A SunCam online continuing education course

Environmental Review and Permitting of Desalination Projects – Part 2

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1. Framework of Environmental Impact Assessment

1.1. Introduction

The purpose of the Environmental Impact Assessment (EIA) for a given desalination project is to:

- Review project purpose, need, scope, site and supporting infrastructure.
- Analyze and quantify potential environmental impacts from project implementation.
- Identify feasible mitigation measures aimed at elimination or reduction of all significant adverse environmental effects of the proposed desalination project.

The EIA encompasses both temporary construction related effects and long-term effects associated with project operation.

Typically, the project EIA addresses three key areas:

(1) Impacts on biological (terrestrial and marine) resources in natural habitats (surface and ground waters, soils, sediments, air) on and around the project site and supporting infrastructure.

(2) Socio-economic and cultural resource impacts such as effects on public wellbeing, services and utilities, changes in existing and planned land uses, traffic and circulation; aesthetics, light and glare, recreation, natural scenery, and population growth.

(3) Public health related impacts associated with the quality of the product water delivered to the project service area, integrity and function of the existing water distribution system, air quality, noise pollution and disposal of the waste streams generated during the production of desalinated water.

The environmental review process of a given project includes the following key steps: (1) project EIA scoping; (2) project definition; (3) environmental analysis; (4) identification of significant environmental impacts and development of mitigation measures. The scope of these project review efforts is described below.

1.2. Project EIA Scoping

The initial desalination project planning efforts aim to define several alternatives for project location, size, and implementation that are normally summarized in a project master plan. This master plan serves as a starting point for the project EIA.

The first step of the EIA scoping is to evaluate and pre-screen the initial project alternatives that are defined in the master plan and based on preliminary determination of their environmental impacts and compliance with pertinent regulatory requirements. A key activity associated with this phase is to also gain a more thorough understanding of the potential socio-economic and regulatory constraints associated with the implementation of the project alternatives defined in the master plan. Such understanding is established by conducting meetings and discussions with public and regulatory agencies having jurisdiction over project implementation and with citizens located in or near the project service area and the potential project plant sites. The public scoping meetings identify, issues, preferences and expectations of the general public in terms of project scope, appearance, location and size.

Based on the analysis of the collected information, project alternatives are reviewed for fatal flaws and usually one preferred project and one or two alternative projects and/or project components are selected as an outcome of the project EIA scoping effort. This project step also defines the scope of the detailed engineering and environmental review studies needed to evaluate the potential environmental impacts of the preferred project.

1.3. Project Definition

Once the scope of the project environmental review effort is determined, the next step is to gain detailed site specific information on the preferred project and the selected project alternatives including:

- Project size, location, needs and objectives.
- Project phasing.
- Environmental setting.
- Desalination plant intake, discharge and treatment alternatives.
- Product water delivery system configuration and pipeline routes.
- Entitlements/agreements, permits and approvals needed for project implementation.

Project definition also includes completion of the geotechnical investigation and utility; biological and archeological surveys of the plant intake, treatment facility and concentrate disposal sites, and water distribution pipeline routes; the characterization of the intake and discharge water quality, and ambient physical and hydrodynamic conditions of the surface water body (for open intakes and discharges) or intake and discharge aquifers for subsurface intakes and deep injection wells.

In addition, the project characterization encompasses evaluation of the potential impacts on the physical integrity and the water quality of the water distribution system due to the introduction of desalinated water. Special attention is often given to the impact of the desalinated water quality on industrial, agricultural and horticultural users located in the desalination plant service area.

The typical engineering documentation produced during the project definition phase of the EIA includes:

1. Visual impact report with desalination plant site renderings from key local viewpoints.
2. Air quality assessment reflective of impacts from construction traffic air emissions and of plant operations.
3. Climate action plan which defines measures that will be needed to mitigate, reduce or eliminate greenhouse gas emissions associated with project construction and operations.
4. Biological resources report that identifies terrestrial life inhabiting the project site and routes of product water delivery pipelines; and aquatic life in the intake and discharge areas. This report focuses on the presence of endangered species and protected habitats.
5. Cultural resources report discussing archeological sites, artifacts or areas of cultural significance that may be impacted by the project construction and operations.
6. Geotechnical report that provides information on soil types and conditions, including soil load bearing capacity, and soil and groundwater contamination with hazardous substances.
7. Bathymetry report describing the geophysical conditions in the intake and discharge areas for project alternatives that include open intakes and discharges.
8. Hydrology report identifying ocean currents, winds, beach erosion, seismicity and other factors that may impact the performance and integrity of the plant intake and discharge systems (for open intakes).
9. Impingement and entrainment assessment quantifying the impact of the construction and operation of an open intake for collection of source water for the desalination plant on the aquatic life near its location.
10. Hydrodynamic study establishing the size, shape, location and salinity distribution in the zone of dilution of the desalination plant concentrate around the location of its discharge.

11. Acoustic assessment defining potential impacts from noise generated by desalination plant equipment in the vicinity of the plant site.
12. Traffic impact analysis providing insights on the changes of traffic patterns and intensity in the vicinity of the project site as a result of project construction and normal operation.
13. Water supply assessment addressing issues such as impacts on the distribution system water quality, corrosion and hydraulics by the desalinated water.

The project definition-related studies listed above are standard for most desalination projects. However, depending on the project size, site-specific conditions and regulatory requirements, some studies may not be necessary or additional site-specific studies may be needed. This observation holds true especially for projects that incorporate the use of existing infrastructure (i.e., existing outfalls and/or discharges) or are proposed to be co-sited with other existing facilities such as power plants or wastewater treatment plants.

1.4. Environmental Analysis

The background information (data, studies and investigations) collected during the Project Definition phase is analyzed to identify and quantify the potential environmental impacts of the preferred project and potential project alternatives. This analysis encompasses the following key impact areas:

- Land use impact assessment.
- Geology, soils and seismicity.
- Hydrology, drainage, and storm water runoff.
- Air quality.
- Noise.
- Use of public services and utilities.
- Aesthetics/light and glare.
- Hazards and hazardous materials.
- Construction related impacts.
- Surface water quality and aquatic biological resources (for surface intakes and discharges) or groundwater quality of the saline intake and discharge aquifers (for subsurface intakes and deep injection well discharges).
- Product water quality issues and impacts on the water distribution system.

Land Use Impact Assessment

Land use impact assessment focuses on the compatibility of the desalination project with the land zoning requirements pertinent to the project site and water distribution infrastructure. This assessment also addresses the consistency of the project needs, objectives, size, scope, service area and points of interconnection to the water distribution system with all applicable local, regional and state water resource management plans, policies and other requirements.

Geology, Soils and Seismicity

Geology, soils and seismicity assessments target the suitability of site topography, geology and location for project construction and long-term operation. In seismic areas, special attention is given to project proximity to major active faults, potential for soil liquefaction and subsidence, lateral spread and landslides, projected magnitude of seismic force, and potential plant impact from tsunamis and/or seiche waves. This information is also used to determine the likelihood of long-term operational wind/water-driven erosion impacts on plant intake and discharge structures and other project-related facilities.

