whether construction is impacting the nearby aquatic environment and taking the necessary corrective measures;
- tracking the condition of seagrass beds in the area of the desalination plant construction site and discharge;
- monitoring and quality control of the dredged materials; and
- monitoring and control of the increase of silt content in the seawater as a result of excavation and runoff activities.

9.3.2.3 Operation Phase

After the plant is commissioned, the plant discharge area is required to be monitored periodically for:

- compliance with numeric water quality parameters of the discharge and at the boundary of the mixing zone;
- biodiversity of the aquatic habitat inside and outside of the ZID; and
- the structural integrity, functioning, and condition of the discharge outfall.

Spanish regulatory agencies do not consider impingement and entrainment of marine organisms by the intakes of desalination plants a significant environmental impact and do not regulate or require mitigation for potential marine life losses caused by intake operations.

9.3.3 Key Permits and Permitting Agencies

All desalination plants operate under a waste discharge permit issued by the General Direction of Environmental Quality (Direccion General de Calidad Ambient). Prior to issuance, the permit is reviewed by various offices of the Ministry of Environment and Rural and Marine Affairs – the Office of Water Quality, the Office of Environmental Planning, the Office of Industrial Waste Regulation, the Office of Protection of the Environment, the Office of Sustainable Environmental Management – as well as local and regional regulatory agencies with jurisdiction over the marine coastal environment and industrial and recreational activities. Key permitting requirements incorporated in most SWRO desalination plant permits are shown in Table 9.3.

9.3.4 Permitting Support Studies

Support studies for the environmental review and permitting of desalination projects in Spain vary significantly from one project to another and at a minimum involve source water quality characterization, bathymetric and biological surveys of the discharge areas before and after plant commissioning, and modeling of the salinity plume of the discharge.

Desalination projects of all sizes are required to do source water quality characterization for at least six months, especially during the summer period when algal blooms may occur. Data collected for source water quality characterization at a minimum include the following:

- TDS
- conductivity
- pH
- temperature
- DO
- silt density index
- oil and grease
- total hydrocarbons
- sodium
- chloride
- calcium
- magnesium
- iron
- manganese
- bromide
- boron
- nitrates
- phosphates
- silica

In addition, source water quality is characterized for all metals and organics regulated in the plant discharge as well as compounds that are regulated by pertinent public health agencies.

Table 9.3. Spanish Regulations Pertinent to Desalination – Key Discharge Permit Requirements.

Parameter	Maximum Concentration
TSS, mg/L	35
pH	6–9
Total nitrogen, mg/L	15
Total phosphorus, mg/L	2
BOD5, mg/L	25

For small plants, the collected source water quality information is used to project the quality of the desalination plant concentrate based on the selected plant design. For plants larger than 26 MGD (100,000 m^3/day), concentrate is generated using a pilot system specifically built for the project. Such concentrate is used to complete chronic and acute WET studies with methodology and test protocols similar to those of the standard U.S. EPA WET tests.

All desalination projects are required to complete a bathymetric survey of the discharge area to document the configuration of the bottom in this area as well as area depth, currents, and waves. A bathymetric survey produces a map of the ocean bottom in the area of the discharge and identifies the depth of the sand cover of the bottom. The information collected during the bathymetric survey is used to complete a biological survey of the discharge area as well as hydrodynamic modeling of the concentrate dispersion.

The environmental review of all projects entails the completion of a biological survey of the marine habitat in the area of the discharge. Such a survey includes the identification of marine species inhabiting the ocean bottom and water column along the length of the plant intake and outfall. The biological survey identifies and maps the location and type of marine habitats in the mixing zone of the discharge, including seagrass beds, kelp forests, coral outcroppings, borrows of benthic organisms and fish, and other habitats that could be impacted by the desalination plant operations. The outcome of this biological survey is a map of marine life information documenting the condition of the discharge area at “time-zero,” before the plant operation begins. The scope of such a survey includes the following:

- the installation of underwater current velocity meters at a depth of 3.3 ft (1 m) from the bottom
- the documentation of conductivity-temperature-depth relationships
- a characterization of the water column (pH, suspended solids, DO, nitrate, and total phosphorus)
- a bottom sediment characterization
- seagrass beds mapping and characterization (coverage, density, speed growth)
- the mapping and identification of other marine habitats in the discharge area (coral reefs, kelp forests, and rocky habitats of crustaceans and other marine species)

Hydrodynamic mathematical modeling of ocean water discharges is usually completed for projects with a capacity of 5.3 MGD (20,000 m^3/day) or larger. CORMIX is the most popular hydrodynamic model used for desalination projects in Spain.

For plants larger than 40 MGD (150,000 m^3/day), a to-scale physical model of the outfall is constructed in a specialized hydraulic laboratory, and the model is used to study and document the projected size, depth, and concentration of the discharge salinity at different discharge volumes, mixing conditions (i.e., wave and wind speeds), and salinity concentrations using tracer dye. Such a model is used to validate the results of the hydrodynamic mathematical modeling.

9.4 Israel

In 1999, the Israeli government initiated a long-term, large-scale SWRO desalination program. The program is designed to provide for the growing demand on Israel's scarce water resources and to mitigate the drought conditions that have characterized most years since the mid-1990s. The Israeli desalination program has defined a cumulative nationwide target volume of desalinated water that must be produced by certain deadlines to address the country's water supply needs. The initial 1999 target capacity of 36 MGD [50 million cubic meters (MCM) per year] was reset in 2002 to 290 MGD (400 MCM/year). This target was reduced in 2003 to 165 MGD (230 MCM/year) in response to an unprecedented large amount of rainfall in 2002. In July 2007, subsequent to several drought years, the targeted production capacity was reset to 370 MGD (505 MCM/year), which was reached in 2013. Additional drought conditions led to a further increase in the target capacity in 2008 to 550 MGD (750 MCM/year), to be reached by the year 2020.

9.4.1 Regulatory Bodies Involved in Permitting

The Ministry of Environmental Protection (MEP) of Israel is the main regulatory entity involved with the development, implementation, and enforcement of regulations related to the discharge of concentrate and other waste streams from desalination plants. The Israeli government actually encourages the construction of desalination plants and considers diversification of the country's water supply as a national goal of the utmost importance.

The actual plant discharge permits are developed and reviewed by an interministerial committee with eight member representatives from seven different ministries as well as one representative from public environmental organizations. The Marine and Coastal Division of the MEP of Israel serves as a professional advisory body to the committee, coordinates committee activities, and is responsible for the monitoring and enforcement of permit compliance.

9.4.2 Existing Regulations Governing Concentrate Management

The marine environmental policy and regulations in Israel are based on MEP requirements (MEP, 2002); the National Master Plan for the desalination of seawater, 34B3; and the experience acquired with the operation of large desalination plants for more than five years. According to the Law for Protection of the Coastal Environment of 2004 (IMEP, 2004), desalination plant discharges should be constructed such that they protect the coastal zone of Israel. The coastal zone is defined as 1000 ft (300 m) inland, 100 ft (30 m) depth, and one nautical mile (6076 ft) offshore. In addition, the discharge of concentrate is regulated by the Land-based Sources Law of 1998, its regulations of 1990, and its amendments of 2005 (Safari and Zask, 2008). The Land-based Sources Law is based on the Barcelona Convention for protecting the Mediterranean Sea from the negative environmental impacts of point discharges.

The Israeli Policy for the Protection of the Mediterranean Marine and Coastal Environment from Desalination Facilities (MEP, 2002) defines the following general criteria for marine outfall construction and operation and thus addresses three key issues:

- discharge type and characteristics
- marine outfall
- discharge monitoring program

9.4.2.1 Discharge Characteristics

Key discharge characteristics used to assess desalination plant discharge impact on the environment are the following:

- Discharge composition, which is mainly driven by the source water quality and the type and quantities of chemicals used at the desalination plant.
- Pretreatment waste streams; that is, which waste streams generated by the pretreatment system will be discharged to the ocean, and if they will be treated before discharge.
- Treatment chemicals; of specific interest are chemicals that can exhibit effluent toxicity, such as antiscalants and membrane cleaning chemicals, as well as such that can trigger algal bloom effects, such as phosphate antiscalants, phosphoric acid, citric acid, nitric acid, and others.
- Plant recovery rate; that is, the percentage of source water that is converted into freshwater. Recovery rate dictates the salinity of the plant discharge and the potential concentration of algal toxins, organics, solids, or other compounds that may result in effluent toxicity.
- Operational regime, the intermittent or continuous discharge of concentrate and spent filter backwash and the associated maximum loads of solids and salinity spikes.
- Flow rate, which impacts the loads of solids discharged in a particular area.
- Increase of turbidity caused by the discharge, which should not be more than 10% of the seasonal average.
- Suspended particulate matter (TSS), which should not exceed the seasonal average by more than 10 mg/L.
- Color of the ambient water, which should not be affected by the discharge outside of the mixing zone.

9.4.2.2 Marine Outfall

The law of 2004 for the protection of coastal environment includes specific guidelines and requirements for desalination plant discharges. The following aspects should be considered when determining the most suitable location of the ocean outfall for a given project:

- natural sand movement,
- ecosystems in the coastal environment,

- fishing activities,
- marine vessel traffic,
- the safety of bathers and surfers in shallow waters, and
- the impact of onshore coastal facilities servicing the plant outfall (e.g., pump stations and storage tanks).

9.4.2.3 Discharge Monitoring Program

The environmental law in Israel prescribes the implementation of a monitoring program of the area of the discharge before and after the desalination plant outfall is built. The monitoring program typically has to incorporate the following information:

- water quality characterization of the receiving ocean area, including measurement of physical, chemical, and biological parameters;
- sediment accumulation in the discharge area; and
- biota (type and diversity).

9.4.3 Permitting Support Studies

Permitting support studies required in Israel are at least one year of source water quality characterization; numerical modeling of the desalination plant discharge; and surveys of the discharge area's flora and fauna six months to one year before and after the commissioning of the desalination plant.

Desalination projects are required to collect source water quality data for at least the following parameters and to determine by projections the concentration of these parameters in the concentrate:

- TDS
- conductivity
- pH
- temperature
- DO
- total hydrocarbons
- nitrates
- phosphates
- turbidity
- TSS
- BOD5

Projects larger than 26 MGD (100,000 m^3/day) are required to complete a biological survey in the mixing zone, which is defined as a circle with a radius of 1000 ft (330 m) centered on the point of discharge. The purpose of this survey is to identify marine species living in the area and to determine their salinity tolerances.

Hydrodynamic mathematical modeling of ocean water discharges is usually completed for projects with a capacity of 11 MGD (40,000 m^3/day) or larger. The CAMERI 3D model has been used in the numeric modeling of the discharges of most of the SWRO desalination plants in Israel, such as Ashkelon, Hadera, and Sorek.

Chapter 10

International Permitting Case Studies

10.1 Perth I Desalination Plant, Australia

10.1.1 Facility Description

As reported at the November 2009 World Congress of the International Desalination Association (Christie and Bonnelye, 2009), the 38-MGD (143,000-m^3/day) Perth Seawater Desalination Plant (Perth I) has been in continuous operation since November 2006. This plant supplies more than 17% of the drinking water of the City of Perth, Australia, which has more than 1.6 million inhabitants.

The treatment facilities of the Perth Seawater Desalination Plant (Figure 10.1) are very typical for state-of-the-art seawater desalination plants worldwide. Since its construction, the Water Corporation of Western Australia (Water Corporation) has built a second desalination plant, Perth II, to provide a drought-proof and reliable water supply to the City of Perth.

Perth I has a velocity-cap type open intake structure extending 660 ft (200 m) from the shore. Source seawater is treated using 24 single-stage dual granular media pressure filters, 14 five-micron cartridge filters, and 12 two-pass RO membrane systems with pressure exchangers (16 ERI PX 220 per RO train) for energy recovery. The RO permeate is post-treated by lime stabilization and sodium hypochlorite disinfection.

Figure 10.1. Perth I Seawater Desalination Plant.

Figure 10.2 provides a general schematic of the Perth I SWRO Desalination Plant. The desalination plant concentrate is discharged to the ocean via an offshore outfall with diffusers. Plant source water salinity varies in a range from 30,000 to 39,000 mg/L (average 37,000 mg/L), and intake temperature is between 54 and 77°F (15-25°C) and averages 68°F (20°C).

10.1.2 Receiving Water Characterization

The Perth I SWRO plant discharge is located in Cockburn Sound, which is a shallow and enclosed waterbody with a very limited water circulation and an average salinity of 37,000 mg/L. Cockburn Sound frequently experiences naturally occurring low oxygen levels during periods of low currents or low wind intensity. This waterbody is connected to the Pacific Ocean. Cockburn Sound is characterized by relatively closed access to the Pacific Ocean and a variable offshore current. The sound consists of a 33 ft (10 m) shelf near the shore location of the desalination plant that becomes a 66 ft (20 m) basin at its deepest part, which is enclosed by the Garden Island further west. The main areas of environmental concern faced at the desalination plant and at its discharge included:

- dilution of the concentrate discharge at the edge of the mixing zone – 150 ft (50 m) in all directions of the diffuser;
- toxicity of the concentrate and its effect on the surrounding ecosystem;
- a perceived threat to DO levels in Cockburn Sound by the environmental regulator and the Cockburn Sound Management Council (who monitor the environmental "health" of Cockburn Sound); and
- discharge of other waste products such as sludge from the dual media backwash water.

