Seawater Concentrate Management

White Paper

May 2011

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WATEREUSE ASSOCIATION
DESALINATION COMMITTEE

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INTRODUCTION

Desalination of seawater is becoming increasingly popular for production of drinking water in the United States (US), as many coastal municipalities and utilities are looking for reliable and drought-proof sources of new local water supply. Similar to conventional water treatment plants and water reclamation facilities, desalination plants generate water treatment byproducts. The disposal of these treatment byproducts has to be managed in an environmentally safe and sustainable manner, compliant with all applicable regulatory requirements. The purpose of this white paper is to discuss the composition of seawater desalination byproducts; provide an overview of applicable regulations; discuss concentrate management alternatives; and highlight case studies of successful concentrate disposal.

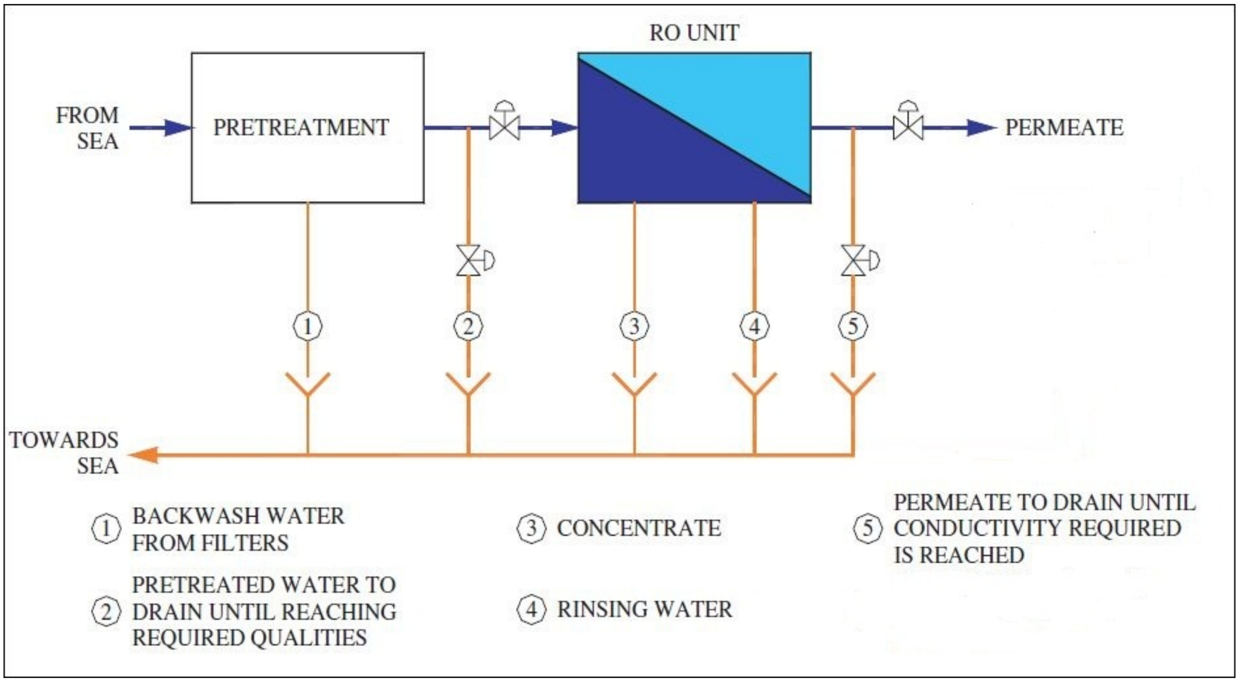
At present, most seawater reverse osmosis (SWRO) desalination plants have the following key components: intake to collect source seawater; pretreatment system to remove solid particulates from the source water; reverse osmosis system to separate the salts from the source seawater and to produce fresh water (permeate); and post-treatment system to condition this fresh water for conveyance and final use.