Hydrology, Drainage, and Storm Water Runoff

Hydrology, drainage and storm water runoff issues under consideration include the likelihood of future violations of applicable storm water discharge requirements, the substantial depletion of groundwater supplies and interference with groundwater recharge. Additional concerns include lowering water table levels of local groundwater aquifers, alteration of the existing drainage pattern of the project site area, creation or contribution to surface runoff that cannot be handled by the existing or planned water drainage systems, and exposure of project structures and staff to flood risks. Particular attention is given to the location of the desalination plant structures holding and handling hazardous waste. Such structures are expected to be located outside of the 100-year flood hazard boundary in this location.

Air Quality

Project air quality impacts are evaluated in terms of their potential to violate any air quality standards established for the project area by pertinent regulatory agencies and their propensity to release significant quantities of greenhouse and hazardous gases or create objectionable odors affecting the nearby residents. The environmental review includes sources of mobile source emissions (i.e., employee vehicles and chemical delivery trucks), as well as stationary source emissions (i.e., emissions from chemical storage and handling facilities). In addition, it accounts for indirect GHG emissions associated with the on-site and off-site power generation facilities used to supply the desalination plant with electricity.

Typically, membrane desalination plants are not sources of air pollution, except in cases where plants self-generate electricity by using diesel fuel or natural gas. In such instances, the power generator is the main air pollution source. Under normal operational conditions, most desalination plants do not self-generate electricity but receive it directly from the power grid. Some desalination plants however, have standby diesel generators.

Noise

Desalination plants employ large size motors, pumps and energy recovery devices that could be significant sources of noise pollution. The environmental review identifies the location of noise sensitive receptors in the vicinity of the plant site (i.e., hospitals, schools, residential buildings, etc.) and evaluates the potential for project-related noise emissions to exceed local standards, ordinances and regulations and have negative impact on the neighboring community.

Noise is of specific importance because the high-pressure reverse osmosis membrane feed pumps operate at very high rotational speed and are usually a significant source of noise pollution (60 to 96 dB). The key sources of noise at the plant are the large high-pressure pumps that feed flow to the reverse osmosis treatment trains and interconnected energy recovery devices. These operations should be located in the reverse osmosis building, which is usually equipped with acoustic attenuation wall panels to contain and dissipate the generated noise.

Many desalination plants are equipped with large intake seawater pumps, pretreatment filter effluent transfer pumps, and product water delivery pumps that are often located outdoors. The potential noise mitigation measures for these pumps are as follows: (1) use of centrifugal pumps instead of piston pumps whenever possible; (2) use of water-cooled motors; (3) installation of acoustic enclosures; (4) installation of sound curtains around the main sources of noise at the plant (e.g., energy recovery units); (5) installation of pumps and motors in an enclosed building.

Centrifugal pumps that have low-noise levels should be used when possible, as an alternative to higher noise-level piston pumps. The main sources of noise in a centrifugal pump station are the pump motors. Water-cooled motors are recommended, instead of standard air-cooled motors, to reduce noise levels, if needed. Commercially available acoustic enclosures can be installed around the pump motors or the entire pump station in order to contain and dissipate the noise from the outdoor mechanical equipment.

Industrially sewn sound curtains can surround the pump stations using floor-mounted hardware. If required to comply with stringent acoustic attenuation requirements, an enclosed building designed to reduce noise emissions can contain all large pumps and motors. Acoustic control panels on the walls of the building can attenuate the noise in the main desalination building that houses the high-pressure pumps and energy recovery devices. Such noise attenuation measures usually reduce the noise levels created by desalination plant equipment down to 60 decibels (dB) or less within three feet from the plant boundaries.

Use of Public Services and Utilities

The construction and operation of desalination plants involves the use of a number of public services and utilities such as fire and police services, roadways, wastewater collection services (typically for disposal of spent membrane cleaning solutions and sanitary wastewater), solids waste collection services, storm water, drinking water and gas utilities, electrical utilities, and telephone and cable utilities. The project environmental review assesses the potential for over-loading of such services and utilities and for non-compliance with service-related pertinent regulatory requirements.

Aesthetics/Light and Glare

Potential aesthetics, light and glare related concerns include any negative impact to the site character, scenic vistas, or substantial damage of scenic resources such as trees, rock outcroppings, and historic buildings within a scenic highway. Furthermore, possible substantial degradation of the existing visual character or quality of the desalination plant site and its surroundings and/or creation of significant light and glare affecting the day or nighttime views of the plant area should be taken in to account.

Hazards and Hazardous Materials

Desalination plants use water treatment chemicals (i.e., sulfuric acid, sodium hypochlorite, ferric coagulants, etc.) that may be classified as hazardous materials, depending on the size of their on-site chemical storage facilities. Therefore, the environmental review addresses the potential to create significant public and/or environmental hazards during the transportation, storage, use and disposal of such chemicals.

Construction Related Impacts

The environmental review also focuses on the construction related effects on adjacent land uses, traffic, biological resources (vegetation, special status wildlife habitats and endangered or protected species), historical/archeological and paleontological resources, hydrology and water quality, air quality, noise, public services and utilities, aesthetics, hazards and hazardous materials.

Surface Water Quality and Aquatic Biological Resources

Desalination plants with open intakes and discharge outfalls may have potential adverse effects on the quality of the water body from which source water is collected (ocean, sea, river estuary, etc.) as well as on the aquatic biological resources in the area of the intake and the outfall. The main desalination plant intake impacts are associated with impingement and entrainment of aquatic organisms and potential loss of natural habitat occupied by the intake structures and piping, while the discharge impacts are related to salinity or mineral-ion imbalance triggered toxicity. Part 1 of this course discusses such impacts in detail.

Product Water Quality Issues and Impacts on the Water Distribution System

The quality of drinking water produced by desalination may differ significantly from that of other sources delivering water to the same distribution system. Usually desalinated water is very soft (i.e., has lower content or calcium and magnesium) and could cause corrosion of the water distribution system and household plumbing, depending on the pH and hardness of the other water sources with which it is blended. In addition, the desalinated water may have a higher level of boron, sodium, chloride and bromide than the other water sources, which may raise public health concerns.

Depending on its water quality, desalinated water could cause a reduction in growth rate and yield of some citrus fruit, strawberries, avocados and other crops, or could have a negative impact on the appearance of some ornamental plants (e.g., kentia palm trees). In addition, the inherently elevated content of bromates, bromamines and boron in the desalinated water may have potential human health impacts.

RO membranes may fail to reject other potential product water quality parameters of concern, such as gases (i.e., H_2S) or nitrates, which could be constituents in the saline source water. . Source water quality characterization and RO membrane performance analysis predicts the potential for such effects. Another aspect of desalinated water quality that is evaluated during the project EIA is the possible presence of algal toxins, which could be a human health concern if they exceed a certain threshold.

2. Identification of Environmental Impacts and Mitigation Measures

The project environmental review described in the previous section determines the magnitude of the potential environmental impacts from the construction and operation of the proposed desalination project, and identifies mitigation measures for the impacts that are found to be significant. Such mitigation measures may involve a change in project scope, site, location, design, methods for source water collection and concentrate discharge, or modification of project scope, service area or potential water uses.