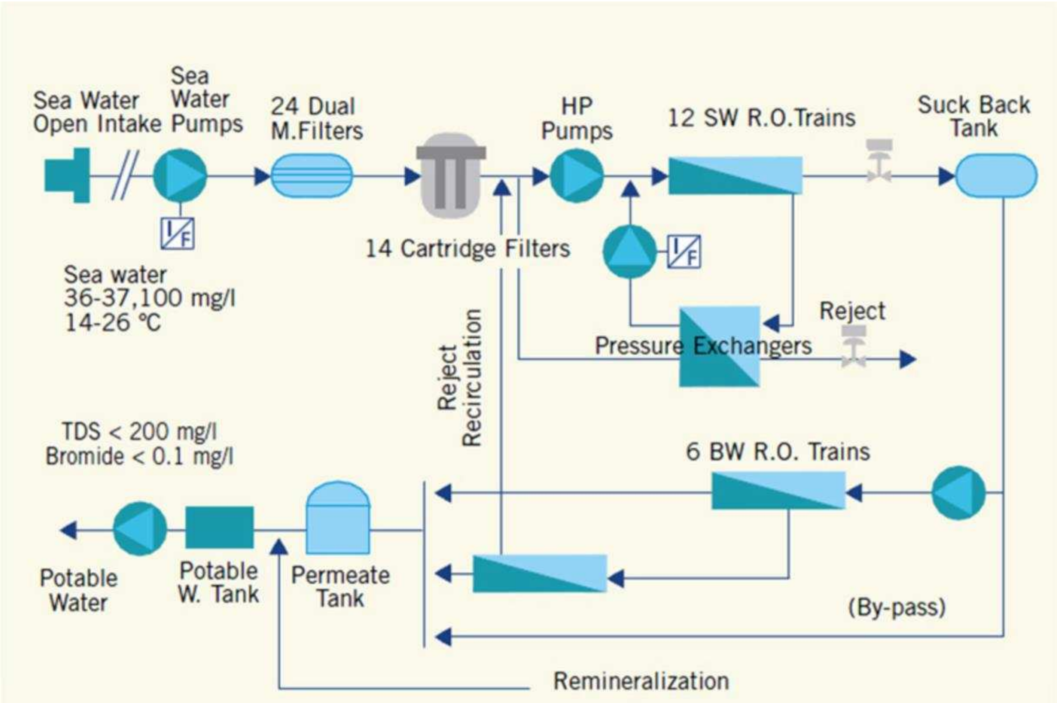


Figure 10.2. General Schematic of the Perth I Desalination Plant, Australia.

10.1.3 Description of Discharge Streams

The desalination plant discharge to the ocean consists of concentrate and spent pretreatment filter backwash water. Concentrate is discharged from the RO system under pressure and then, after conveyance to a small retention chamber, is discharged to the plant's ocean outfall. The spent filter backwash water is pretreated in lamella settlers and equalized prior to discharge with the concentrate. Sludge generated in the lamella settlers is dewatered in a belt filter press and disposed of off-site to a sanitary landfill. Neutralized membrane cleaning solution generated from RO membrane CIP is discharged to the sanitary sewer.

10.1.4 Description of Plant Outfall

Because the Perth I SWRO plant discharge area has very limited natural mixing, the desalination plant project team constructed a diffuser-based outfall that is located approximately 1640 ft (500 m) offshore and has 40 ports along the final 660 ft (200 m) at about 1.6 ft (0.5 m) from the seabed surface at a 60° angle. The diffuser was designed to provide a dilution ratio of 45:1 within the mixing zone. The diffuser ports are spaced at 16 ft (5 m) intervals with a 9-in (220 mm) nominal port diameter at a depth of 33 ft (10 m; see Figure 10.3). Diffuser length is 520 ft (160 m). The outfall is a single glass-reinforced-plastic pipeline with a diameter of 60 in. (1600 mm).

This diffuser design was adopted with the expectation that the plume would rise to a height of 28 ft (8.5 m) before beginning to sink because of its elevated density. It was designed to achieve a plume thickness at the edge of the mixing zone of 8 ft (2.5 m) and, in the absence of ambient cross-flow, to extend the plume to approximately 160 ft (50 m) laterally from the diffuser to the edge of the mixing zone (see Figure 10.4).

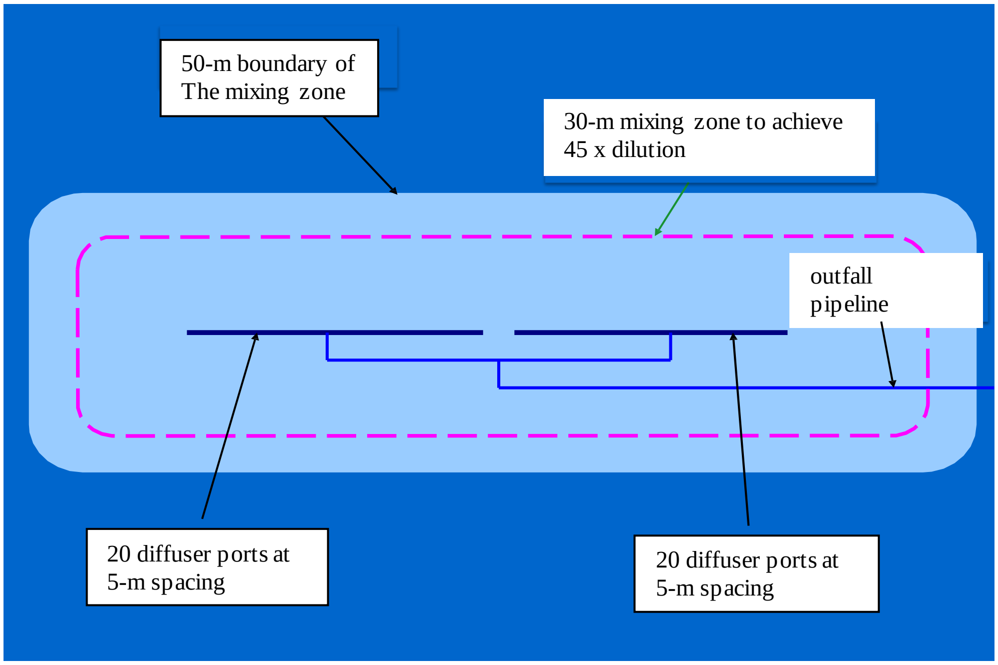
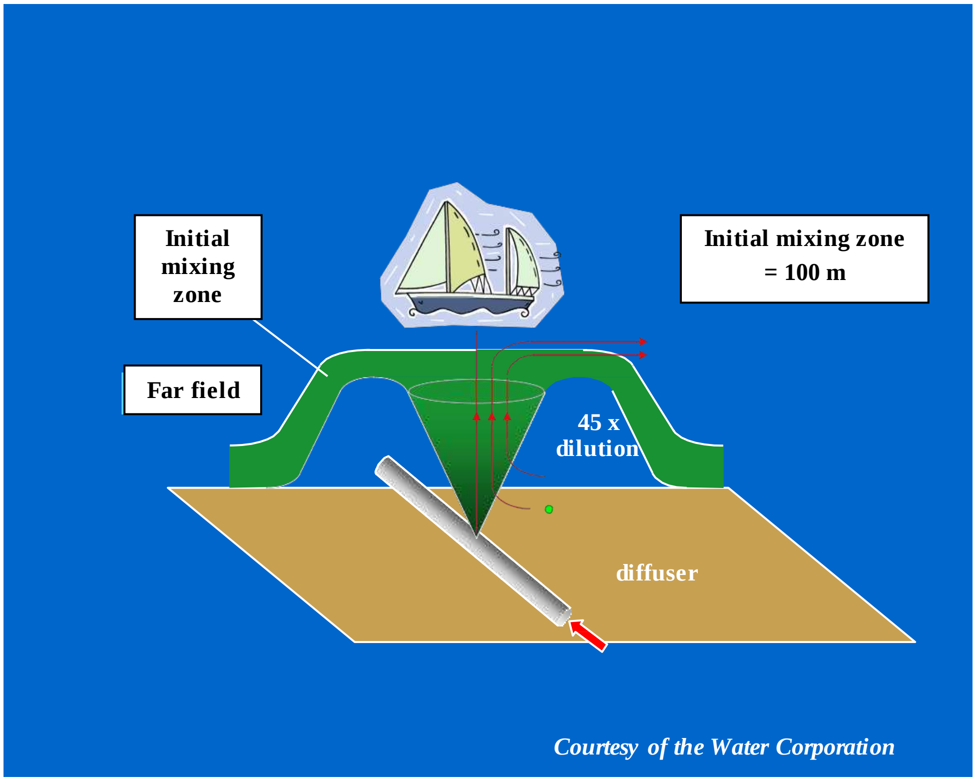


Figure 10.3. Perth I Desalination Plant Discharge Configuration.

Plant operations data (Christie and Bonnelye, 2009) show that the actual dilution ratios achieved with this design were between 50:1 and 120:1 (measured at the edge of the mixing zone), depending on the actual direction of local currents; this value is well above the plant permit dilution ratio requirement of 45:1.

It should be noted that the plant has a provision (which is allowed by the permit) to recirculate intake seawater into the plant concentrate discharge during periods of reduced plant capacity to increase the discharge velocity and improve dilution and oxygen content, if needed for compliance with the minimum dilution ratio defined in the permit.

The diffuser design was optimized using computer fluid dynamics models based on the Roberts equation, which allowed for the optimization of the diameter and angle of discharge. During the design phase, studies were performed at the University of New South Wales using a hydraulic calculation model as well as physical 1:15 scale modeling for the confirmation of the design of the outfall {plume thickness and height, impact, ultimate dilution [a <1.2 ppt at 156 ft (50 m) objective]}.



Courtesy of the Water Corporation

Figure 10.4. Perth I Desalination Plant Mixing Zone.

10.1.5 Key Discharge Permit Requirements

Table 10.1 presents a summary of key requirements included in the plant discharge permit.

Table 10.1. Perth I SWRO Desalination Plant – Key Discharge Permit Requirements – Permit No. L8108/2004/4.

Permit Discharge Parameter	Average	Maximum	Minimum
Distance factor at the edge of mixing zone			1:45
Distance from diffusers to edge of mixing zone		165 ft (50 m)	
Salinity increment above average at the edge of mixing zone	0.8 ppt	1.2 ppt	
Turbidity concentration		8 NTU	
Oxygen concentration			5 mg/L
pH units		8.3	7.0
Conductivity of undiluted concentrate		92,999 µS/cm	

The plant discharge permit (referred to as its "operational environmental license") is issued by the DEC of Western Australia. The permit prescribes that the discharge should achieve a dilution factor of 45:1 at a distance of 165 ft (50 m) in all directions of the diffuser (the edge of the defined mixing zone). The dilution factor is calculated based on the salinity concentrations of concentrate and ambient seawater [measured in practical salinity units (psu)] as follows:

$$\text{Dilution Factor} = (SB - SS) / (SD - SS)$$

where SB = salinity of the discharged seawater concentrate in psu, SD = salinity at 165 ft (50 m) from the diffuser (average of the concentrate plume; see explanation of the average in the following) in psu, and SS = salinity of intake seawater in psu.

The seawater salinity at the edge of the mixing zone is measured in as close as is practicable to 1.65 ft (0.5 m) intervals in the bottom 16.4 ft (5 m) of the water column. The pycnocline due to the diffuser discharge is identified, and only those depths below the pycnocline are averaged to determine the diffuser performance. Salinity measurement is required for at least three minutes at each depth and then is time averaged prior to the determination of the pycnocline depth and any depth averaging.

The discharge permit requires salinity monitoring to be completed 12 times per year during the first year to obtain data representative of seasonal salinity variations. The frequency of salinity measurement is reduced to two times per year after the first year.

In addition to the requirements of the discharge permit issued by the DEC, the Western Australian Environmental Protection Authority has added a permit condition to complete WET testing at the time of plant commissioning and after 12 months of operation. These tests aim to confirm that the actual plant dilution is adequate to prevent chronic toxicity of the marine flora and fauna.

One of the key concerns of the regulators was that the concentrate, which is denser than the ambient seawater, would sink to the deeper [66 ft (20.1 m)] basin of Cockburn Sound and cause the formation of a hypoxic layer and DO suppression. Hypoxia would in turn cause potential fish kills. Therefore, the plant permit requires the operator to monitor DO levels in the deeper basin of Cockburn Sound, and the plant is required to limit production to one-sixth of its capacity when the oxygen concentration decreases below certain prescribed levels.

10.1.6 Permit Compliance Observations

Extensive real-time monitoring was undertaken in Cockburn Sound for 12 months before and after the plant began operation in November 2006 to ensure that the marine habitat and fauna were protected. This monitoring included continuous measurement of DO levels via sensors located on the sandy bed of the sound.

Visual confirmation of the plume dispersion was achieved by the use of 14 gal (52 L) of Rhodamine dye added to the plant discharge. It was reported that the dye billowed to within approximately 10 ft (3 m) of the water surface before falling to the seabed and spilling along a shallow sill of the sound towards the ocean. The experiment showed that the dye had dispersed beyond what could be visually detected within a distance of approximately 0.9 miles (1.5 km) – well within the protected deeper region of Cockburn Sound, which is located approximately three miles (5 km) from the diffusers. The environmentally benign dye experiment was first commissioned in December 2006 and repeated in April 2007, when discharge conditions were calm.

In addition to the dye study, the project team completed a series of toxicity tests with a number of species in the larval phase to verify that the actual mixing ratio of the plant outfall diffusers is higher than the minimum dilution ratio needed at the edge of the ZID:

- 72-h macro-algal germination assay using the brown kelp *Ecklonia radiate*;
- 48-h mussel larval development test using *Mytilis edulis*;
- 72-h algal growth test using the unicellular algae *Isochrysis galbana*;
- 28-day copepod reproduction test using the copepod *Gladioferens imparipes*; and
- 7-day larval fish growth test using the marine fish pink snapper, *Pagrus auratus*.