The main by-product generated by the desalination plant's salt separation process is commonly referred to as concentrate or brine. In addition to concentrate, desalination plant discharges may also include other treatment process side-streams, such as spent pretreatment filter backwash water, SWRO membrane rinsing water, and treated membrane cleaning water (Figure 1).

Desalination concentrate consists of dissolved compounds (minerals, organics, metals, etc.) rejected by the reverse osmosis membranes. Backwash water is generated during the periodic cleaning of the pretreatment filters and contains particulates and other compounds removed from source water prior to desalination

SEAWATER DESALINATION BYPRODUCTS

Concentrate typically constitutes 90% to 95% of the total desalination plant discharge volume. This byproduct of the seawater separation process contains the minerals and other constituents which are removed from the pretreated source seawater as well.



Source: Water Globe Consulting

Figure 1 – Typical Discharge Components of Seawater Desalination Plant

The percentage of the total volume of seawater converted into fresh water is referred to as desalination plant recovery. SWRO desalination plants are typically designed to recover 45% to 55% of the source water as fresh product water. In simple terms, a desalination system operating at 50% recovery collects two gallons of source seawater to generate one gallon of fresh water and one gallon of concentrate.

The fresh water produced during the desalination process has a very low mineral content – typically 100 mg/l to 500 mg/L of salinity in the form of total dissolved solids (TDS). Containing over 99% of all source seawater salts and dissolved constituents, concentrate mineral content is approximately 1.5 to 2 times higher than that of the source seawater.

Concentrate from seawater desalination plants using open ocean intakes typically has the same color, odor, oxygen content and transparency as the source seawater from which the concentrate was produced. Therefore, concentrate discharge to surface water bodies (ocean, river, etc.) does not typically change its physical characteristics or aesthetic impact on the aquatic environment, except for its density.

When a coagulant such as ferric chloride or ferric sulfate is used for seawater pretreatment, the spent pretreatment filter backwash will have a red color due to the high content of ferric hydroxide in the backwash water. If this backwash water is blended with the SWRO system concentrate, the concentrate and the entire desalination plant discharge will typically be visibly discolored. In order to address this challenge, most recent desalination projects, including the 25 MGD seawater desalination plant in Tampa Bay, Florida, are equipped to remove the ferric hydroxide from the backwash water, dewater it and dispose of it to a landfill in a solid form. As a result, the visual appearance of the desalination plant discharge is the same as that of the ambient seawater – i.e., the concentrate is transparent and clear.

There is no relationship between the level of salinity and biological or chemical oxygen demand of the desalination plant concentrate – over 80% of the minerals that encompass concentrate salinity are sodium and chloride, and they are not food sources or nutrients for aquatic organisms. The dissolved solids in the concentrate discharged from seawater desalination plants are not of anthropogenic origin as compared to pollutants contained in discharges from industrial or municipal wastewater treatment plants.

The amount of particles, total suspended solids and biochemical oxygen demand in the concentrate are typically very low ($\leq$ 5 mg/l) because these constituents are removed by the desalination plant's pretreatment system.

As indicated previously, in most recently built seawater desalination plants, the filter backwash water is processed at the desalination plant site by settling. Therefore, the treated backwash water which is combined and discharged with the SWRO system concentrate is also very low in terms of total suspended solids and biochemical oxygen demand. The organics and solids removed from the source seawater are disposed to a landfill as solid residuals. As a result, the total suspended solids content of the desalination plant discharge is lower than the solids content of the ambient source seawater collected for desalination. Ambient seawater quality is usually very consistent and over 98% of the seawater concentrate salinity is attributed to five dissolved minerals: sodium, chloride, sulphate, magnesium and calcium.

DESALINATION PLANT DISCHARGE MANAGEMENT ISSUES AND SOLUTIONS

Environmental Impact of Elevated Salinity

Salinity Concentration. Seawater desalination plants usually produce concentrate salinity which is approximately 1.5 to 2 times higher than the salinity of the ambient seawater. Since ocean water salinity in US open-ocean coastal waters typically varies between 33 ppt to 35 ppt, concentrate salinity is usually in a range of 52 ppt to 70 ppt. While many marine organisms can adapt to this salinity range, some aquatic species are less tolerant to elevated salinity concentrations than others. For example, gobies, which are one of the most common species inhabiting coastal waters, are tolerant to very 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 the abalone and sea urchins have lower salinity tolerance.