In some cases, environmental impacts are significant, but they may be unavoidable and may be considered acceptable by the regulatory agencies involved in the environmental impact assessment and permitting of the project. This is the case if the project yields benefits that outweigh such impacts or if the impacts are temporary and have a short duration. If significant impacts are found to be unavoidable, the EIA usually identifies minimization and/or remediation activities that could address these impacts.

The desalination plant construction and operation permits and licenses incorporate the project mitigation measures identified by the EIA, which are enforced by the respective regulatory agencies that issue such permits/licenses and have responsibility for independent project monitoring and oversight.

All significant project environmental impacts and their proposed mitigation measures are incorporated into a project environmental management plan that is included in the overall desalination project implementation plan and schedule. Besides identifying key environmental impact mitigation activities, this plan also defines monitoring requirements that document and confirm the effectiveness of these activities.

3. Overview of Desalination Project Permitting Process

A critical EIA component for a given desalination project is the identification of all applicable regulatory requirements associated with project planning, design, construction and operation. Along with this list requirements, the EIA establishes a plan to obtain project permits and licenses stipulating such regulatory requirements (i.e., project permitting plan).

The number and type of permits, as well as permit requirements and regulatory agencies responsible for issuing and enforcing such permits, varies significantly from project to project, country to country, state to state and even on a regional or local agency level. Therefore, 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 and US 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 US. Texas and California have state-specific general guidelines for desalination project environmental planning, review and permitting (Wreck, 2004; CDWR, 2008).

In general, there are three categories of desalination project related permits: (1) source water intake related permits; (2) plant discharge related permits; and (3) product water related permits. The next section discusses the main issues associated with such permits and typical support studies needed to address these issues.

4. Source Water Intake Related Permits

4.1. Key Permitting Issues

Requirements for Plants with Subsurface Intakes

Source water intake related permits and issues vary significantly depending on the type of desalination project (seawater vs. brackish water) and the type of intake (subsurface vs. open intake). For seawater projects with subsurface intakes (e.g., water extraction wells and infiltration galleries), determining whether the intake is under the influence of surface water contamination is the main permitting issue. Regulators will establish drinking water permitting requirements based on this determination.

However, in California, construction of subsurface intakes located within 5 miles of the shore are also under the jurisdiction of the California Coastal Commission and the construction of such intakes requires a Coastal Development Permit.

For brackish water desalination projects with subsurface intakes, the key permits include water test well permit, water production well registration permit, production well construction and alteration permit, and production well operation permit. In addition, an important requirement associated with well permitting is the possession of water rights and take (pumping) of groundwater at a target intake capacity from a specific aquifer and/or groundwater basin.

Requirements for Plants with Open Intakes

The main permitting requirements for brackish and seawater desalination plants with open intakes relate to the environmental impacts of these intakes in terms of impingement and entrainment of aquatic organisms. Part 1 of this course examines such impacts in detail.

No federal or state regulatory requirements specific to impingement and entrainment reduction of desalination plant intakes currently exist. However, some state regulatory agencies apply requirements that originate from US EPA, Section 316 (b) of the Clean Water Act regulating cooling water intakes of power plants.

In addition, desalination plants in the US need a federal, Clean Water Act Section 404 (Dredge and Fill) permit and a Rivers and Harbors Acts permit (Section 10 Permit) for the construction of a new intake forebay structure and pipes in navigable waterways. The US Corps of Engineers administers such permits and usually requires concurrence with other federal agencies regulating coastal development such as the National Oceanic and Atmospheric Administration (NOAA). For some states, such as California, state regulatory agencies are involved, i.e.. the California Coastal Commission and the California State Lands Commission.

However, a desalination plant co-located with a power plant and does not need a Section 404 Permit, since it does not require the construction of new intake.
Desalination plants with open intake/outfall structures may require review by the National Marine Fisheries Service and/or US Fish and Wildlife Service, for their potential impacts on endangered, threatened or sensitive species. Additionally, they may need an Incidental Take Permit for protected marine mammals and migratory birds that may be impacted by the plant open intake operations. In some states, depending on the location of the intake, intake construction may call for an erosion prevention permit.

Some desalination projects include intake, discharge and product water delivery pipelines that cross roads, highways and underground utilities, which are under the jurisdiction of federal, state and local agencies. Construction of such project components requires encroachment permits, easements, or utility permits and authorizations.

As compared to subsurface intakes, desalination projects with open seawater intakes do not require water rights. However, in some states (e.g., Texas), such water rights are required if the open intake is located in enclosed or semi-enclosed water bodies such as bays and estuaries or in a river.

4.2. Intake Permitting Support Studies

Subsurface Intakes

For subsurface intakes, the main two permit support studies needed are:

- Test well pumping study.
- Hydrogeological investigation.

The test well pumping study aims to determine the production capacity of the intake wells and source water quality. The hydrogeological investigation assesses the type and productivity of the source water aquifer and determines whether the well water quality is under the influence of surface or subsurface contamination sources. It also examines whether the well pumping may mobilize pollutants and minerals from adjacent aquifers and introduce them into the source water aquifer.

The hydrogeological investigation entails the following key activities:

1. Completion of preliminary geological survey to identify if the selected site is suitable for the construction of subsurface water intake.

2. Implementation of a drill-test to collect samples of the aquifer formation deposits for visual classification and grain-size distribution analysis.
3. Installation of one or more test wells and observation wells to conduct pumping tests to determine the site-specific hydraulic characteristics on the aquifer, necessary for subsurface system design and to quantify the intake system's safe yield. The test should be a minimum 72 hours long. Usually a number of tests are completed in sequence to determine the optimum yield. After initial testing, a longer-term test follows to determine the aquifer transmissivity.
4. Collection of an adequate number of samples of the saline source water which is planned to be used by the desalination plant for production of fresh water and laboratory analysis of sample water quality, with special emphasis on the content of iron, manganese, barium, strontium, silica, radon, carbon dioxide, arsenic, and hydrogen sulfide in the source water. If the aquifer water quality is under the influence of a surface water source (i.e. river, lake) with quality and quantity that varies seasonally, then a year-round intake water quality sampling is completed to quantify seasonal fluctuations of source water quality.
5. If the subsurface intake system requires the installation of multiple collection facilities (wells, infiltration galleries/river bank filtration facilities), then a computer model analysis is completed to establish the response of the production aquifer to pumping and potential impact of groundwater collection on adjacent fresh or saline water aquifers, which could interact with the water supply aquifer.
6. Beach erosion, seismic and 100-year storm impact analyses of the intake area are completed in order to evaluate whether the intake system will be able to retain its integrity, productivity, and water quality over the useful life of the desalination plant.
7. Survey of potential sources of contamination of the source water aquifer within the area of influence of the subsurface intake (landfills, cemeteries, oil fields, gas stations, etc.) is completed to identify whether such sources will impact the desalination plant intake water quality.
8. Survey of existing drinking water wells within the area influence of the desalination plant subsurface intake is implemented to determine whether the desalination plant operations will impact the fresh water production capacity and quality of these wells.
9. Survey of the coastal wetlands, marshes or other natural coastal habitats in the area of influence of the subsurface intake to determine whether they could be impacted (e.g., drained) by the operation of the subsurface intake.
10. Survey of seismic faults located in the area of influence of the subsurface intake and assessment whether future earthquakes could cause negative impacts on the saline source

water aquifer and on the structural integrity and productivity of the subsurface intake (e.g., wells, infiltration gallery, etc.)