The results of the toxicity tests indicate that the plant concentrate dilution needed at the edge of the mixing zone to protect the sensitive species listed previously is 9.2:1 to 15.1:1, which is well within the actual design diffuser system mixing ratio of 45:1.

In addition to the toxicity testing, the Perth desalination project team completed two environmental surveys of the desalination plant discharge area in terms of macro-faunal community and sediment (benthic) habitat (Okel et al., 2007; Oceanica Consulting, 2009). The March 2006 baseline survey covered 77 sites to determine the spatial pattern of the benthic macro-faunal communities, whereas the repeat survey in 2008 covered 41 sites originally sampled in 2006 and five new reference sites. Some of the benthic community survey locations were in the immediate vicinity of the discharge diffusers, whereas others were in various locations throughout the bay. The two surveys showed no changes in benthic communities that could be attributed to the desalination plant discharge.

Water quality sampling completed in the discharge area has shown no observable effect on ocean water quality except that the salinity at the ocean bottom increased up to 1 ppt, a salinity level that is well within the naturally occurring salinity variation (Christie and Bonnelye, 2009).

Figure 10.5 depicts the conductivity of the Perth SWRO plant discharge over the period of January 2007 to September 2009. Taking into consideration that the ratio between salinity and conductivity is 0.78, the plant discharge salinity varied between 64,500 mg/L (88 µS/cm) and 56,200 mg/L (72 µS/cm), which is below the discharge permit limit of 90 µS/cm.

The DO concentration of the discharge for the same period was between 7.6 and 11.0 mg/L and was always higher than the minimum regulatory level of 5 mg/L. Similarly, the concentrate pH was between 7.2 and 7.6, which was well within 10% of the ambient ocean water pH and above the minimum pH limit of 7.

Discharge turbidity for the same period (January 2007 to September 2009) was always less than 3 NTU (see Figure 10.6). It should be pointed out that the spent filter backwash water from the plant's pretreatment system is treated on site in lamella settlers, and the supernatant from this treatment process is discharged with the desalination plant concentrate. The solids generated as a result of the backwash treatment process are dewatered using a belt filter press and disposed of in a landfill.

In summary, all studies and continuous environmental monitoring completed at the Perth I Seawater Desalination Plant to date indicate that the desalination plant operations do not have a significant environmental impact on the surrounding marine environment.

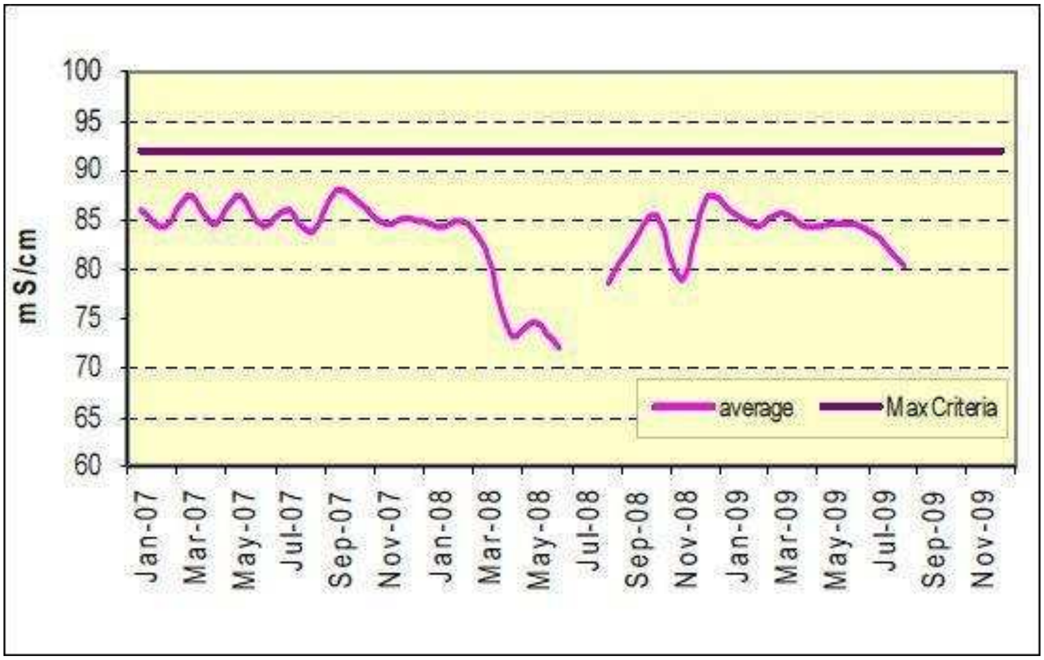


Figure 10.5. Perth I Desalination Plant Discharge Conductivity.

Source: Christie and Bonnelye, 2009

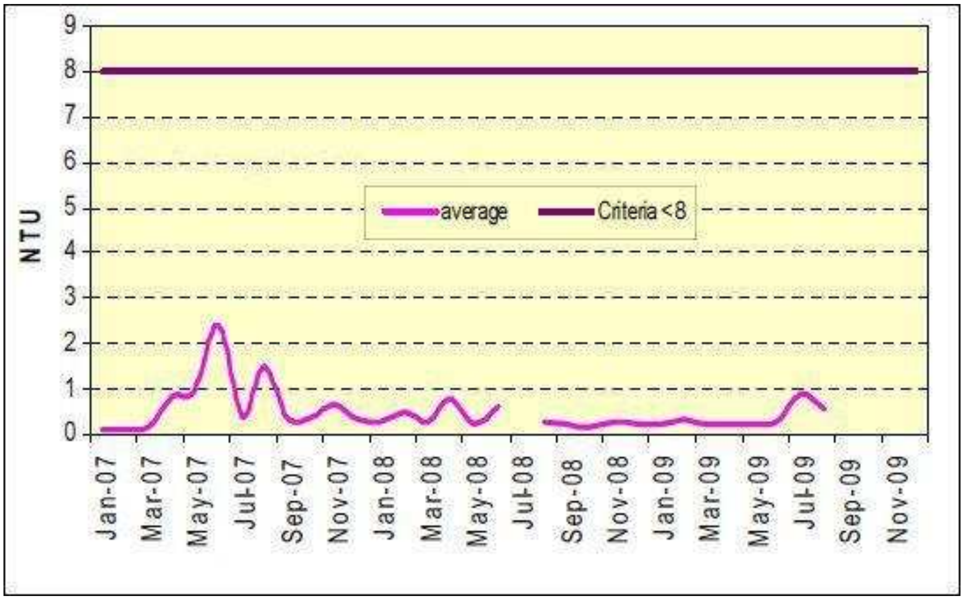


Figure 10.6. Perth I Desalination Plant Discharge Turbidity.

Source: Christie and Bonnelye, 2009

10.2 Gold Coast Desalination Plant, Australia

10.2.1 Facility Description

The Gold Coast 35-MGD (132,000-m^3/day) desalination plant is located in southeast Queensland, Australia, in an area that is a renowned tourist destination (see Figure 10.7). The desalination plant has been in operation since November 2008 and employs an open ocean intake, a gravity dual granular media filtration system for seawater pretreatment, and a two-pass, two-stage RO desalination system. Desalinated water produced by the plant is post-treated by lime stabilization and sodium hypochlorite disinfection. The backwash generated by the pretreatment system is treated in lamella settlers, dewatered in belt filter presses, and disposed of as sludge in a landfill. This plant is equipped with a Double Work Exchanger Energy Recovery (DWEER) pressure exchanger system for energy recovery.

10.2.2 Receiving Water Characterization

According to a recent publication presented at the 2009 World Congress of the International Desalination Association (Cannesson, 2009), the aquatic habitat in the area of the Gold Coast Desalination Plant discharge is a sandy bottom inhabited primarily by widely scattered tube anemones, sipunculid worms, sea stars, and burrowing sponges.

10.2.3 Description of Discharge Streams

The desalination plant discharges plant concentrate and treated spent filter backwash generated by the pretreatment system through its outfall. Spent cleaning solutions generated during RO train cleaning are equalized, neutralized, and discharged to the sanitary sewer.

Figure 10.7. Gold Coast Seawater Desalination Plant.

10.2.4 Description of Plant Outfall

The Gold Coast Desalination Plant is a stand-alone facility that discharges concentrate with a salinity of 67 ppt and a volume of up to 92 MGD (360,000 m³/day) through a multiple diffuser system. The regulatory mixing zone of this plant is 400 ft × 1050 ft (120 m × 320 m). The plant's discharge diffusers are located at the ocean bottom and discharge concentrate upwards into the water column to a height of approximately 34.5 ft (10.5 m; see Figure 10.8).

A minimum concentrate dilution ratio of 40:1 was predicted at 197 ft (60 m) from a diffuser port, thus ensuring diffuser performance objectives would be met. This was taken to define the regulatory mixing zone for calm marine conditions (currents ≤0.033 fps or 0.01 m/s) as assumed by the model. However, strong currents may enhance mixing and dilution, and the size of the plume may increase, distorting in the direction of the prevailing currents. Therefore, the regulatory mixing zone was extended up to 660 ft (200 m) from any diffuser port under "high kinetic" marine conditions (currents ≥1.64 fps or 0.5 m/s).

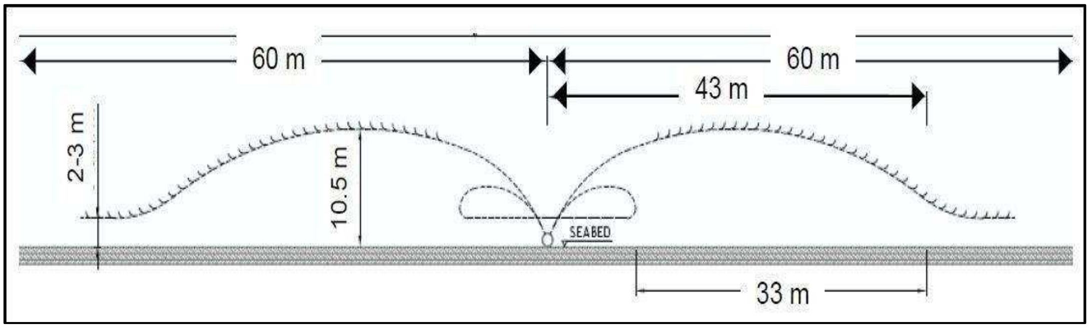


Figure 10.8. Discharge of the Gold Coast Seawater Desalination Plant.

10.2.5 Key Discharge Permit Requirements

Table 10.2 summarizes key discharge permit requirements of the Gold Coast plant.

Table 10.2. Gold Coast SWRO Desalination Plant – Key Discharge Permit Requirements – Permit No. EPPR00881713.

Permit Discharge Parameter	95th Percentile	Maximum	Minimum
Discharge volume		360,000 m^3/day (95 MGD)	
Distance from diffusers to edge of mixing zone		200 ft (60 m)	
Salinity of plant discharge	<67 ppt if BG < 38; otherwise 67 × BG/38	≤75 ppt if BG < 38; otherwise 75 × BG/38	
Turbidity of plant discharge	BG + 5 NTU	BG + 20 NTU	
DO concentration of plant discharge			3.4 mg/L
pH of plant discharge, standard units	8.5	9.5	5.5
Total chlorine	0.12 mg/L	0.70 mg/L	

Note: BG = background concentration in the ocean for a sample collected at the plant intake

10.2.6 Permit Compliance Observations

The actual dilution ratio at the end of the mixing zone is typically 16:1 or more (as compared to the regulatory target of 10:1 to meet WET requirements). For 18 months prior to the beginning of desalination plant operations, the project team completed baseline monitoring to document the original existing environmental conditions, flora, and fauna in the area of the discharge.

Once the plant began operations in November 2008, the project team completed marine monitoring at four sites around the discharge diffuser area at the edge of the mixing zone and at two reference locations 1640 ft (500 m) away from the edge of the mixing zone to determine environmental impacts and verify salinity projections.

Based on this data, the plant staff completed a Marine Contamination Risk Assessment (MCRA). The objective of the MCRA was to assess the ecological risk posed by each of the chemical additives used in the desalination treatment process that is likely to be retained in the effluent stream and discharged into the receiving environment.

This MCRA identified the toxicological risks posed by all known compounds in the desalination effluent from the Gold Coast Desalination Plant that could be considered contaminants to the receiving marine environment in the vicinity of the discharge location. The MCRA was based on a review of existing information and a limited number of assumptions regarding the operational performance of the desalination plant. The data obtained from the toxicity tests, in conjunction with data obtained from the Perth Seawater Desalination Plant, demonstrated a lowest-observed-effect concentration of concentrate that was higher than the expected maximum concentration of brine at the edge of the mixing zone at sea (60 m from any of the 14 diffuser nozzles).

As a part of the MCRA, the water quality and the benthic in-fauna abundance and diversity results after the start of Gold Coast plant operations were compared with the baseline monitoring results as well as with the results of the monitoring sites. The results of pre- and post-plant-commissioning clearly indicate that the desalination plant operations did not have a measurable impact on the marine habitat in the area of the discharge – the aquatic fauna practically remained the same in terms of both abundance and diversity. The Gold Coast Desalination Plant has been in operation for more than six years, and monitoring to date has confirmed that the plant's discharge is environmentally safe.

The results from the concentrate discharge monitoring completed at the Gold Coast SWRO Desalination Plant between March 2009 and February 2010 (Vargas et al., 2011) for the control and impact sites are shown in Table 10.3. As shown in this table, the 12-month median values for temperature, DO, salinity, and turbidity were within the plant discharge permit requirements.

10.3 Torrevieja Desalination Plant, Alicante, Spain

10.3.1 Facility Description

The 63-MGD (240,000-m^3/day) Torrevieja Desalination Plant located in the City of Alicante (see Figure 9.1) is the largest SWRO plant in Europe and one of the largest in the world. Although this plant was built in 2006, it began operation in the fall of 2013 because of delays associated with the regional government of Valencia granting the plant environmental discharge permit. As reported (WDR, 2011), the main reasons for the delay were political in nature and related to the change in Spain's central government and its policies.