The nature, magnitude and significance of elevated concentrate salinity impacts mainly depend upon 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 Carlsbad seawater desalination project, and completed based on testing of over two dozen marine species frequently encountered along the California coast, indicates that based on whole effluent toxicity (WET) tests these marine species can safely tolerate salinity of 40 ppt (19.4 % above ambient salinity)[1].

For this case in point, it is important to note that subsequent acute toxicity bioassay testing using standard top smelt test organisms (*Atherinops affinis*) completed in conformance with the National Pollutant Discharge Elimination System **(**NPDES**)** permit requirements for the Carlsbad desalination project[1] identified the following: (1) The No Observed Effect Concentration (NOEC) of the test occurred at 42 ppt of concentrate salinity; (2) The Lowest Observed Effect Concentration (LOEC) was found to be 44 ppt; (3) The plant was well below the applicable toxicity limit for salinity of 46 ppt or lower; (4) The No Observed Effect Time (NOET) for 60 ppt concentration was 2 hours, while the Lowest Observed Effect Time (LOET) for the 60 ppt concentration was 4 hours. This means that for a short period of time the species may be exposed to salinity as high as 60 ppt without any observed effect.

A site investigation of a number of existing full-scale seawater desalination plants operating in the Caribbean completed by scientists from the University of South Florida and the South Florida Water Management District in 1998[2] has concluded that the salinity levels of 45 ppt to 57 ppt have not caused statistically significant changes in the aquatic environment in the area of the discharge.

Discharge Salinity Related Regulatory Requirements. At present, there are no federal or state salinity discharge limits in the US and worldwide. The pertinent federal and state laws in the US regulate salinity of desalination plant concentrate discharges by establishing project-specific acute and chronic 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 realistic and potentially synergistic environmental impacts of concentrate with other constituents in the concentrate. Besides the effect of elevated salinity on the marine habitat in the area of the discharge, the effect of dissolved solids (salinity) contained in the concentrate (e.g., metals, organics, suspended solids) is considered alongside other waste streams that may be contained in the desalination plant discharge (e.g., spent filter backwash, membrane flush water). In short, salinity is only a measure of the dissolved mineral (salt) content of the concentrate rather than the complex chemistry of the discharge in relationship to the receiving body of water.

[1] http://www.swrcb.ca.gov/rwqcb9/press_room/announcements/carlsbad_desalination/updates_3_13_09/item_2.pdf

[2] Hammond et al. (2008), Effects of the Disposal of Seawater Desalination Discharges on Near Shore Benthic Communities.

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; 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.

The *California Ocean Plan* establishes a daily maximum acute toxicity receiving water quality objective of 0.3 TUa (acute toxicity units). Requirement III.C.4 (b) of the *California Ocean Plan* designates that this 0.3 TUa 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. Initial dilution is defined within Appendix I of the *California Ocean Plan* 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."*

Salinity tolerance of aquatic life is site specific and depends on the organisms inhabiting the area of the discharge as well as the nature of the discharge. Therefore, a single, non-site specific "blanket" narrative or numeric water quality objective (discharge limit) for salinity does not provide additional protection to the site specific marine environment in the area of a given discharge, beyond that which is already provided by the acute and chronic toxicity objectives.

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 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[1, 2]. The referenced limits are applicable to the point of discharge and reflective/protective of the acute toxicity effect of the proposed discharge.

The 50 MGD Huntington Beach SWRO Project 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 for the salinity discharge from the desalination plant of 40 ppt and is derived from site-specific analysis of the conditions of the discharge for this project.