The key EIA related criteria derived from the test well pumping study and the hydrogeological investigation are as follows:

- The type of source water aquifer (confined vs. unconfined).
- The aquifer permeability (hydraulic conductivity), which is a measure of the velocity of water movement through the ground (typically measured in m/s).
- The average specific yield (productivity) of the aquifer (in m^3/day per linear meter of riverbank or seashore along which the collector wells are located).
- The thickness of the production aquifer deposits and associated well depth.
- The source water quality of the subsurface intake, to determine the desalination plant pretreatment.
- Fatal flaws for use of subsurface intakes such as severe beach erosion, damaging seismic activity.
- Sources of subsurface contamination in the intake area and the existence of nearby fresh or brackish water aquifers that could be negatively impacted by the intake well operations or may have measurable effect on intake well water quality.

Open Intakes

Impingement and Entrainment Study. The environmental permitting and assessment of open intakes requires a 12-month study that involves the collection of source water samples in the vicinity of the intake, usually two to four times per month, that determines the annual and daily amounts of marine organisms that could potentially be impinged on the source water intake and entrained into the desalination plant through the intake.

Impingement is very much dependent on the intake type, configuration and through screen velocity. As previously indicated, entrainment is typically considered proportional to the plant flow and the abundance of marine organisms in the intake area.

The results from the impingement and entrainment study project the potential reduction of the quantity and type of aquatic species in the area of influence of the desalination plant intake as a result of its continuous operation. Once the type of impacted aquatic species is known and their potential loss is quantified, the impact is evaluated against the productivity of the intake area to determine significance and whether the impacted aquatic species are of critical importance to sustain the local aquatic ecosystem and of measurable commercial or recreational fishing value.

Flow, Impingement and Entrainment Minimization Plan. If the regulatory agencies having jurisdiction over the source water resources determine that the open intake of the desalination plant at its proposed configuration and size will cause significant environmental impacts, then the desalination project proponent (permit applicant) will have to prepare and submit a plan for agency review that indicates how the proponent will minimize intake flow, impingement and entrainment, by the selection of alternative intake and location, and the use of combination of best technologies available (BTA), design and operational measures. Pertinent regulatory agencies will review and approve a flow, impingement and entrainment plan that summarizes such measures.

Plan for Impingement and Entrainment Mitigation. While using low through-screen velocity could significantly reduce intake impingement, entrainment cannot be fully eliminated. Depending on the local environmental setting, the permitting agencies with jurisdiction over the intake area may require the project proponent to develop and implement an I&E mitigation plan. The purpose of such a plan is to implement an aquatic life restoration program that produces environment (i.e., wetlands) and aquatic species in-kind to these lost as a result of impingement and entrainment. Part 1 of this course discusses potential measures for the reduction and/or mitigation of impingement and entrainment impacts of intake operations on the surrounding aquatic environment in the vicinity of the open intake.

5. Plant Discharge Related Permits

5.1. Key Permitting Issues

Overview of Regulatory Framework in the US

Desalination plant discharges are classified by the United States Environmental Protection Agency (USEPA) as industrial waste, even though these discharges are distinctively different from most industrial discharges. Several regulatory programs in the US address the disposal of desalination plant discharges: (1) the Clean Water Act (CWA); (2) the Underground Injection Control (UIC) Program, ordinances that protect groundwater; and (3) the Resource Recovery and Conservation Act (RCRA), which regulates solid waste residuals. The permits required for concentrate discharge in the US vary depending on the type of discharge (surface or subsurface).

To discharge concentrate from desalination plants in to surface waters in the US, the plant owner must obtain a National Pollutant Discharge Elimination System (NPDES) permit, which in most states is issued by the state regulatory agency that is delegated such responsibility by the US EPA. Besides numerical limits for specific contaminants and for whole effluent toxicity (WET), NPDES permits typically contain receiving water quality anti-degradation requirements that mandate the plant discharge to be within 10% of the ambient levels of naturally occurring contaminants, to prevent impairment of the receiving water quality in terms of colour, odour, and visual appearance.

Wastewater collection system discharges require a permit issued by the local sewer agency to meet its sewer ordinance and the CWA Industrial Pre-treatment Program (IPP) requirements, as stipulated in the agency's NPDES permit.

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

The US EPA, under the UIC program of the Safe Drinking Water Act, regulates concentrate disposal by deep well injection. The related construction, monitoring, and other permits are issued and enforced by the US EPA region or state agency that have jurisdiction over the desalination plant location.
RCRA regulates the disposal of solid waste generated by desalination plants such as precipitated salts and sludge. If a given plant generates solids which contain arsenic or other toxin above levels, which classify them as a hazardous waste, and such sludge does not pass the toxic characteristic leaching procedure (TCLP) test, then such sludge is considered a hazardous waste and must be handled accordingly.

It should be pointed out that sludge generated from typical seawater desalination plants with open intakes is usually non-hazardous and can be disposed in a sanitary landfill without further treatment. One exception is the sludge generated by saline water pre-treatment with diatomaceous media filters, since the diatomaceous media is considered a hazardous material in the US. For comparison, sludge from some brackish water sources could sometimes contain high levels of naturally occurring toxic compounds such as arsenic and cyanide, which may require its disposal to a hazardous waste landfill.

Salinity and Whole Effluent Toxicity Requirements for Surface Discharges
At present, most countries do not have numeric standards for salinity content in the concentrate discharge. The site-specific conditions of a given project determine the discharge limit for this water quality parameter. The pertinent federal and state laws in the US regulate salinity of desalination plant concentrate discharges by establishing project-specific acute and chronic whole effluent toxicity (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 potential synergistic environmental impacts of concentrate with other constituents in the concentrate.

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

The *California Ocean Plan* (CSWRCCB, 2009) establishes a daily maximum acute toxicity receiving water quality objective of 0.3 TU_a (acute toxicity units). Requirement III.C.4 (b) of the *California Ocean Plan* designates that this 0.3 TU_a objective applies to ocean waters outside the acute toxicity-mixing zone. Requirement III.C.4 (b) defines the acute toxicity-mixing zone as follows:

> *"The mixing zone for the acute toxicity objective shall be 10 percent (10%) of the distance from the edge of the outfall structure to the edge of the chronic mixing zone (zone of initial dilution)."*

The *California Ocean Plan* defines the zone of initial dilution (ZID) as the zone in which the process of initial dilution is completed. Appendix I of the *California Ocean Plan* defines initial dilution 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."*

Despite the fact that site-specific acute and chronic WET objectives indirectly regulate environmental impacts associated with concentrate salinity, the discharge permits for some of the existing seawater desalination plants in the US also contain specific numeric salinity limits (see Table 1).