The plant layout is shown in Figure 10.9. This plant has an open intake located approximately 1.8 miles (2.9 km) from the site that is constructed as a box attached to the west dike of the Alicante harbor. This configuration avoided an intake location in areas that have Poseidonia and Cymodocea seagrass fields. The source seawater is conveyed to 32 dissolved air flotation clarifiers, from which it is processed through 56 pressure dual media filters, 23 cartridge filters, and a SWRO system of 16 RO trains each equipped with a separate energy recovery system. The RO permeate is post-treated in a lime and carbon dioxide conditioning system. Approximately 50% of the finished water produced by the desalination plant is dedicated to the drinking water supply, and the rest to agricultural irrigation.

10.3.2 Receiving Water Characterization

The plant discharge is completed through a diffuser system located in an area of low biological significance (sandy bottom with no vegetation and scarce benthic marine life). The discharge is more than 0.5 miles (0.8 km) away from seagrass fields, coral reefs, kelp forests, and other habitats of marine life. The ambient salinity averages 37.5 ppt.

Table 10.3. Gold Coast Discharge Water Quality for Permit Regulated Compounds for the Period of March 2009 to February 2010.

Depth	Parameter	Median Value		Discharge Limit	
		Control	Impact	Min	Max
0–26 ft (0–8 m)	Salinity, psu	36.6	36.3	35.1	37.1
	Temperature, °C	21.2	21.2	19.9	24.0
	DO, mg/L	8.0	8.1	6.8	9.1
	Turbidity, NTU	0.9	1.0	None	3.2
	pH	8.1	8.0	8.2	8.4
40–66 ft (12–20 m)	Salinity, psu	36.9	36.8	35.0	37.2
	Temperature, °C	20.4	21.0	19.6	22.7
	DO, mg/L	8.0	8.1	6.8	9.1
	Turbidity, NTU	0.9	0.9	None	4.1
	pH	8.1	8.0	8.1	8.3

Figure 10.9. Torrevieja Desalination Plant, Alicante, Spain.

10.3.3 Description of Discharge Streams

The desalination plant concentrate is blended with the treated filter backwash water and neutralized spent RO membrane cleaning solution and is discharged continuously through two ocean outfall pipes that are equipped with diffusers and located one mile (1.6 km) offshore. The filter backwash water is treated in lamella settlers and dewatered by centrifuges. The spent RO membrane cleaning solution is neutralized in a separate retention tank to a pH of 7 to 9 and then blended with the rest of the plant discharge streams.

10.3.4 Description of Plant Outfall

The desalination plant outfall consists of two pipes with diameters of 94 in. (2400 mm) and 78 in. (2000 mm). Concentrate is discharged at a depth of 33 ft (10 m). The section of the outfall pipes that has diffusers is 1040 ft (315 m) long. Each outfall pipe has a total of 64 diffusers with a diameter of 6 in. (150 mm) each that are installed approximately 5 ft (1.5 m) above the ocean floor. The distance between diffusers is 16.5 ft (5 m). The diffusers are oriented at 50° upwards and are designed to operate at an exit velocity of 14.8 fps (4.47 m/s) and an exit flow of 1250 gpm (0.079 m^3/sec). The diffusers are designed so they can be capped to maintain a high concentrate stream ejection velocity (see Figure 10.10) when the plant is operated at low production capacity.

10.3.5 Key Discharge Permit Requirements

Table 10.4 summarizes the key desalination plant permit requirements. All of these requirements are applied to the discharge from the desalination plant prior to its mixing with the ambient seawater.

The plant permit has maximum flow limits for the three key desalination plant discharge streams:

- concentrate: daily, 77 MGD (293,000 m^3/day); instantaneous, 53,738 gpm (3.39 m^3/s); annual, 25,600 MG/year (97,000 m^3/year)
- spent filter backwash: daily, 7.7 MGD (29,000 m^3/day); annual, 2560 MG/year (9700 m^3/year)
- spent RO membrane cleaning solution: daily, 4.7 MGD (736 m^3/hr); annual, 1.31 MG/year (4960 m^3/year)

10.3.6 Permit Compliance Observations

Since its commissioning in mid-September 2013, the plant has been in compliance with its discharge permit. At present, the plant is operating at 20 to 50% of its capacity.

Figure 10.10. Capped Ocean Outfall Pipe.

Table 10.4. Torrevieja SWRO Desalination Plant – Key Discharge Permit Requirements – Permit No. 0300008774.

Permit Discharge Parameter	Daily Average	Maximum	Minimum
TDS, ppt		68.2	
TSS concentration, mg/L		3.5	
pH		9.0	7.0
Total iron, mg/L		0.5	
Total phosphorus, mg/L		0.2	
Total nitrogen, mg/L		1.5	
Total organic carbon (TOC), mg/L		3.0	
Detergents (sodium lauryl sulfate), mg/L		0.5	
DO concentration, mg/L		10	>80% of ambient
Temperature increment above ambient		3.0°C	

10.4. Alicante 1, Javea, and San Pedro del Pinatar Plants, Spain

10.4.1 Facilities Description

An independent overview of the discharges of three desalination plants in Spain [the 6-MGD (22,000-m^3/day) Javea SWRO Plant; the 18-MGD (68,000-m^3/day) Alicante 1 SWRO Plant; and the 18-MGD (68,000-m^3/day) San Pedro del Pinatar SWRO Plant] completed by the University of Alicante, Spain (Torquemada, 2009) provides insights related to the environmental impacts of desalination plant discharges. The three plants are located within 50 miles (80 km) of each other, and the salinity of their discharges is 68,000 to 70,000 mg/L. The Alicante 1 and San Pedro de Pinatar plants have well intakes, whereas the Javea plant has an open ocean intake. All plants have very similar treatment systems: source water chemical conditioning with iron coagulant, pressure filtration with granular media (anthracite and sand), and two-pass/two-stage SWRO membrane desalination. Permeate of all three plants is treated by lime/carbon dioxide conditioning.

10.4.2 Receiving Water Characterization

The Alicante 1 SWRO Plant discharges its concentrate in a turbulent and tidally well-mixed area via one onshore outfall. This feature of the desalination plant discharge allows the Alicante plant to operate without measurable environmental impacts even at a relatively low mixing ratio of 1.5:1 to 5:1 between the concentrate and ambient seawater at the edge of the mixing zone.

10.4.3 Description of Discharge Streams

All three desalination plants discharge a combination of concentrate, untreated filter backwash water, and spent membrane cleaning solution that is pH adjusted.

10.4.4 Description of Plant Outfalls

The discharge of the Alicante SWRO Plant is located directly on the shoreline to take advantage of the turbulent tidal mixing that naturally occurs in the discharge area. The discharge of the San Pedro del Pinatar SWRO Plant is through a diffuser located 3.1 miles (5 km) away from the shore at 150 ft (38 m) depth.

The discharge of the Javea SWRO Plant is in an open canal that then carries the concentrate into the ocean. The concentrate from this plant is diluted in the channel from 69,000 mg/L down to 44,000 mg/L in a 4:1 mixing ratio. This salinity level was found not to have a negative impact on the marine habitat in the discharge area.

10.4.5 Key Discharge Permit Requirements

The three desalination plants have discharge permit requirements similar to those of the Torrevieja SWRO Plant.

10.4.6 Permit Compliance Observations

All three desalination plants have been in operation for more than five years each. The water quality and environmental monitoring of the three discharges indicates that the size of the salinity plume and the time for the dispersion of the salinity plume vary seasonally. These variations, however, have not affected the benthic organisms inhabiting the seafloor.

The desalination discharge of the Javea plant has high oxygen levels that diminish the naturally occurring apoxia in the area of the discharge. The independent overview emphasizes the fact that well-designed desalination discharge can result in minimal environmental impacts and in some cases can be beneficial to the environment because of its high oxygen content.

10.5 Maspalomas II Desalination Plant, Canary Islands, Spain

10.5.1 Facility Description

The Maspalomas II Desalination Plant is located on Gran Canarias and has a freshwater production capacity of 0.8 MGD (3000 m^3/day). The treatment plant has a pressure driven pre-filtration system with anthracite and sand media, cartridge filters, and a two-pass/two-stage SWRO system with ERI pressure exchangers.

10.5.2 Receiving Water Characterization

The Maspalomas discharge conditions are challenging: (1) very high salinity of the concentrate (90,000 mg/L) and (2) seagrass habitat for fish and other marine organisms. Because of the naturally occurring near-shore mixing, the salinity of the discharge is dissipated down to 38,000 mg/L (38 psu) within 66 ft (20 m) from the discharge point, as shown in Figure 10.11. The salinity in this figure is presented in psu, which have the same value as ppt of salinity concentration.

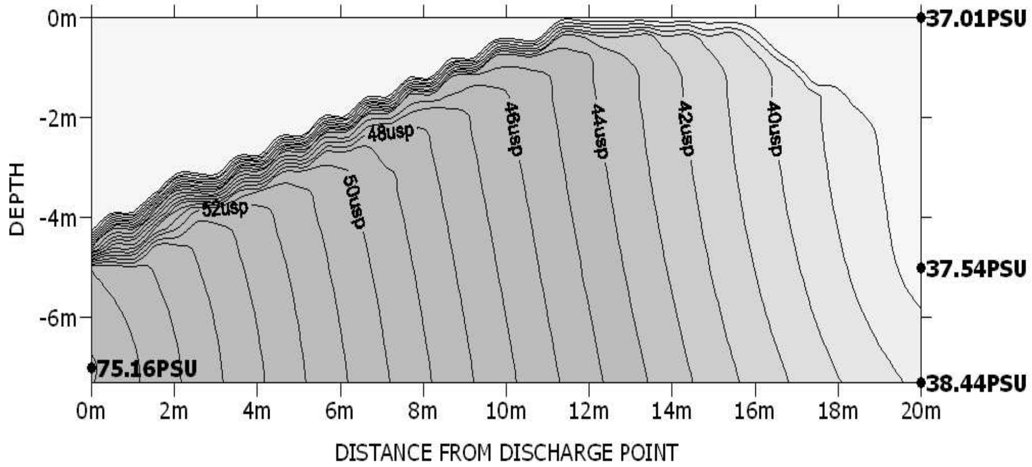


Figure 10.11. Discharge of the Maspalomas II Desalination Plant.

10.5.3 Description of Plant Outfall

The plant has two concentrate outfalls that extend 1000 ft (300 m) away from the shore (Talavera and Ruiz, 2001). The outlet of the discharge outfalls does not have diffusers (see Figure 10.12), and the mixing between the concentrate and ambient seawater is mainly driven by the velocity of the discharge and the fact that the discharge is located in an area with naturally occurring underwater currents of high intensity. The depth of the discharge is 25 to 26 ft (7.5-8.0 m).

10.5.4 Key Discharge Permit Requirements

The desalination plant has discharge permit requirements similar to those of the Torrevieja SWRO Plant.

10.5.5 Permit Compliance Observations

The mixing zone of the Maspalomas II Desalination Plant is a sandy bed with practically no flora. This zone is surrounded by seagrass beds, but, as shown by an environmental study of the discharge area, they are not significantly affected by the desalination plant discharge.

10.6 Ashkelon Desalination Plant, Israel

10.6.1 Facility Description

The Ashkelon Desalination Plant was the first large SWRO desalination plant in Israel, and it has a freshwater production capacity of 85 MGD (322,000 m^3/day). The plant has been in operation since 2005 and provides approximately 15% of the domestic water supply of Israel (Sauvet-Goichon, 2007). In 2011, the desalination plant produced 87 MGD (330,000 m^3/day) of desalinated water (Drami et al., 2011).

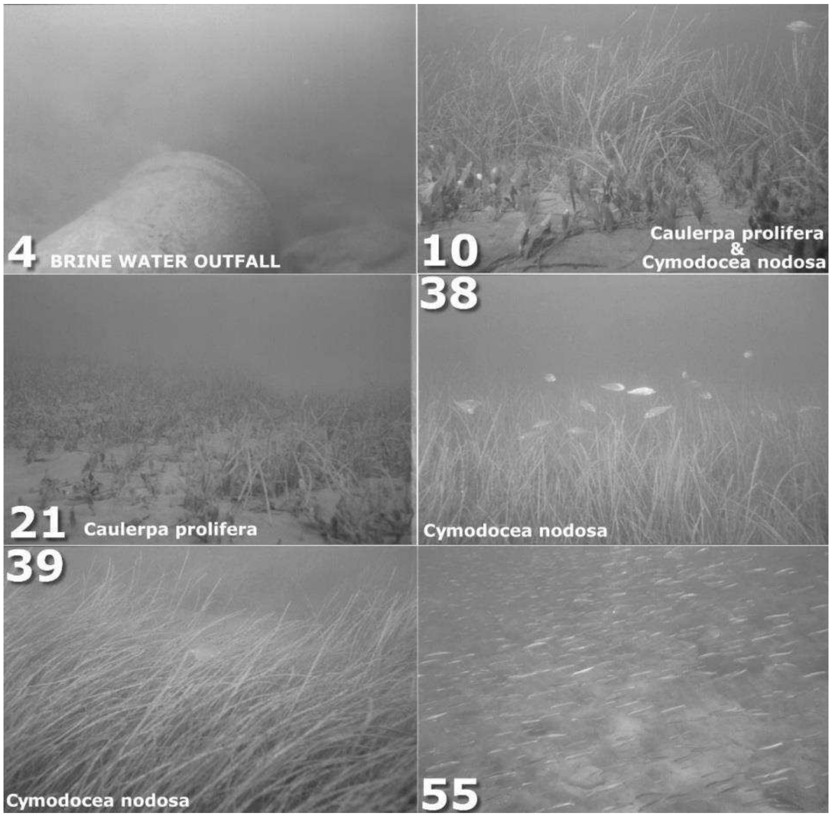


Figure 10.12. Discharge of the Maspalomas II Desalination Plant.