Some state regulatory agencies in the US (e.g., the State Water Resources Control Board in California) are considering the introduction of a single state-wide salinity limit for all ocean discharges of 10% above ambient ocean water salinity or other blanket numeric value, including disposal of concentrate from seawater desalination plants. This approach and reasoning are flawed because of several key considerations.

The salinity of the natural background varies at different locations and therefore, the salinity limit derived from such objectives will differ and sometimes may exceed or underestimate the salinity tolerance of the site-specific aquatic environment in the area of the discharge. This is especially true for transient marine species. For example, a salinity tolerance study completed for the marine organisms living in the vicinity of the Carlsbad project can tolerate long-term exposure to salinities of 40 ppt and greater[1].

If the background salinity near Carlsbad (33.5 ppt) is examined for discussion purposes and a 10% increment is applied as a criterion, the salinity limit imposed at the edge of the zone of initial dilution would be 36.85 ppt, as opposed to the 40 ppt limit set forth in the Carlsbad NPDES Permit. Both limits would be equally protective of the marine environment based upon the previously discussed WET testing results. However, if a limit of 36.8 ppt is used rather than 40 ppt, this limit would be overly restrictive for the project and would not have a basis in science or precedence with respect to NPDES permitting requirements. This example shows that a "blanket" salinity limit may unduly hinder the implementation of desalination projects rather than protect marine environment. Moreover, the effect on the environment is associated with the actual tolerance of the marine organisms which inhabit it, rather than with the value of the background salinity.

The variation in background ambient salinity may differ significantly from one location to another. Open-ocean salinity would naturally vary ± 10% from the average annual value (i.e., a total salinity variation bracket of 20%). However, in shallow areas along the shore or in shallow bays, this variation may be higher. An example is the source water quality variation documented during the desalination pilot testing completed by the Marin Municipal Water District in 2005/2006 (see Table 2)[3].

[3] Raynolds, T. et al. (2007) Desalination on San Francisco Bay; Results from the MMWD SWRO Pilot Program, Proceedings of 2007 AWWA Membrane Technology Conference.

Table 2 – Salinity Variation in San Francisco Bay

		Typical Pacific Ocean Seawater[a]	Historical Drought Bay Water Quality[b]	Pilot Study Source Water (Bay Water) Quality[c]		
Parameter	**units**		**Max.**	**Avg.**	**Max.**	**Min.**
TDS	mg/l	34,465	32,000	21,700	29,000	2,500
Conductivity	umhos/cm	–	48,000	39,200	43,500	5,000
Calcium	mg/l	400	371[d]	210	310	71
Magnesium	mg/l	1272	1,181[d]	755	910	580
Sodium	mg/l	10,560	9,805[d]	6,700	8,100	3,300
Potassium	mg/l	380	353[d]	262	350	190
Ammonia	mg/l	0.4	0.4	ND	ND	ND
Barium	mg/l	5	3	5.0	27	0.011
Strontium	mg/l	13	12[d]	2.63	5.9	.004
Bromide	mg/l	–	–	6.9	8.1	6.0
Bicarbonate	mg/l	142	110[d]	101	110	94
Temperature	°C	10	21.7	17	21	10
pH	units	8.2	8.19	7.9	8.3	7.6
Sulfate	mg/l	2,560	2,377[d]	1,533	1,900	1,000
Chloride	mg/l	18,980	17,620	11,000	15,000	2,100
Fluoride	mg/l	1.4	1.3[d]	0.682	0.79	0.5
Boron	mg/l	4.6	4.3[d]	2.3	3.3	1.7

Notes:
(a) From Van der Leeden, et al., 1990, The Water Encyclopedia.
(b) Historical North San Francisco Bay Water Quality Data: 1990 MMWD Pilot Study and USGS data.
(c) On-line and grab samples from March 2005 to April 2006.
(d) Value calculated by taking the ratio of analyte concentration to TDS concentration in typical seawater and multiplying it by the San Francisco Bay TDS historical maximum value for that analyte.