Table 1 – Examples of Desalination Plant Discharge Limits

Desalination Plant	Total Flow (MGD)	TDS (Avg.) (ppt)	TDS (Max.) (ppt)	Acute Toxicity TUa	Chronic Toxicity TUc	Flow Ratio
Carlsbad - 50 MGD; • 33.5 ppt - TDS(source); • 67.0 ppt (conc.)	54/60.3 (Conv. Pretreat) 57/64.5 (Mem. Pretreat)	40 (daily) (19.4 % Above Ambient)	44 (Maximum Hourly) (31.3 % Above Ambient)	0.765	16.5	Mixing Zone 15.1:1
Huntington Beach – 50MGD • 33.5 ppt – TDS (source); • 67.0 ppt (conc).	56.59 (Conv. Pretreat)	None	None	None	8.5	Mixing Zone 7.5:1 Min. Dilution =2.24:1
Tampa – 25 MGD • 26 ppt – TDS (source); • 43 ppt (conc.)	22.8 (Conv. Pretreat)	35.8 (38% Above Ambient)	35.8 (38% Above Ambient)	None	None	Dilution =28:1 (20:1– minimum)

Note: 1 part per thousand (ppt) = 1,000 mg/L

The Carlsbad Project NPDES discharge permit, for example, contains an effluent limitation for chronic toxicity at the edge of the zone of initial dilution in combination with numeric limitations for average daily and average hourly total dissolved solids (salinity) concentrations of 40 parts per thousand (ppt) and 44 ppt, respectively. These salinity limits were established based on a site-specific Salinity Tolerance Study and chronic and acute toxicity testing completed for this project (City of Carlsbad, 2005). The referenced limits are applicable to the point of discharge and the reflective/protective of the acute toxicity effect of the proposed discharge.

The NPDES Permit for the 50 MGD Huntington Beach SWRO Project in California 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 for the salinity (TDS) of the discharge from the desalination plant of 40 ppt and is derived from site-specific analysis of the conditions of the discharge for this project. Dilution ratio is used as a surrogate to salinity discharge limit for many other desalination projects worldwide.

Concentrate disposal to surface water bodies (oceans, bays, rivers) may have impacts other than direct changes in salinity. In some circumstances, concentrate plume density may lead to increased stratification reducing vertical mixing. This stratification may in turn reduce the dissolved oxygen level in the water column or at the bottom of the ocean in the area of the discharge, which may have ecological implications.

5.2. Discharge Permitting Support Studies

Support Studies for BWRO Plants with Subsurface Discharges

Deep well injection is one of the most commonly used methods for discharge of concentrate from brackish water desalination plants. In the US, such discharges are regulated at a federal level under the SDWA's UIC program. A typical permitting-related study for such discharges is the water quality characterization of the concentrate and of the hyper-saline aquifer, which is planned to receive this concentrate in order to confirm that the receiving aquifer will not be impaired by the discharge. In addition, a hydrogeological study is completed to determine whether the receiving hyper-saline aquifer is confined and can prevent the delivered concentrate from migrating to other adjacent aquifers and contaminating them.

Support Studies for SWRO Plants with Subsurface Discharges

Shallow exfiltration beach wells and galleries are sometimes used for disposal of concentrate from small desalination plants into the coastal aquifer closet to the ocean bottom. Shallow exfiltration beach wells and gallery discharges are typically regulated as surface discharges and require an NPDES permit.

Permitting-related studies for such wells mainly focus on determining the concentrate water quality and its ability to meet applicable surface water quality discharge requirements, since this concentrate is ultimately dispersed by the receiving surface water body (ocean, river, etc.).

Support Studies for BWRO and SWRO Plants with Surface Water Discharges

Discharge Salinity Dispersion Modeling. The main purpose of the evaluation of the concentrate dispersion rate from the point of discharge is to establish the size of the zone of initial dilution (ZID) required to dissipate the discharge salinity plume down to within 10 % of ambient water TDS levels; and to determine the TDS concentrations at the surface, mid-level of the water column, and at the bottom in the ZID.

The TDS concentration of the saline plume at these three levels is then compared to the salinity tolerance of the aquatic organisms inhabiting the surface (mostly plankton), the water column (predominantly invertebrates), and the bottom sediments of the receiving water body in order to determine the impact of the concentrate salinity discharge on these organisms.

The discharge salinity field in the ZID and the ZID boundaries are established using hydrodynamic modeling. This modeling allows 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 existing wastewater or power plant outfall facilities.

The model selected for identifying 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 concentrate dispersion and recirculation for large desalination plants usually requires sophisticated brine discharge plume analysis and is completed using various computational fluid dynamics software packages tailor-made for a given application (Voutchkov, 2013). The models most widely used for salinity plume analysis are CORMIX and Visual Plumes. Both models allow depicting the concentrate plume dissipation under a variety of outfall and diffuser configurations and operational conditions.
These models have been developed for and approved by the US Environmental Protection Agency for mixing zone analysis and establishment of total maximum discharge limits (TMDLs). 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 extended beyond the near-field ZID using various computational fluid dynamics (CFD) software packages, which are tailor-made for a given application.

Discharge Whole Effluent Toxicity (WET) Study. Whole effluent toxicity testing is an important component of the comprehensive evaluation of the effect of the concentrate discharge on aquatic life. Completion of both acute and chronic toxicity testing is recommended for the salinity levels that may occur under worst-case combination of conditions in the discharge. Use of at least one species indigenous to the targeted discharge is desirable.

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

In the US and Australia, the discharge permit (license) issued by the government regulatory agency in charge of the surface discharges will typically include limits on whole effluent toxicity (WET). The WET bioassay testing in the US must be performed according to US EPA-approved protocols to assess acute, chronic, and bio-accumulative toxicity to receiving water biota. The bioassays use approved pollutant-sensitive species.

Some brackish water RO plants in the US have produced concentrates that fail WET limits tests. Most of such cases in Florida were associated with high calcium levels while others were complicated by toxicity due to high fluoride levels (Mickley, 2006). Toxicity caused by high levels of major ions is a correctable chemical imbalance, unlike toxic contamination from heavy metals or pesticides. For this reason, Florida has exceptions for major ion toxicity when it is the only toxin present in a concentrate.

Concentrate Water Quality Characterization Study. Such study involves collection of concentrate samples from a pilot desalination plant followed by laboratory analysis of these samples using discharge water quality parameters established by pertinent regulatory agencies having jurisdiction over concentrate disposal. At a minimum, concentrate samples are recommended to be collected under 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, and very low and high source water temperatures and salinities. If seasonal events, such as winds, high waves, or underwater currents, occur in the area of the intake, concentrate sampling should survey these events as well.

The pilot plant used for generation of concentrate samples should be operated at the same recovery, flux and product water quality targets, as would the planned full-scale desalination plant in order to collect representative samples. If possible, the use of 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: TDS, metals, turbidity, and radionuclides.