Source: Talavera and Ruiz, 2001

The desalination plant consists of an offshore intake with four intake towers located approximately 3300 ft (1000 m) from the shore at a depth of 50 to 65 ft (15-20 m). The source water from the intake towers is conveyed to the plant intake pump station at the shore via 63 in. (1600 mm) high-density polyethylene pipes. The five (4 + 1) intake pumps deliver the source water to 20 single-stage dual media (anthracite and sand) gravity filters. Coagulant (ferric sulfate or ferric chloride) is added to the source seawater, and this water is pH adjusted with sulfuric acid prior to filtration (see Figure 10.13). Figure 10.14 shows the plant layout. The pretreated water is processed through cartridge filters and then desalinated via membrane separation in a four-stage SWRO system. The complex four-stage design of this plant is driven by the very stringent limits for chloride and boron content in the product water – 20 mg/L and 0.4 mg/L, respectively.

The energy contained in the RO system concentrate is recovered using Double Work Exchanger Energy Recovery (DWEER) devices. The desalinated water produced by the SWRO system is post-treated using limestone filters. Plant feed seawater temperature varies between 59 and 86°F (15-30°C), and its salinity is in the range from 39,000 to 41,000 mg/L (average 40,679 mg/L).

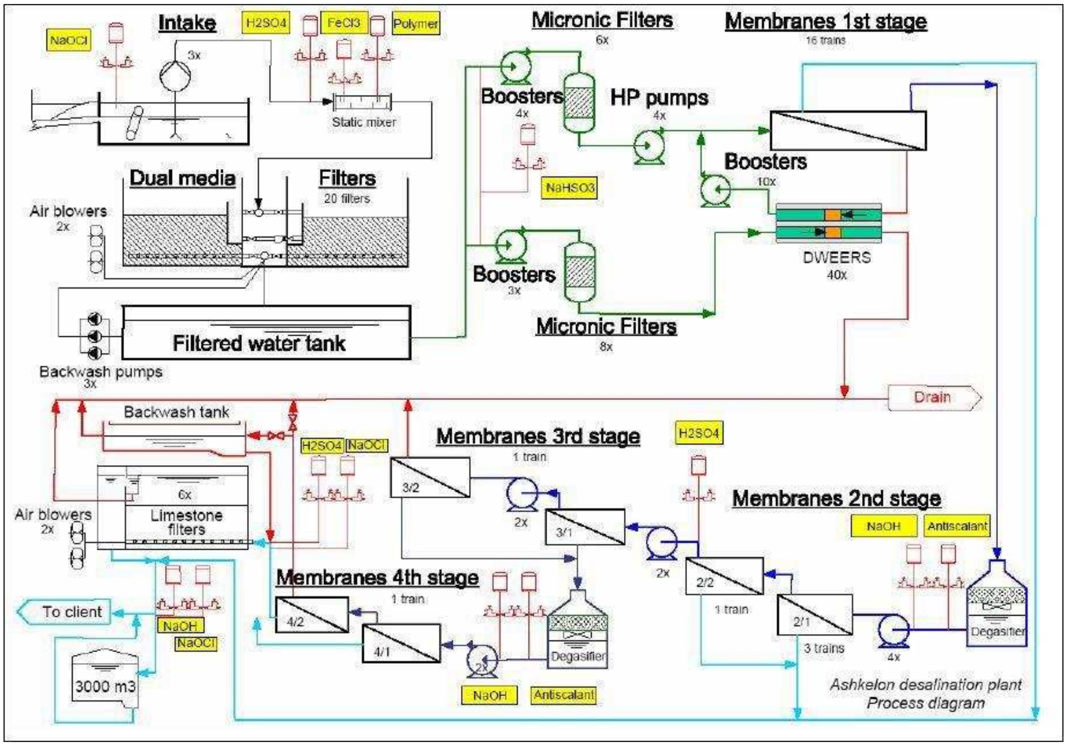


Figure 10.13. Schematic of the Ashkelon SWRO Desalination Plant, Israel.

Figure 10.14. Ashkelon Desalination Plant Intake, Outfall, and Site Locations.

10.6.2 Receiving Water Characterization

The receiving water area is a near-shore rocky environment with a high level of natural mixing from currents, wind, and tidal movement. Approximately 3300 ft (1 km) south of the discharge, there is a marine reserve (“Yam Shikma”). The near-shore waters where the discharge is delivered are characteristic with exceptionally low nutrient concentrations, algal content, and bacterial content, and a low presence of other fauna. The near-shore area of the discharge was already modified by anthropogenic activity at the time of plant construction, and the plant is located in an industrial area.

The receiving near-shore waters of the Ashkelon plant are high-energy, well-flushed environments with sandy bottoms devoid of aquatic life, unique biological resources, and endangered marine habitats.

10.6.3 Description of Discharge Streams

The main discharge stream from the plant is the concentrate, which is approximately 95% of the total discharge volume. The remaining 5% consists of untreated backwash water from the pretreatment system and equalized and neutralized spent membrane cleaning solutions. When the plant began operation, the spent filter backwash water from the plant was discharged directly to the ocean as generated.

Because of the high content of ferric hydroxide in the water, originating from the pretreatment coagulant, ferric chloride, the discharge was discolored red every time a filter was backwashed for a period of 10 to 20 minutes. To address this concern, the plant has installed a backwash equalization tank that retains the individual filter cell backwashes and slowly and continuously discharges the filter backwash with the concentrate, thereby addressing the issue associated with the visible discoloration of the discharge area.

10.6.4 Description of Plant Outfall

The Ashkelon Desalination Plant has an onshore outfall, which is located within 82 ft (25 m) of the outfall of the nearby Rutenberg Power Station, operated by the Israeli Electricity Company (IEC; see Figure 10.15). The desalination plant discharge volume averages between 110 and 130 MGD (416,000-493,000 m^3/day) at the average plant freshwater production of 72 MGD to 87 MGD (274,000-320,000 m^3/day). The power plant discharges 3040 MGD (11,506,848 m^3/day), which dilutes the concentrate in a ratio of 35:1 to 42:1. In a worst-case scenario with only two of the four power plant outfalls discharging, the dilution ratio is 10:1.

10.6.5 Key Discharge Permit Requirements

Table 10.5 summarizes the key desalination plant permit requirements. All of these requirements are applied to the discharge from the desalination plant prior to its mixing with the ambient seawater.

Table 10.5. Ashkelon SWRO Desalination Plant – Key Discharge Permit Requirements – Permit No. 513102384.

Permit Discharge Parameter	Daily Average	Maximum	Minimum
Suspended solids concentration, mg/L	15	20	
Turbidity (15-min average)	15 NTU	30 NTU not more than 4% of the time; 100 NTU not more than 1% of the time	
pH		9.0	6.5
Total iron	2 mg/L	190 tons/year	
Total phosphorus		40 tons /year	
Temperature increment above ambient water		5° C	
Total nitrogen		11 tons/year	
Total organic carbon (TOC)		24 tons/year	
Ag, As, Cd, Cu, Cr, Hg, Ni, Pb, Zn		Within 10% of ambient water	
DO concentration			≥80% of ambient

10.6.6 Permit Compliance Observations

The Ashkelon desalination permit requires monitoring of the water quality near the surface and near the bottom of the discharge area for a number of parameters including temperature, salinity, TSS, turbidity, pH, DO, BOD, total organic carbon (TOC), nutrients, chlorophyll a, and heavy metals. In addition, bottom sediments are analyzed for heavy metals and suspended particular matter, granulometry, TOC, infauna, and epifauna. Monitoring is carried out quarterly. The monitored zone around the discharge is an elliptically shaped area with its major axis parallel to the coastline; it extends up to 0.9 miles (1.5 km) to the north and south of the plant outfall. The minor axis extends a few hundred feet west and east of the outfalls. In Ashkelon, the special distribution of the seawater salinity and the temperature are also measured over wider areas – approximately 1.9 miles (3 km) from the outfall. The monitoring program includes a control station located 1.5 miles (2.5 km) away from the outfall.

The hydrodynamic model developed for this project indicated that the salinity of the discharge would reach 10% of the ambient seawater salinity within 120 ft (400 m) from the outfall. In-situ monitoring, however, indicates that the salinity is well within 3% of the ambient within 1650 ft (500 m) from the point of discharge.

In 2005, the desalination plant completed a concentrate dispersion monitoring study (Safari and Zask, 2008). The study was completed during a period when the plant operated at only half of its capacity and when one of the power plant units was not in operation. Figure 10.15 depicts the salinity distribution in the discharge area. As shown, the salinity in the discharge area reached very close to the ambient level within a very short distance of the point of discharge.

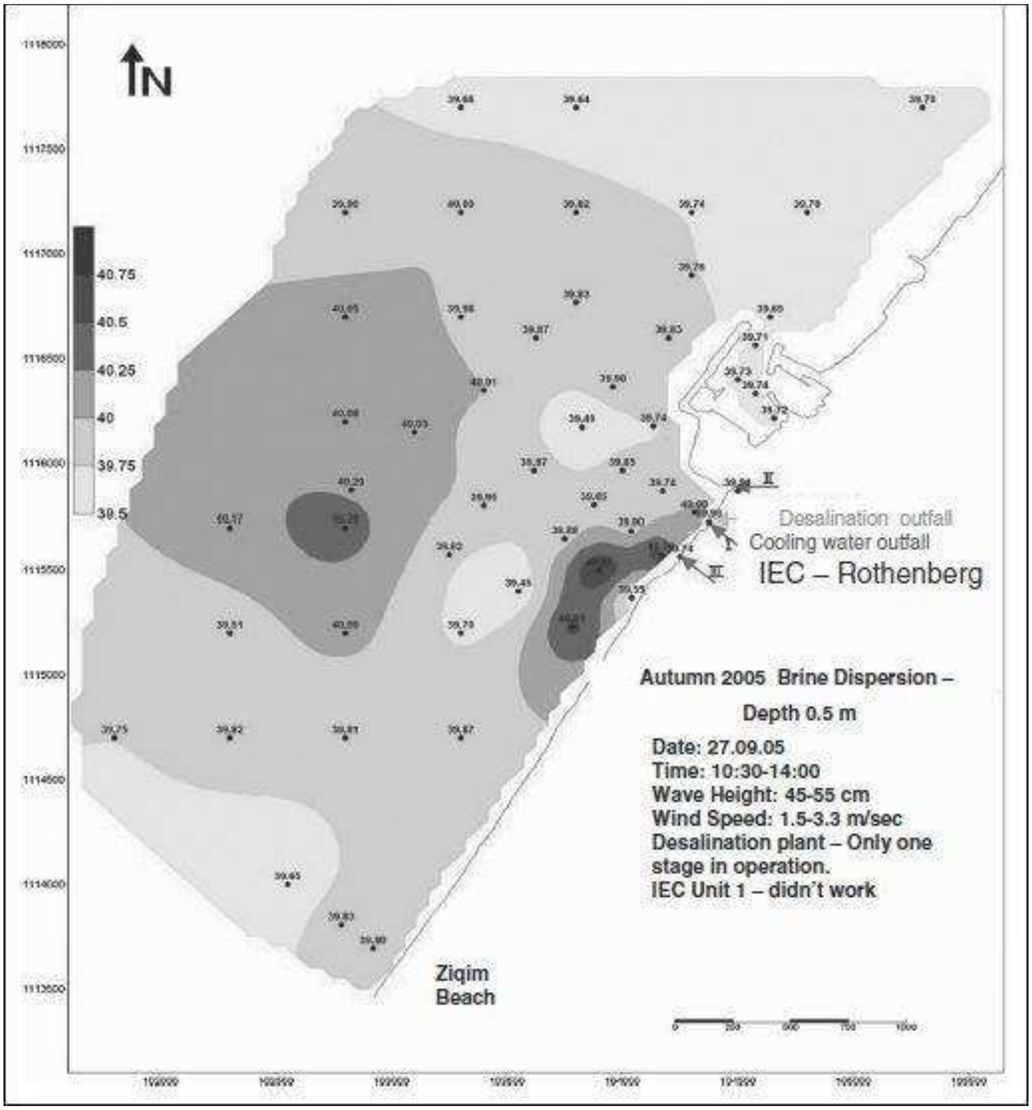


Figure 10.15. Salinity Distribution of Ashkelon Desalination Plant Discharge.

A comparison of the marine environment before (in 2003) and after the commissioning of the desalination plant (2005) indicates that the desalination plant discharge resulted in some discharge exceedances (Safari and Zask, 2008), including an elevated content of total nitrogen, some occurrences of oxygen levels lower than 80% of the ambient intake water during the autumn of 2005, and elevated TOC concentrations on several occasions when comparing autumn and spring of 2003 and 2005. It should be pointed out that these effects are cumulative impacts from three discharges in the same vicinity: the Ashkelon Desalination Plant; the IEC power plant, which is a once-through power generation facility; and a smaller 0.5-MGD (2000-m³/day) BWRO desalination plant. Although the BWRO plant has a relatively small discharge volume, its contents of nitrogen, phosphorous, and silica are an order of magnitude higher than those of the Ashkelon Desalination Plant.