Most laboratory analysis guidelines, worldwide, are developed for testing freshwater rather than high-salinity concentrate. The elevated salt content of the concentrate samples could 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 and seawater analysis. The same recommendation applies for the laboratory retained to complete the whole effluent toxicity testing and source water quality characterization using techniques designed for saline water.

If a given project cannot complete site-specific pilot testing, the concentrate water quality, in terms of mineral content, could be projected by characterizing the desalination plant source water quality for the operational conditions described above and analyzing this data with RO membrane performance projection software, which is available from all manufacturers of membrane elements (i.e., Hydranautics, Toray, Dow-Filmtec).

This RO system performance projection 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 the 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 projection software does not have the provisions to calculate the concentrations of most of the regulated metals, organics, and pathogens in the discharge.

Salinity Tolerance Evaluation Study. Determining the tolerance of aquatic organisms to the actual desalination plant concentrate is beneficial, since it may minimize the complexity of the plant outfall structure, especially if a salinity tolerant species inhabits the discharge area. A novel method for identifying the salinity tolerance of the aquatic life in the area of a desalination plant discharge (referred to as Salinity Tolerance Evaluation Method) 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) biometrics test at average discharge salinity; (4) salinity tolerance test at varying concentrate dilution levels.

Determining test salinity range. The first step of the implementation of the salinity tolerance evaluation (STE) process is to define the minimum and maximum TDS concentrations, which are projected to occur in the area of the discharge after the startup of desalination plant operations. This salinity range should be established 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 water body (currents, winds, tidal movements, temperature differences, etc.) as well as the mixing energy introduced with the desalination plant discharge diffuser system.

If the desalination plant concentrate is diluted with other discharge (i.e., cooling water from power plant or wastewater treatment plant effluent) prior to the exit from the outfall into the surface water body, this additional dilution should also be accounted for when establishing the salinity range for which the salinity tolerance of the aquatic species is assessed.

Because of the complexity of the various factors that impact mixing and dilution of desalination plant concentrate with the ambient surface water, especially for medium and large projects (i.e. projects with discharge volume of 20,000 m^3/day - 5 MGD or higher), the actual salinity range that would 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 zone of initial dilution to the maximum bottom salinity concentration at the edge of the ZID (Jenkins and Wasyl, 2001).

The ZID is typically defined as the area of the ocean within 300 m (1,000 ft.) radius from the point of the desalination plant discharge. However, the ZID boundary in terms of TDS is established as the distance from the point of discharge at which the salinity of the concentrate is within 10% of the ambient salinity of the receiving water body. Depending on the naturally occurring mixing intensity at the point of discharge, this distance may be shorter or longer than 300 m (1,000 ft.).

Identifying test species. The purpose of the second step of the STE method is to identify the most sensitive, site-specific species that would be indicative of the salinity tolerance of the aquatic flora and fauna in the area of the desalination plant discharge. These species are used for the Biometrics and Salinity Tolerance Tests. At least three species should be selected for the tests: one representative for the fish population in the area, one for the invertebrate population and one for macro-algal population (i.e., kelp, red algae, etc.), if such species are present and occur in significant numbers (Chapman et al., 1995; California State Water 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/protected marine species are first priority); (3) sensitivity to salinity in the range projected to occur in the discharge; (4) significance in terms of commercial and recreational harvesting/fishing.

Biometrics Test. The purpose of the biometrics test is to track how well the indicative test species could handle a long-term steady-state exposure to the elevated average discharge salinity that would occur in the middle of the zone of initial dilution after 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 water body (ocean, river, etc.), to obtain salinity that does not exceed the middle of the ZID 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) of the same size with the same number and type of test aquatic organisms should be employed, the main difference being that this tank should be filled with ambient water from the receiving water body collected from the area of the discharge. The control tank should be operated in parallel with the test tank and observations from this tank should be used to serve as a baseline for comparison and statistical analysis.

Once the salinity in the aquariums is set to target levels, they are populated with the selected test species. Key biometric parameters (appearance; willingness to feed; activity; weight gain/loss, and gonad production) of these species are to be monitored frequently (minimum every two days) by expert marine biologist over a prolonged period of time (minimum of three months, preferably five or more months).

Percent weight gain/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 identify any significant differences, especially in terms of weight gain/loss and fertilization capabilities.

Salinity Tolerance Test. The main purpose of the salinity tolerance test is to establish survivability of the selected test species under extreme salinity conditions that may occur within the ZID and on the edge of the ZID. Testing also determines if test organisms will be able to retain their capacity to reproduce after exposure to these conditions for a length of time that is expected to occur in full scale plant operations under worst-case scenario.

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 ZID (mid-depth) and the high end should be the maximum salinity above the seabed at the boundary of the ZID. In general, discharge salinity is expected to decrease with an increase in distance away from the point of concentrate discharge and to increase with depth. The rate of decrease of 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: one for each test salinity level and a control tank. The duration of the salinity tolerance test is determined based on the length of time 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 it is likely that extreme salinity conditions could extend beyond two weeks in specific circumstances, then the length of the study should be extended accordingly. Starting from the low end of the salinity concentration, individual test tanks should be set for salinity increments of 1 to 2 ppt (1 ppt = 1,000 mg/L) until the maximum test salinity concentration is reached.

Case study - Application of the STE Test for the Carlsbad Desalination Project. The STE procedure described above was applied to assess the discharge impact of the 189,000 m^3/day (50 MGD) Carlsbad seawater desalination project, located in Southern California, USA. This project includes direct connection of the desalination plant intake and discharge facilities to the discharge outfall of an adjacent coastal power generation plant using seawater for once-through cooling (see Figure 1).

The power plant has a total of five electricity generators and, depending on the number of units in operation, it pumps between 76,000 m^3/day and 310,0000 m^3/day (20 MGD and 82 MGD) of cooling water through the condensers. This cooling water is collected via onshore open intake from a man-made lagoon referenced on Figure 1 as Agua Hedionda Lagoon. The warm cooling water from all condensers is directed to a common discharge tunnel and lagoon leading to the ocean. The full-scale desalination facility is connected to this discharge tunnel for both desalination plant feed water and for discharging high-salinity concentrate downstream of the intake area.

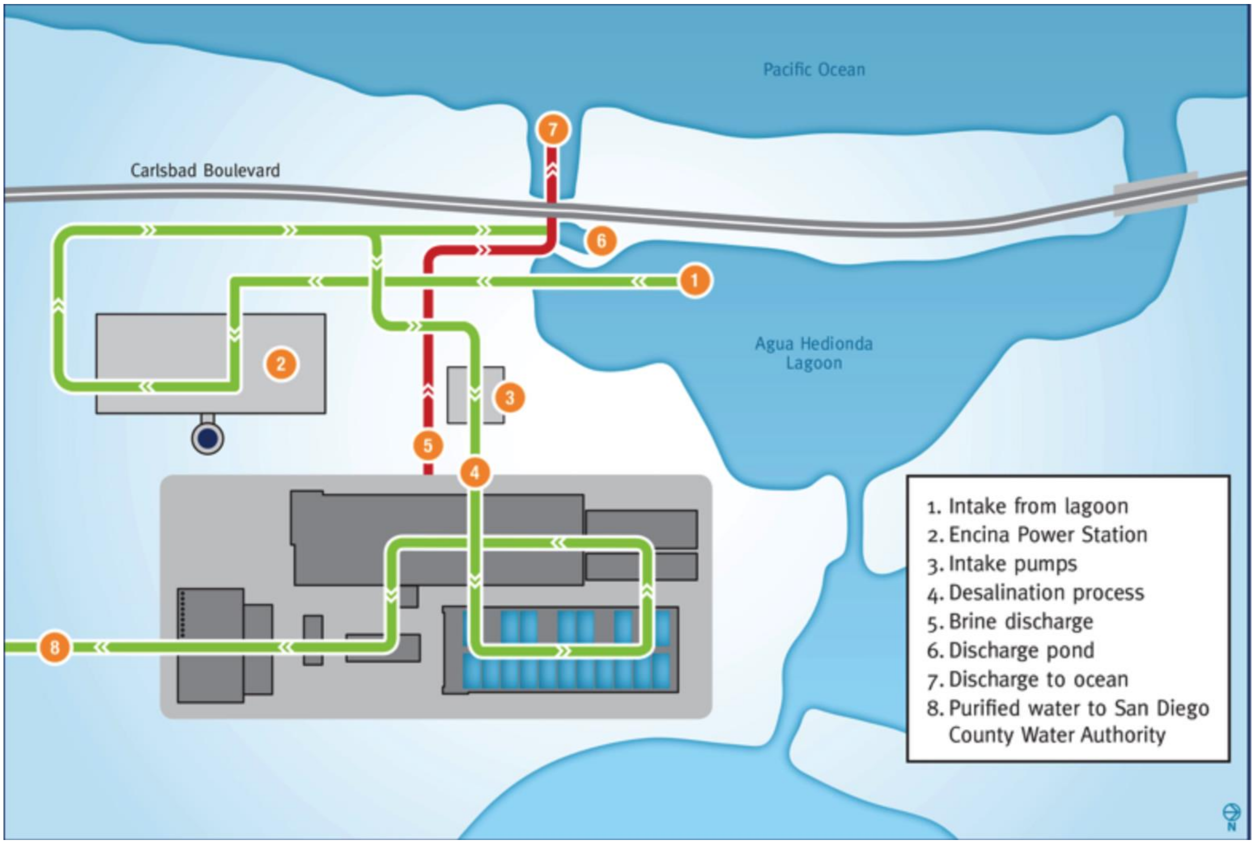

Figure 1 – Schematic of Carlsbad Seawater Desalination Plant

Water collected from one end of the power plant discharge canal will be conveyed to the desalination plant to produce fresh water. The concentrate from the desalination plant will be returned to the same discharge canal, 270 meters (810 ft.) downstream from the point of intake. The desalination plant concentrate, containing approximately two times the salinity of the source seawater (67 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 Carlsbad seawater desalination plant and the power plant will be between 35 to 40 ppt. The average salinity in the middle of the ZID is projected to be 36.2 ppt. Therefore, the biometrics test was completed for this salinity, while the test range for the salinity tolerance test covered 37 ppt to 40 ppt in 1 ppt increments. Both tests were executed by marine biologist very familiar with the local flora and fauna in the area of the future desalination plant discharge (Le Page, 2004).

The salinity tolerance test was completed using three local species, which are known to have highest susceptibility to stress caused by elevated salinity (Le Page, 2004):

- The Purple Sea Urchin *(Stronglyocentroutus purpuratus)*, Figure 2.
- The Sand Dollar *(Dendraster excentricus)*, Figure 3.
- The Red Abalone *(Haliotis rufescens)*, Figure 4.

Figure 2 – Purple Sea Urchin

Figure 3 – Sand Dollars

Figure 4 – Red Abalone

A list of the 20 marine species selected for the biometrics test for the Carlsbad Project is presented in Table 2.

Table 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 clathratus*	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 miniata*	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 elegantissima*	Aggregating anemone	4
18	*Muricea fruticosa*	Brown gorgonian	1 colony
19	*Haliotis rufescens*	Red Abalone	5
20	*Dendraster excentricus*	Sand Dollar	5

The biometrics test continued for a period of 5 months. The results of this test are summarized in Table 3, and indicate that all organisms have 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.

Table 3: Overall Condition of Biometrics Test Species

Scientific Name	Common Name	Avg.% Weight change (grams)	% Weight change (Control group)	Sig.	Appearance and Feeding
Paralichthys californicus	California halibut	91.3	96.9	n/s	Strong
Paralabrax clathratus	Kelp bass	114.3	104.8	n/s	Strong
Paralabrax nebulifer	Barred sand bass	106.8	113.5	n/s	Strong
Hypsoblennius 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	2.3	n/s	Strong
Haliotis fulgens	Green abalone	9.6	7.7	n/s	Strong
Megathura crenulata	Giant keyhole limpet	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	119	48.9	n/s	Strong
Haliotis rufescens	Red abalone	9.2	7.8	n/s	Strong
Dendraster excentricus	Sand dollar	3.5	4.5	n/s	Strong

Note: n/s = not significant and Sig. = Statistical significance.

The duration of the salinity tolerance test for the Carlsbad project was 19 days. The results of this test are given in Table 4 and show that both sand dollars and red abalones had 100% survival in all test tanks and in the control tank. One individual of in the purple sea urchin group died in each of the test tanks and one died in the control tank.

Table 4: Results of Carlsbad Desalination Project 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.

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 420-liter (110-gallon) marine aquariums (Figure 5).

Figure 5 – Carlsbad Desalination Project Test Marine Aquarium

In summary, the Salinity Tolerance Evaluation Method applied to the Carlsbad seawater desalination project confirms that the elevated salinity in the vicinity of the plant discharge would not have a measurable impact on the marine organisms in this location and 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 United States Environmental Protection Agency's standard whole effluent toxicity 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 for these species occurs for TDS concentration of over 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 over 50 ppt on a short-term basis (one day or more) without impacting this otherwise salinity-sensitive species.

6. Product Water Related Permits

6.1. Key Permitting Issues

The Safe Drinking Water Act regulates the quality of drinking water produced by desalination plants in the US. Compliance with these regulations is enforced by the US EPA and, in most states, delegated to the state authorities responsible for public health protection. Desalinated water has to comply with all regulatory requirements applicable for potable water. From this perspective, drinking water related permits and associated studies that must be completed for permitting of desalination plants are very similar to those required for permitting of conventional fresh water treatment plants.

As discussed previously, potential water quality issues with desalinated water versus those found in drinking water from conventional sources originate from the significantly different content of some minerals such as bromide, boron, sodium and chloride. In addition, desalinated water usually has lower alkalinity and hardness than conventional surface water resources such as rivers or lakes.

Additional concerns associated specifically with desalinated brackish water are the potentially high content of odorous gases, nitrates, and sometimes disinfection byproducts. Another concern is the presence of algal toxins in the desalinated seawater during the times of algal blooms, when such toxins are released in ambient seawater by the decaying algae.