A study completed from 2008 to 2009 (Drami et al., 2011) has also evaluated nutrient, chlorophyll a, pico-phytoplankton, and iron concentrations in the discharge area. At the time of the study, the plant discharged 85 MGD (320,600 m³/day) of concentrate, and concentrate salinity was 75,300 mg/L. The nearby power plant discharged an average of 1953 MGD

(7,392,000 m^3/day) during the same period. The desalination plant discharge contained concentrate, untreated spent filter backwash, and spent cleaning solutions from periodic RO cleaning. The amount of iron discharged to the ocean in 2007 was 535 tons/year, whereas in the years 2008 and 2009 this amount was reduced to 270 and 175 tons/year, respectively. The content of total iron in the concentrate varied between 0.2 and 1.1 mg/L, which is in compliance with the discharge limit of this plant (2 mg/L). Since 2010, the backwash water has been equalized and continuously mixed with the plant concentrate prior to discharge, which keeps the discharge level of iron in the source water below 2 mg/L.

The discharge also typically contains polyphosphonate antiscalant (34 tons/year as total phosphorus); hydrochloric acid (15 tons/year); sodium hydroxide (20 tons/year); and sodium bisulfite (70 tons/year). Figure10.16 indicates the sampling locations used for the 2008 to 2009 discharge study. On this figure, the Ashkelon SWRO plant is denoted "A" and the nearby power plant "B." The location of the desalination plant discharge outfall is indicated as "2," and the three cooling water outfalls of the power plant are shown as "1." Line "3" represents the coal unloading dock of the power plant; line "4" depicts the location of the discharge sampling area; and "W" is the location of the sampling station for background (ambient) seawater quality. The location of the seawater intake is depicted as "SWRO," and that of the power plant cooling water intake is shown as "CW." Samples were collected before and during filter backwash discharges to capture peak and off-peak levels of iron in the discharge. Desalination plant and power plant discharges were sampled separately to discern the impact of the cooling water discharge on desalination plant plume dispersion.

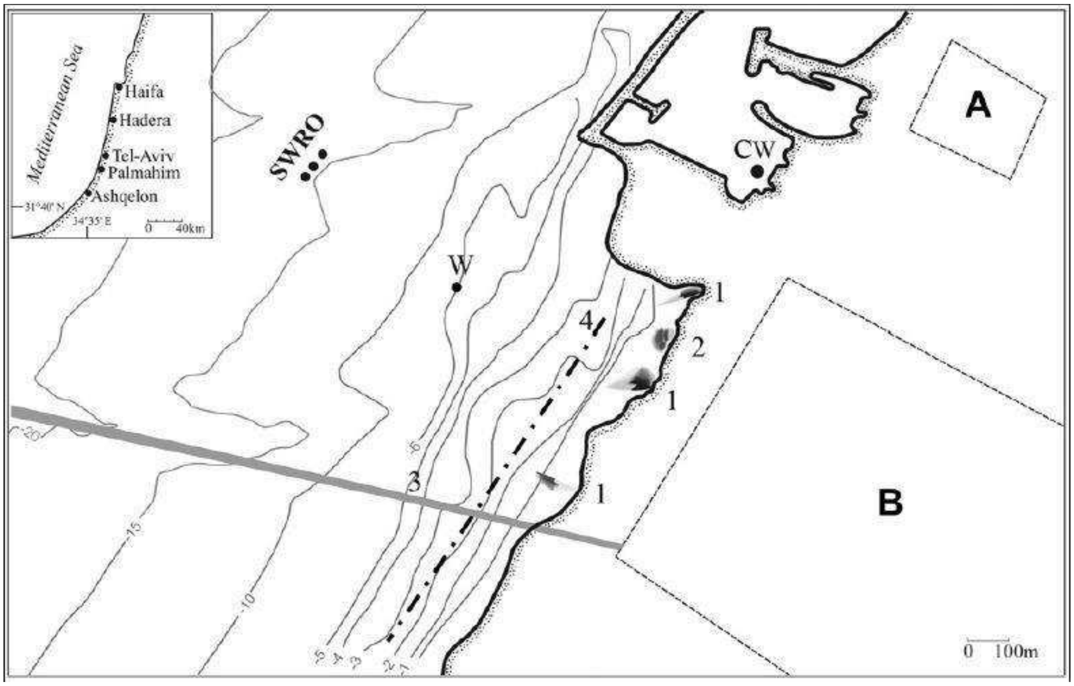


Figure 10.16. Sampling Locations for the 2008 to 2009 Ashkelon Discharge Study.

The 2008 to 2009 discharge study indicates that the power plant and desalination plant discharges blended within 165 ft (50 m) of the shore and that the blended concentrate and power plant discharge was buoyant, which allowed the effective dispersion of the concentrate to near background levels within 1650 ft (500 m). The maximum salinity measured in the sampling locations was 41.5 ppt as compared to a background of 38.42 ppt (8% increment). At this measurement, the maximum temperature of the surface layer of the blended plume water was 86.7°F (30.4°C) compared to a background seawater temperature of 72.1°F

(22.3°C); such temperatures were reached in the spring of 2008. The actual salinity measurements were lower than those projected using hydrodynamic modeling of the discharge.

Nutrient concentrations (total nitrogen, total phosphorus, nitrates) were higher at the outfall but quickly diminished within 820 ft (250 m) of the discharge. The algal content (measured as chlorophyll a) was lower at the outfall and discharge sampling locations compared with background levels, which indicates that the discharge of iron did not trigger accelerated algal growth and algal blooms as claimed by some environmental groups concerned about the impact of desalination plant discharge on the environment. The decreased content of algae in the water was positively correlated with the salinity and temperature of the discharge: the higher the salinity and temperature, the more significant the suppression of algal growth observed in the area of the discharge. Elevated turbidity and particularly iron content in the discharge were found to also have a suppressive effect on the growth of algae in the area of the discharge. Similar effects of the plant discharge were observed on bacterial production: bacterial growth was reduced with an increase in temperature, salinity, iron content, and turbidity.

10.7 Sorek Desalination Plant, Israel

10.7.1 Facility Description

The Sorek Desalination Plant has a freshwater production capacity of 108 MGD (410,000 m^3/day) and is one of the largest membrane desalination plants in the world (see Figure 10.17).

Figure 10.17. General Layout of the Sorek SWRO Plant, Israel.

The plant has been in operation since the end of 2013 and has incorporated some of the latest technological developments in the field of desalination technology and equipment such as 16 inch SWRO elements, vertically installed pressure vessels, and an advanced energy recovery system.

The Sorek Desalination Plant is located 1.5 miles (2.4 km) away from the Mediterranean shore and approximately nine miles (15 km) from Israel's capital, Tel Aviv. The plant has an open intake with two intake towers, which are located approximately 0.7 miles (1150 m) offshore at a depth of approximately 20 ft (6 m) from the ocean surface and 13 ft (4 m) from the bottom. The source water is delivered to the desalination plant site via two feed water pipelines. The plant is configured to operate as two independent 54-MGD (205,000-m^3/day) facilities with separate pretreatment, RO, and post-treatment systems.

The plant pretreatment system consists of single-stage gravity filters with anthracite and sand media. The source seawater is conditioned with coagulant (ferric chloride) prior to filtration. After granular media filtration, the pretreated water passes through cartridge filters and is fed to a SWRO system designed with a three-pressure center configuration, similar to that at Ashkelon, where all RO trains are fed by a common set of high-pressure pumps and where energy from the concentrate is recovered in an energy recovery system common for all trains. (In conventional designs, each RO train is serviced by a separate set of high-pressure pumps and a separate energy recovery system.)

The RO system employs 16-in. elements located in vertical pressure vessels. Although such a design makes the plant RO system fairly tall and complex, it significantly reduces its footprint, which is an important feature for this desalination plant site because of the severe site constraints. The post-treatment of the desalinated water is identical to that in Ashkelon and employs limestone contactors.

10.7.2 Receiving Water Characterization

The discharge area selected for the desalination plant outfall is an underwater "desert" with a sandy bottom and is void of flora and fauna with low salinity tolerances and endangered or sensitive marine species. The depth of the discharge area is approximately 66 ft (20 m) from the surface.

10.7.3 Description of Discharge Streams

The average discharge volume of the plant concentrate is 130 MGD (490,000 m^3/year), and its salinity is 74,150 mg/L. The plant pretreatment backwash volume averages 16 MGD (60,600 m^3/day). In contrast with Ashkelon, the spent filter backwash from the pretreatment system is treated in lamella settlers prior to blending with the plant concentrate and discharge to the sea. The sludge generated in the lamella settlers is dewatered in centrifuges and disposed of in a landfill.

10.7.4 Description of Plant Outfall

The desalination plant outfall is a structure located 1.2 miles (1850 m) offshore at a discharge depth of 66 ft (20 m). The outfall structure has diffusers at the ends of the discharge pipes. Based on discharge dispersion modeling, under worst-case natural mixing conditions in the sea, the discharge salinity is projected to be within 5% of ambient at a distance of 380 ft (115 m) from the diffusers and within 1% of ambient salinity at 2800 ft (845 m) away from the discharge (Kit et al., 2011). The discharge will be within 10% of the ambient salinity at a distance of 66 ft (20 m) from the diffusers (Sladkevich et al., 2011).

10.7.5 Key Discharge Permit Requirements

Table 10.6 presents the discharge requirements for the Sorek SWRO Plant discharge.

10.7.6 Permit Compliance Observations

Since the plant began operation in late 2013, it has been in compliance with its discharge requirements. Follow up discharge area monitoring is scheduled to be completed in 2015.

Table 10.6. Sorek SWRO Desalination Plant – Key Discharge Permit Requirements – Permit No. 8633520.

Permit Discharge Parameter	Daily Average	Maximum	Minimum
Suspended solids concentration, mg/L	5	20	
Turbidity (15-min average)	10 NTU	15 NTU not more than 7% of the time; 50 NTU not more than 3% of the time	
pH		9.0	6.5
Total iron	0.5 mg/L	56 tons/year	
Total phosphorus		60 tons/year	
Total nitrogen		16 tons/year	
TOC		31 tons/year	
Ag, As, Cd, Cu, Cr, Hg, Ni, Pb, Zn		Within 10% of ambient water	
DO concentration			≥80% of ambient

10.8 Analysis and Comparison of Permitting Practices

10.8.1 Country Permitting Systems

Permitting practices in Australia, Spain, and Israel have a number of similarities to those in the United States. In all of these countries at present, there are no specific regulations or regulatory guidelines for the permitting of desalination plant discharges, and the regulations and permitting processes for such discharges are the same as those applied for the permitting of discharges from WRRFs. Australia has the discharge regulations most similar in structure to those in the United States, where the federal government has established the baseline legal framework for the regulation of waste discharges, and the individual states have enhanced the federal regulations with state- and location-specific regulatory requirements.

Despite the similarities, the permitting of medium and large projects in the United States usually takes longer than it does in Australia, Spain, and Israel. For example, the permitting of the Tampa Bay and Carlsbad SWRO desalination projects was completed within 2.4 years and five years, respectively. In contrast, the average time needed to permit similar size projects in Australia is 1.5 to two years and in Spain and Israel is nine to 12 months. The main reasons are as follows:

- Streamlined regulatory process: Usually only one or two agencies are involved in the environmental review of the desalination project as compared to four to six agencies in most U.S. states and up to 24 agencies in California.
- Priority review of desalination projects: Spain, Israel, and Australia recognize the national and state strategic importance of seawater desalination for securing a sustainable and drought-proof long-term water supply in their countries. As a result, they have long-term plans for the development and implementation of desalination projects, which are under the close oversight of the central government in Spain and Israel and the state government in Australia. Because the timely implementation of such plants is considered of high importance and priority for the respective countries, the regulatory agencies are given support at the federal level in the case of Spain and Israel, and at state level in the case of Australia, in terms of expertise, direction, and funds, to expedite and give priority to the environmental review of desalination projects as compared to other types of projects.
- Superior expertise of regulatory agencies in the permitting of desalination plants: In the United States, mainly because of funding constraints, many of the regulatory agencies involved in the permitting of desalination projects do not usually maintain staff with all the types of expertise needed to complete an expedited review of desalination projects, such as marine biologists, experts in outfall discharge modeling, and engineers with experience in the design and operation of desalination plants. In contrast, the key agencies involved in desalination project review in Spain, Australia, and Israel have such experts on staff or, if such experts are not originally available, they are retained in an expeditious manner at the beginning of the environmental project review to minimize the time needed. Most of the agencies involved in desalination review in California, for example, do not have such experts, and as a result, the environmental review process goes through six to 12 rounds of requests for additional information by the regulatory agency reviewers because they learn on the job and ask their questions piecemeal as they learn more about the project.
- Sharing of regulatory expertise between various agencies: In all of the listed countries, the key regulatory agencies involved in the permitting of desalination projects have internal meetings where they share their experience with various permitting issues. Such regulators also actively participate in professional conferences and public forums, presenting in a clear manner their requirements and expectations associated with the type and detail of information needed from the project sponsors to minimize the time needed for project permitting. Mainly because of a lack of funds, U.S. regulators involved in the permitting of desalination projects usually do not have such professional experience exchange opportunities in or out of state and rarely attend professional conferences or present their expectations in professional forums.

In all countries referenced previously, the desalination plant permits are issued after a thorough environmental review of the impact of the plant discharge on the surrounding aquatic environment. The impact is determined based on the following:

- Projections of concentrate water quality are developed based on a source seawater quality characterization and on the specific design features of the desalination plant (plant recovery, product water quality, and type of intake and discharge).

- A biological survey of the discharge area documents the type and quantity of marine species inhabiting this area and their salinity tolerance.
- In all of the referenced countries, the salinity tolerance of marine organisms is determined based on chronic or (in the case of some Australian states) acute WET testing of the most sensitive species inhabiting the discharge area. In Australia, the marine organisms are tested in the embryonic stage of development, which results in the most stringent requirements for concentrate dilution, as compared to those in Spain and Israel, where the test species used for determining the salinity tolerance are in the adult phase.
- The mixing requirements for a desalination project are determined based on the WET testing study and hydrodynamic modeling of the discharge area.