6.2. Product Water Related Permitting Support Studies

The supporting studies that are commonly completed as a part of the process for obtaining drinking water permits for a given desalination project include: (1) Watershed Sanitary Survey/Source Water Assessment; (2) process performance and operations monitoring plan; (3) plan for product water integration in the distribution system. The first study aims at identifying potential sources of contamination in the intake area of the desalination plant, while the second study addresses potential concerns for negative impacts on the existing distribution system from the introduction of desalinated water in this system.

Watershed Sanitary Survey/Source Water Assessment

Watershed Sanitary Survey. For desalination plants using open intakes or subsurface intakes under the influence of surface or subsurface contamination, the US EPA requires the completion of a Watershed Sanitary Survey, which characterizes the source water quality in terms of contaminants regulated by the Safe Drinking Water Act and additional water quality parameters specified by applicable state regulatory agencies. This survey also identifies potential sources of water quality contamination in terms of pathogens and other anthropogenic pollutants located within one-mile radius of the intake.

The US EPA Groundwater Rule requires a sanitary survey of the well head facilities/well construction for all plants (including desalination facilities) with groundwater well intakes. The US EPA Long Term 2 Enhanced Surface Water Treatment Rule (also known as the "LT2 Rule") defines intake siting/location requirements, setbacks, depth or laterals and other intake configuration details for intake configuration. In addition, compliance with the LT2 rule requires the project proponent to complete 24 months of monitoring of *Cryptosporidium* content in the desalination plant intake area for water treatment plants with open intakes as well as for plants with subsurface (well) intakes that are determined by the state and local human health protection regulatory agencies to collect ground water under direct influence (GWUDI) of surface water contamination. Of these 24 months, 12 months of monitoring is required to be completed before the construction of the desalination plant with the remaining 12 months of monitoring to be implemented after the desalination plant begins to produce drinking water. Besides *Cryptosporidium,* regulatory agencies often require measurement of turbidity, temperature, and total coliforms in the source water samples.

The public health regulatory agencies use the results from the first 12 months of water quality monitoring required under the LT2 rule to determine the level of pathogen log removal that has to be achieved by the desalination plant treatment facilities. These removal requirements in turn, dictate the type of pretreatment, RO system design, and post-treatment that will have to be used by the desalination plant.

Typically, Watershed Sanitary Surveys contain descriptions and evaluations of the following: (1) water source/s (protection, physical components and condition); (2) source water treatment approach that addresses the site-specific water quality challenges of a given project; (3) impact on the distribution system from the new source of water supply; (4) finished water storage facilities; (5) product water pump facilities and controls; (5) monitoring, reporting and data verification; (6) water system management/operations; and (7) operator compliance with state drinking water requirements.
Development and subsequent five-year updates of the Watershed Sanitary Survey for a given desalination project with an open intake or subsurface intake under influence of surface or groundwater contamination is a costly effort, and usually takes over one year to complete.

Source Water Assessment. If the desalination plant has subsurface intake that is not under the influence of surface water contamination (i.e., confined brackish water aquifers), current regulations allow for a more simplified source water quality characterization - Source Water Assessment. However, conclusively determining if water collected from a subsurface intake is not under surface water influence can prove challenging, as current regulations do not specify a clear path to such a determination. This determination is more straightforward if the source of water is a deep confined brackish water aquifer, but less so if the facility uses a subsurface intake such as vertical beach wells, infiltration galleries, and horizontal and slant wells, which collect water from unconfined shallow aquifers. This issue is further complicated by the fact that beach erosion and storm impacts can change the depth of the filtration layer separating the intake from the surface water over the useful life of the desalination project.

In general, a Watershed Sanitary Survey is a much more detailed evaluation of a drinking water source than a Source Water Assessment. One challenge, in the case of seawater desalination, is the selection of an appropriate approach to delineate the source area. Delineating the entire watershed as the source area is consistent with guidance for Watershed Sanitary Surveys. However, in the case of an ocean intake, the appropriate method to delineate the source area is sometimes difficult because issues such as tides and currents affect the boundaries or the intake area. Such factors are site specific and have to be considered based on close consultation with the permitting agency in the state that is responsible for protection of public health.

Operations Monitoring Plan

This plan identifies the key treatment processes that will be employed at the desalination plant for pretreatment of the source water, salt separation and post-treatment of desalinated water. It also defines the projected removal of contaminants and inactivation of pathogens contained in the source water and provides an overview of the overall plant operation approach. In addition, the Operations Monitoring Plan identifies what monitoring equipment, procedures and control measures are incorporated in the plant design and operations to assure that the desalination plant is producing water meeting applicable regulatory requirements under both normal and extreme source water quality conditions (i.e., heavy storms and algal blooms for surface intakes). The plan also addresses monitoring that will be implemented in the product water distribution system and at points of water delivery/final use.

Plan for Product Water Integration in the Distribution System

Such a plan is of critical importance when the distribution system will receive desalinated water of varying quality and quantity of that will be blended with other water sources of diverse quality.

The plan typically identifies the diurnal and monthly fluctuations of the flow and quality of the water mixture and potential water quality impacts in terms of disinfection byproducts, bromides, boron, sodium, chloride, odor, taste, nitrification, salinity and temperature.

If each water source within the same distribution system used a different disinfectant, a desktop and/or laboratory analysis is usually needed to gain a better understanding of the overall stability of the residual disinfectant in the water blends as well as the changes in content of disinfection byproducts.

Similarly, if waters of different hardness, pH, temperature and alkalinity are blended in the distribution system, at minimum, a desktop water quality analysis is completed to confirm the compatibility of the post-treatment methods and chemicals applied to the desalinated water and the other water sources and to ensure that the introduction of desalinated water will not trigger corrosion of the distribution system and household plumbing

Other Studies. Depending on the site-specific contaminants encountered in the source water, the regulatory agencies involved in issuing drinking water permits may require the completion of additional studies such as algal toxin rejection, control analysis and source water characterization for endocrine disruptors and/or specific carcinogens, if sources of such pollutants may be present in the watershed.

7. Other Permits

Depending on the type and size of the plant, the plant intake, and outfall type and location, the construction and operation of a given desalination project may require a number of other permits. For example, California has a special agency, the California Coastal Commission, dedicated to the permitting facilities located in the 5-mile coastal zone. . This agency regulates project construction and operation through a Coastal Development Permit which can be obtained by the completion of most of the studies discussed in the previous sections. Other permits, such as the stream alteration permit issued by the California Department of Fish and Game, regulate activities within inland waters, bays and estuaries. If the desalination plant has its own power generation system or a standby diesel generator, in most states, operation of this equipment will require an air emission permit.

As seen from the overview presented above, numerous state and local agencies may be stakeholders in the desalination project permitting process. Therefore, the very first step in any desalination project permitting process is to identify all permits and authorizations needed for the planning, construction and operation of the desalination project, determine the permitting jurisdictions and their requirements, and define a clear sequence of efforts needed to minimize the time, efforts and expenditures associated with project implementation.

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