In Spain and Israel, usually only one environmental regulatory agency has the right to make decisions and establish discharge permit requirements and mitigation measures. If other agencies are involved in the project review, they provide comments to the lead agency but have no right or jurisdiction to change the permitting requirements except by internal consensus. In Australia, key decisions are made at a state level by one lead agency. In contrast, the independent multi-agency review process typical in states such as California results in numerous conditions and permits that regulate the discharge and that may have different requirements in terms of the mitigation of environmental impacts. Such practices not only delay the permitting process but also put a significant burden on the project sponsor associated with project implementation, operations monitoring, and data reporting.

10.8.2 Country Positions on Key Permitting Issues

Australia, Spain, and Israel have similar positions on key permitting issues. The following discussion mainly emphasizes the differences in some of these key issues:

- Discharge salinity or conductivity limit: None of the referenced countries has a limit for discharge salinity or conductivity. Despite this fact, the discharge permits of some of the Australian desalination projects have a conductivity limit applicable to the point of entry of the discharge into the waterbody. Such a limit is usually determined based on the worst-case design recovery and maximum plant production.
- WET testing species and conditions: Usually, WET testing in Australia, Spain, and Israel is completed using the standard test species (plant, fish, and crustacean) that are prescribed in each country's testing protocols. If no suitable standard test species are identified, habitat-specific test species are selected based on mutual agreement with the pertinent regulatory agencies. In Australia, acute and chronic WET testing is completed on species in the juvenile phase to establish the dilution ratio needed by the desalination plant outfall system. The Spanish and Israeli WET testing protocols typically prescribe the use of juvenile species for acute WET testing and adult species for chronic testing and apply the chronic WET testing results to establish the dilution ratio needed by the plant outfall. As a result, the concentrate dilution requirements derived from the WET testing in Australia are usually higher (45:1 to 60:1) than those in Spain and Israel (10:1 to 20:1). This more conservative approach to WET testing used in Australia results in much more costly and elaborate outfalls, which is one of the key reasons why the desalination plants constructed in this country were the most costly desalination projects completed over the last 20 years, worldwide. The dilution ratios selected for most of the Australian desalination projects were conservative because the approval process for these plants was

quite new for the regulators; conservative ratios were often adopted to speed up the approval process because of the pressing water issues that required the construction of the plants. Another factor that amplified the conservative estimation of the required dilution ratios was the use of relatively long acute WET tests (72 h vs. a typical duration of 48 h or 24 h) and chronic WET tests (14 days vs. a typical duration of seven days).

- Biological survey: All medium and large projects in Australia, Spain, and Israel are required to complete a biological survey of the area of the plant discharge. However, the scope of such survey is most elaborate in Australia in terms of the number of representative areas and sampling points and the frequency of data collection. Such enhanced testing requirements have resulted in elevated project costs, and, based on a comparative analysis of the environmental monitoring of existing desalination plants in Australia, Spain, and Israel, the more complex, frequent, and elaborate sampling has not produced better results. To a great extent, the main reason is the fact that the discharge diffusers are designed to dilute the concentrate down to less than 10% of ambient conditions within 330 ft (100 m) from the point of discharge, but the monitoring field usually extends to more than several kilometers from the discharge and at such distance the salinity changes are indiscernible and well within the level of the accuracy of the monitoring instruments.
- Salinity tolerance of marine species: In all of the referenced countries, the salinity tolerance of marine species is determined based on mortality effects. It is interesting to note that for the species monitored in the reference projects, the salinity tolerance limits (40-50 ppt) are relatively high compared to the new salinity limit promulgated in the latest California Ocean Plan – 2 ppt above ambient salinity, which for open ocean water will be 33.5 ppt + 2 ppt = 35.5 ppt.
- Environmental impacts from concentrate discharge: The long-term operational experience at the projects referenced in the report clearly demonstrates that well-designed desalination plants and concentrate discharge outfalls do not cause short- or long-term environmental damage.

Chapter 11

Findings, Conclusions, and Recommendations

11.1 Introduction

This report identified and researched environmental-impact-related issues associated with SWRO desalination concentrate discharge. Regulatory and permitting systems and practices in three U.S. states (California, Florida, and Texas) and in three countries (Australia, Israel, and Spain) were examined to identify and document how issues of concentrate discharge were addressed and managed. The findings, highlighted in the following paragraphs, show many similarities and some unique differences. The final sections of this chapter address conclusions and recommendations.

11.2 Regulatory Guidelines for SWRO Concentrate Discharge

Because the majority of the existing desalination plants in the United States are located in California, Florida, and Texas, these states have the most experience and the most advanced regulatory framework for the permitting of such projects. All three of the primary states in the United States (California, Florida, and Texas), which are the focus of this study, are delegated to operate the NPDES program in their state.

The Texas Water Development Board has developed a generic guidance document clarifying the permitting agencies involved in the permitting of desalination projects in Texas; it is relatively old (2004). In California, The CCC has prepared a position paper that presents its views on the permitting of desalination projects; it also is quite outdated (2004).

The Guidelines for Implementing Seawater and Brackish Water Desalination Facilities (WRF, 2010)provide a general overview of permitting and regulatory requirements and challenges in the United States. Texas and California have state-specific general guidelines for desalination project environmental planning, review, and permitting (R.W. Beck, 2004; CDWR, 2008).

These documents do not contain any specific technical details or engineering guidance [as are contained in the Ten State Standards (GLUMRB, 2012) and in the U.S. EPA Water Reuse Guidelines (U.S. EPA, 2012)] related to the scope and nature of the environmental studies needed and to specific design and planning recommendations to expeditiously permit and successfully complete a desalination project.

Thus, at present, there are no legally binding desalination-project-specific regulations or publically available regulatory guidelines specifically for desalination projects in the states of California, Florida, and Texas issued by the state agencies responsible for the environmental review and the permitting of such projects. State regulators issue desalination project permits based on their prior experience with similar projects.

The lack of federal regulatory guidelines for the implementation and permitting of desalination projects has arguably hindered the implementation of many desalination projects in the United States, especially those in California and Florida. Development of federal desalination guidelines similar to the U.S. EPA Water Reuse Guidelines (U.S. EPA, 2012) would benefit significantly the advancement and implementation of desalination projects in the United States and provide an independent source of information to all stakeholders in future desalination projects. Similar to the Water Reuse Guidelines, the desalination guidelines could share the successes and lessons learned from other projects and could streamline the data that needs to be collected and the studies that need to be conducted to complete the environmental review of desalination projects more expeditiously.

Similarly to the United States, in Australia, Spain, and Israel at present there are no specific regulations or regulatory guidelines for the permitting of desalination plant discharges, and the regulations and permitting process for such discharges are the same as those applied to the permitting of discharges from WRRFs. Australia has the discharge regulations most similar in structure to those in the United States, where the federal government has established the baseline legal framework for the regulation of waste discharges, and the individual states have enhanced the federal regulations with state- and location-specific regulatory requirements. Spain and Israel have national desalination project implementation programs, but they do not have national legislation specifically related to desalination concentrate management or the permitting of desalination plant discharges.

11.3 Regulatory and Permitting Processes

Australia, Spain, and Israel all have comprehensive experience with medium and large seawater desalination projects. The environmental review and permitting process and practices in each of these countries have many similarities with those in the United States.

In Australia, all individual states have based their regulatory requirements for desalination projects on a fairly general federal legislative framework and on additional state-driven regulations, which are reflective of the statewide water quality goals of the specific waterbodies within the state territory to which the concentrate is discharged. In Spain, the main legislative framework is defined by the state, but the local (regional) governments issue the actual permits and have the right to enforce more stringent discharge requirements. In Israel, all permit-related legislature is developed at a state level; this is one of the few countries in the world where the state has a centralized long-term program for the development of a series of desalination projects at strategic locations for a centralized water supply.

As in the United States, in each of the three countries, the desalination plant permits are issued after a thorough environmental review of the impact of the plant discharge on the surrounding aquatic environment.

Further, a practically identical permitting process, including events undertaken and information developed to define discharge limitations, and depicted in Figure 5.1 for the United States, applies to all large desalination projects in Australia and Europe as well. The mixing requirements for the desalination projects are determined based on a WET testing study and on hydrodynamic modeling of the discharge area.

Despite the similarities, the permitting of medium and large projects in the United States usually takes longer than in Australia, Spain, or Israel. In these three countries, the time needed to complete the environmental review and issue the desalination plant discharge permit (one to two years) is usually shorter than the time to construct the plant (two to three years). In contrast, the environmental review and permitting of the Tampa Bay SWRO project took approximately 2.5 years, and that of the Carlsbad Desalination Plant from project inception (2000) to permit process completion (2010) took approximately 10 years. At present, the United States is the only country in the world where the permitting of medium and large desalination projects takes much longer (three to 10 years) than their construction (two to three years). An underlining comparative observation of the permitting regulations and process in the United States and that of other developed countries of proven track record with successful and environmentally safe desalination projects is that the U.S. regulatory process would benefit from the development of federal desalination guidelines to streamline the permitting process. The main reasons are discussed in the following sections.

11.3.1 Streamlined Regulatory Process

Usually only one or two agencies are involved in the environmental review of the desalination projects in most advanced countries worldwide (Australia, Israel, Spain, the UK, Cyprus, the Middle East, Singapore, Japan), compared to four to six agencies in most U.S. states and up to 24 agencies in California. In Australia, Spain, and Israel, usually only one environmental regulatory agency has the right to make decisions and establish discharge permit requirements and mitigation measures. If other agencies are involved in the project review, they provide comments to the lead agency but have no right or jurisdiction to change permitting requirements except by internal consensus. In contrast, the independent multi-agency review process typical in states such as California results in numerous conditions and permits that regulate the discharge and that may have different requirements in terms of the mitigation of environmental impacts. Such practices not only delay the permitting process but also put a significant burden on the project sponsor associated with project implementation, operations monitoring, and data reporting.

11.3.2 Priority Review of Desalination Projects

Spain and Israel recognize the strategic importance of seawater desalination in securing a sustainable and drought-proof long-term water supply in their countries. As a result, they have long-term plans for the development and implementation of desalination projects, which are under the close oversight of the central government. Because the timely implementation of such plants is considered of high importance and priority in the respective countries, the regulatory agencies are given support at the state and local levels in terms of expertise, direction, and funds to expedite and give priority to the environmental review of desalination projects, compared to other types of projects. Australia does not have a countrywide desalination program at the federal level, and the initiative for planning, permitting, and implementing desalination projects is left to the individual states.

11.3.3 Superior Expertise of Regulatory Agencies in the Permitting of Desalination Plants

In the United States, mainly because of funding constraints, many of the regulatory agencies involved in the permitting of desalination projects do not usually maintain staff with all the types of expertise needed to complete an expedited review of desalination projects, such as marine biologists, experts in outfall discharge modeling, and engineers with experience in the design and operation of desalination plants. In contrast, the key agencies involved in desalination project review in Spain and Israel have such experts on staff, or if such experts are not originally available, they are retained in an expeditious manner at the beginning of the environmental project review to minimize the time needed. Most of the agencies involved in desalination review in California, for example, do not have such experts, and as a result, the environmental review process goes through six to 12 rounds of requests for additional information by the regulatory agency reviewers because they learn on the job and ask their questions piecemeal as they learn more about the project. Staffing expertise and experience varies from state to state in the United States and Australia.

11.3.4 Sharing of Regulatory Expertise between Various Agencies

In all of the listed countries, except for the United States, the key regulatory agencies involved in the permitting of desalination projects have internal quarterly or biannual meetings at which they share experiences with various permitting issues. The regulators also actively participate in professional conferences and public forums, presenting in a clear manner their requirements and expectations associated with the type and detail of information needed for permitting. Mainly because of a lack of funds and the lack of recognition of seawater desalination as an important source of a drought-proof water supply, U.S. regulators involved in the permitting of desalination projects do not have professional experience exchange opportunities in or out of state and rarely attend professional conferences or present their expectations in professional forums.

11.4 Salinity Limits

Regulatory bodies of all U.S. states, including California (where it can be petitioned for), allow the maximum salinity limit of the regulatory mixing zone boundary to be established for the site-specific conditions of a project.

The maximum limit is based on the level of dilution that is required for marine species inhabiting the area, or for predetermined standard test species defined by the respective regulatory agency, not to exhibit chronic and/or acute toxicity. The marine organisms selected for testing are identified based on a biological survey of the discharge area, usually completed during the initial environmental review phase of the project, and the standard test species are determined by the pertinent regulatory agencies. The selected test marine organisms are further based on their sensitivity to salinity at embryonic, juvenile, and/or adult phases of development.

To determine the salinity threshold at which no chronic (and/or acute) toxicity is exhibited, usually, most regulatory agencies require as a minimum standard chronic WET testing of at least one marine plant, one fish, and one crustacean.

Thus, although regulations do not spell this out explicitly, WET limits and requirements that define the mixing zone ultimately regulate the salinity of the discharge. For example, Florida and Texas do not have numeric TDS limits in their regulations. However, these states regulate desalination plant salinity impact on the marine environment by chronic and sometimes acute WET limits. Similarly, the Huntington Beach Desalination Plant does not have a salinity limit in its NPDES permit but has a chronic toxicity limit that defines the size of its mixing zone and ultimately the mixing or dilution ratio between the ambient water volume and the volume of the concentrate. Such a dilution ratio in turn determines the maximum discharge salinity, which in the case of the Huntington Beach project is the same as that in the Carlsbad SWRO Desalination Project: 40 ppt at an average discharge flow and 42 ppt at maximum discharge flow.

The most recent amendment of the California Ocean Plan has introduced a “blanket” non-site-specific limit of 2.0 ppt for the maximum salinity increment over the ambient ocean water salinity at the edge of the mixing zone. Because such a prescriptive “one-size-fits-all” limit is overly restrictive and is not reflective of the site-specific aquatic environment in the area of the plant discharge, it is very likely that proponents of large desalination projects in the future will pursue the opportunity included in the California Ocean Plan (which is similar to regulations in other states) to establish a site-specific limit for the conditions of their respective project.

If the concentrate passes the WET test, even if the discharge salinity is higher than 2 ppt over the ambient ocean water salinity, it is unlikely that such salinity will result in negative impacts on the environment. Therefore, except for in California, no U.S. state regulation or other environmental regulation worldwide (including the CWA) contains a specific numeric salinity limit, but all of these regulations contain WET limits. From this perspective, the addition of a maximum salinity limit to a desalination project's permit requirements may introduce an overly constraining burden in terms of compliance costs and delay to the regulatory process because the WET toxicity compliance requirements are already reflective of the potential negative effect of elevated salinity on the ambient aquatic life. Further, such a limit is not reflective of the site-specific conditions or the salinity tolerance of the flora and fauna in the discharge area.

Most likely, the blanket maximum salinity limit introduced in the latest California Ocean Plan will be used only for smaller desalination projects, where investment in site-specific studies is not economically viable and where the salinity impacts are minimal and the achievement of the prescriptive limit will be possible without a significant cost burden to the project. As previously mentioned, a WET-test-based salinity limit can be petitioned for.

In any discharge permit of any state, there is a statement that if a discharge causes negative impacts on the local biota, regardless of what the cause is (salinity, metals, or other compounds that are not presently regulated), the regulatory agency has the right to revisit the regulatory requirements for such discharge. There is no exception for salinity from this practice, but also there is no special limit or requirement. The successful operation of more than 300 desalination plants for more than 15 years in the United States and more than 17,000 such facilities over the last 30 years worldwide is a testament that WET testing works: if there were many cases in which WET testing did not capture the toxic effect of salinity on the environment and in which elevated salinity caused environmental damage in spite of meeting WET requirements, the regulatory agencies in various states would have noticed, and there would be a separate specific salinity limit by now.

According to current regulations in the United States, if a desalination plant discharge meets all water quality objectives defined in the applicable federal and state regulations as well as acute and chronic WET objectives, then the proposed discharge does not present a threat to aquatic life, regardless of what the actual salinity level of this discharge is or what increase above ambient salinity this discharge may cause, because WET accounts for the salinity-related environmental impacts of concentrate.

11.5 Other Regulatory and Permitting Issues

11.5.1 WET Testing Species and Conditions

As previously mentioned, regulatory bodies of all U.S. states, including California, allow the maximum salinity limit for the regulatory mixing zone to also be established for the site-specific conditions of the project. The maximum limit is based on the level of dilution that is required for marine species inhabiting the area, or for predetermined standard test species defined by the respective regulatory agency, not to exhibit chronic toxicity. To determine the salinity threshold at which no chronic toxicity is exhibited, most regulatory agencies usually require standard chronic WET testing of at least one marine plant, one fish, and one crustacean.

WET testing in Australia is completed for marine species that inhabit the discharge area and/or by using standard test species based on direction from the pertinent regulatory agencies. The test marine organisms are determined based on their sensitivity to salinity at the embryonic phase and their presence in the discharge zone. Standard species are often used when they are determined to be representative of the marine life inhabiting the discharge area.

WET testing in Spain and Israel is completed using standard test species (plant, fish, and crustacean) that are prescribed in the testing protocols developed by the respective regulatory agencies. The Spanish and Israeli WET testing protocols typically use adult species for testing and apply the chronic WET testing results to establish the dilution ratio needed to be provided by the plant outfall. In Australia, a mix of acute (24- or 72-h) tests and chronic (14-day) tests on species in a more sensitive embryonic or larval phase are used to establish the mixing zone requirements. As a result, the concentrate dilution requirements derived from the WET testing in Australia are usually higher (20:1-40:1) than those in Spain and Israel (10:1-20:1). This more conservative approach to WET testing used in Australia results in much more costly and elaborate outfalls, which is one of the key reasons why the desalination plants constructed in this country were the most costly desalination projects completed over the last 20 years, worldwide.

11.5.2 Biological Survey

In the United States, biological surveys may be included in the discharge permit; monitoring requirements such as these are discussed in Chapter 6 with regard to the Tampa Desalination Plant in Florida as well as the Carlsbad, Huntington Beach, and Santa Barbara SWRO desalination facilities in California.

All medium and large projects in Australia, Spain, and Israel are required to complete a biological survey of the area of the plant discharge. However, the scope of such survey is most elaborate in Australia in terms of the number of representative areas and sampling points and the frequency of data collection. Such enhanced testing requirements have resulted in elevated project costs, and, based on a comparative analysis of the environmental monitoring of existing desalination plants in Australia, Spain, and Israel, more complex sampling has not produced better results or more comprehensive protection of the marine environment. To a great extent, the main reason is the fact that the discharge diffusers are designed to dilute the concentrate down to less than 10% of ambient conditions within 330 ft (100 m) from the point of discharge, but the monitoring field usually extends to more than several kilometers from the discharge. At such distance the salinity changes are indiscernible and well within the level of the accuracy of the monitoring instruments.

11.5.3 Salinity Tolerance of Marine Species

Because of the high salinity of SWRO concentrate relative to that of receiving waters, the main environmental impact of concentrate on aquatic life in the vicinity of a desalination plant discharge is typically associated with the salinity of this discharge and the ability of the native habitat to tolerate this salinity. As a result, this report gives considerable discussion to both salinity limits and salinity tolerance (primarily in Chapters 5 and 6). The topic of salinity limits is discussed in Sections 5.3 and 8.4.2.4. In this subsection, the focus is on salinity tolerance.

The determination of the salinity impact on marine organisms depends on the salinity tolerance of the organisms, and the determination of this tolerance is critical to the establishment of salinity limits – whether posed as a numeric salinity limit or via WET test limits. The attention and importance of the topic is reflected in the California Desalination Amendment, which is part of the latest revision of the California Ocean Plan, and in the extensive salinity-related testing involved with determining the salinity impact of the CDP. Protocols and policy for the determination of salinity tolerance have (and will in the future have) considerable impact on SWRO concentrate discharge in California, and likely at other locations.

Protocols for the determination of salinity tolerance need to specify

- what organisms to test,
- which life stages of the organisms to test, and
- how the organisms should be prepared for tolerance tests (e.g., should the organisms be exposed to a gradual increase in salinity up to the test level, or should they be directly exposed to the test's maximum level of salinity).

As stated, such protocols apply to all WET tests associated with SWRO discharge impacts, not just those used in the determination of salinity impact.

In the United States and all of the referenced countries, the salinity tolerance of marine organisms is determined based on chronic (or in the case of some Australian states, acute) WET testing of the most sensitive species inhabiting the discharge area. In Australia, the marine organisms are tested in the embryonic or larval stage of development, which has resulted in more stringent requirements for concentrate dilution compared to those in Spain and Israel, where the test species used for determining salinity tolerance are usually in the adult phase.

11.6 Conclusions

There are considerable similarities between the regulatory and permitting systems in the states of California, Florida, and Texas, as all of them must conform to the general federal regulatory framework and guidelines. Such regulations are also very similar to those of developed countries such as Australia, Spain, and Israel. Individual U.S. states can and do implement policies and regulations that are consistent with the federal framework yet somewhat different from state to state.

1. **Guidelines**: As discussed in Section 8.4.2.2, at present there are no legally binding desalination-specific regulatory guidelines in the states of California, Florida, and Texas. Similarly, in Australia, Israel, and Spain, at present, there are no specific regulations or regulatory guidelines for the permitting of desalination plant discharges. A document that would be helpful for the U.S. EPA to develop to close this regulatory gap could follow the structure and content of the Ten State Standards or the U.S. EPA Water Reuse Guidelines. This document could contain information related to the scope and nature of the environmental studies needed and recommendations for the specific design and planning activities to be implemented to expeditiously permit and successfully complete a desalination project.

2. **Regulatory process**: The general regulatory processes, discussed in Section 11.3, show many similarities among the states and countries considered. Desalination plant permits are issued after a thorough environmental review of the impact of the plant discharge on the surrounding aquatic environment. The events undertaken and information developed to define discharge limitations (depicted in Figure 5.1 for the United States) in general apply for all large desalination projects in Australia, Israel, and Europe as well. The mixing requirements for the desalination projects are determined based on WET testing and hydrodynamic modeling of the discharge area. Effluent limits are determined based on mixing zone considerations.

   A marked difference, however, exists between the United States and Australia, Israel, and Spain in regards to the amount of time needed to complete the environmental review and to issue a desalination plant discharge permit. Factors discussed that likely contribute to this situation include (in Australia, Israel, and Spain):

   - the streamlined regulatory process,
   - the priority review of desalination projects,
   - the superior expertise of regulatory agencies in the permitting of desalination plants, and
   - the sharing of regulatory expertise between various agencies involved in the desalination project permitting process.

   Each of these factors differs substantially from what exists in the U.S. federal and state regulatory systems.

3. **Discharge salinity standards**: The effect of higher salinity discharge on receiving water marine organisms is a fundamental issue in determining and limiting or regulating the environmental impact of discharge. Presently, in the United States and in Australia, Israel, and Spain, this effect is determined via WET tests and regulated through WET-test-based limits. California has implemented a non-site-specific general numeric salinity limit in addition to site-specific WET test limits. WET is a more comprehensive measure of the environmental impact of concentrate than a salinity limit because WET water quality objectives also account for potential synergistic environmental impacts of concentrate with other constituents in the concentrate.

   Use of a non-site-specific salinity limit raises questions including the following:

   - What is gained by the use of both limitations rather than the WET standards alone?
   - Why apply a salinity limitation when a discharge passes WET tests (reflecting no toxicity due to salinity) but not the salinity limitation?
   - What are the implications in terms of time and costs associated with project permitting and the role of non-site-specific limitations versus site-specific limitations?

4. **WET test species and conditions**: The states and countries reviewed vary on the use of standard test species or site-specific test species and on the life stage of the species tested. More conservative approaches have resulted in more stringent discharge limits, higher required dilution ratios, and (as a result) more elaborate and costly outfall systems, which can be a significant portion of total project costs.

5. **Biological surveys:** In the United States, biological surveys are a standard part of the monitoring requirements as part of NPDES permits. Monitoring surveys are also required in the countries referenced.

6. **Salinity tolerance of marine organisms used in WET tests:** More broadly than the title implies, the issue here is the lack of standard protocols for conducting WET tests, including the preparation and adaption of test organisms for higher-salinity tolerance tests.

7. **Site-specific versus non-site-specific standards:** This point was mentioned previously in Items 3 and 4. A possible trade-off that is not yet well defined is non-site-specific standards requiring less testing and allowing shortened permit times but resulting in more conservative and more expensive outfall and diffuser designs.

8. **Miscellaneous items:** Although not discussed in the report, various protocols could benefit from study and standardization, including the following:

   - what type of dilution water to use in WET tests (i.e., actual seawater versus artificial seawater)
   - what analytical tests to use on higher-salinity samples
   - what time length to use in acute and chronic tests

11.7 Recommendations

The broad and general federal framework for regulating the environmental impacts of wastewater discharges, which currently is applied to SWRO concentrate discharges, is appropriate. The issues of concern are in the details of how this framework is implemented by the states specifically for seawater desalination projects. Much room is left to the states to define the particulars of regulation, and because of the relative newness of medium- and large-scale SWRO desalination in the United States, few states have had to deal with the regulatory and permitting issues associated with SWRO concentrate discharge. As stated in Chapter 1, U.S. permitting protocols and issues associated with SWRO concentrate discharge are in various stages of investigation, definition, and clarity that could benefit from broad consideration and study and from the definition of appropriate guidelines. Although research studies in California associated with the Desalination Amendment to the updated Ocean Plan are timely and appropriate, questions still remain concerning various issues as detailed previously.

Project recommendations presented in the following are associated with each of the conclusions listed previously.

- Development of federal regulatory and permitting guidelines for desalination projects similar to the U.S. EPA Water Reuse Guidelines will benefit significantly the use of desalination as an alternative drought-proof water supply source and provide a strong framework for the development of statewide guidelines.
- Development of statewide desalination guidelines to address desalination-specific permitting challenges will also benefit the wider use of seawater desalination as an alternative source of water supply.
- Creation of frequent opportunities for state regulators to exchange information,

practices, and experience in the permitting of desalination projects will be beneficial and is highly recommended.

- Enhancement of the Standard Methods for Analysis of Water and Wastewater to include the analysis of seawater and concentrate for TSS, radionuclides, and metals will be of great benefit in streamlining concentrate management and permitting.
- Development of a uniform methodology for establishing the salinity tolerance of site-specific marine organisms by the U.S. EPA will simplify the desalination project permitting process and establish the opportunity to minimize expenditures associated with the construction of costly outfalls.
- Enhancement of the existing WET testing procedures for seawater discharges will allow them to reflect the site-specific conditions of the receiving marine environment.
- Increased funding of state regulatory agencies to enhance the number and qualification of staff with desalination experience will benefit the use and application of desalination.

In summary, the permitting of seawater desalination plants in the United States is a protracted and challenging process because of the limited experience and regulatory guidance at the federal and state levels available to all key stakeholders (regulators, proponents, the environmental community, and the public at large). Review of the desalination permitting practices in countries with advanced environmental legislation such as Australia, Israel, and Spain indicates that the desalination permitting process could be simplified and streamlined to reduce the time needed for desalination project implementation.

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