The average salinity concentration of the source water for this proposed desalination plant was 21.7 ppt, the maximum was 29.0 ppt (+34%) and the minimum was 2.5 ppt (-768%). If, for example, a typical open ocean salinity variation of 10% is chosen as a "blanket" narrative objective, then this numeric objective would be overly restrictive and completely unrealistic for the Marin County desalination project, because the source water of the desalination plant will be more saline than the concentrate salinity limit; and if the +34% salinity variation is chosen, then the maximum state limit for the salinity discharge of the Carlsbad desalination plant would be 44.6 ppt, which is higher than the level established in the current Carlsbad NPDES permit. In both examples, however, the beneficial uses would be fully protected by the WET objectives applied to site-specific conditions in the vicinity of the discharge.

A similar observation can be made for the Tampa Bay desalination plant discharge where the ambient seawater salinity also varies in a very wide range of 16 ppt to 33 ppt and averages 26 ppt. In this case, because the 19 MGD of desalination plant concentrate is diluted with 1.4 billion gallons of cooling water from the power plant with which the desalination plant is collocated, the actual salinity increment is within the level of accuracy of the salinity measurement instruments.

Discharge Salinity Dispersion Modeling. The main purpose of the evaluation of the concentrate dispersion from the point of discharge is to establish the size of the zone of initial dilution (ZID) required to dissipate the discharge salinity plume to near-ambient seawater TDS levels and to determine the TDS concentrations at the surface, mid-level of the water column, and at the ocean bottom in the ZID. The TDS concentration fields at these three levels are then compared to the salinity tolerance of the marine organisms inhabiting the surface (mostly plankton), the water column (predominantly invertebrates) and the bottom dwellers in order to determine the impact of the concentrate salinity discharge on these organisms.

While the *California Ocean Plan* does not specifically address the example of a negatively buoyant discharge, it may be inferred from the buoyancy/turbulent momentum definition of the ZID that it may also be applied to a negatively buoyant discharge. For such a negatively buoyant discharge, initial dilution would occur as a result of the combined momentum of the discharge and the negative buoyancy which causes discharged effluent to rapidly mix and sink in the water column until it reaches neutral buoyancy.

The discharge salinity field in the ZID and the ZID boundaries are established using hydrodynamic modeling. This modeling allows for determination of the most suitable location, design configuration and size of the ocean outfall and diffusers if a new outfall is needed, or assessment of the feasibility of using existing wastewater or power plant outfall facilities.

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 this and other water quality management applications, such as 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. One example is a fully 3-dimensional far field dispersion model, SEDXPORT, that is a process-based stratified flow model with the complete set of littoral transport physics including tidal transport, and wind & wave induced transport and mixing. It also accounts for the local bathymetric interaction with wave and current transport dynamics, as illustrated in Figure 2, around the discharge tower for the Huntington Beach Desalination Project. There is an apparent offshore bias to the spreading of both 40 ppt and ZID contours in Figure 2 due to the unrestricted tendency for the denser brine to move down slope and offshore as gravity flow. At the outfall atop the discharge tower, the initial concentrated sea water discharge (55.37 ppt end-of-pipe) is propelled vertically upward as a free jet that encroaches on the sea surface, due to the absence of a velocity cap at the top of the discharge tower.

As the momentum of this jet mixes and dilutes into the receiving water, there is no longer enough momentum flux to support the weight of the denser brine near the sea surface and it subsides to the sea bed. The subsiding brine layer only moves a short distance uphill toward the shore before reaching hydrostatic equilibrium with the surrounding water mass. However, the brine is free to move down slope, propelling itself as a gravity flow by exchanging potential energy in elevation for kinetic energy of turbulent motion. As the brine continues down slope, it entrains a portion of the surrounding water mass, diluting itself until its density is reduced to that of the surrounding water mass. This occurs abruptly when the brine plume travels far enough down slope to run into colder bottom water (i.e., at the point where the ambient ocean thermocline in the receiving water intersects the shore rise bottom profile).

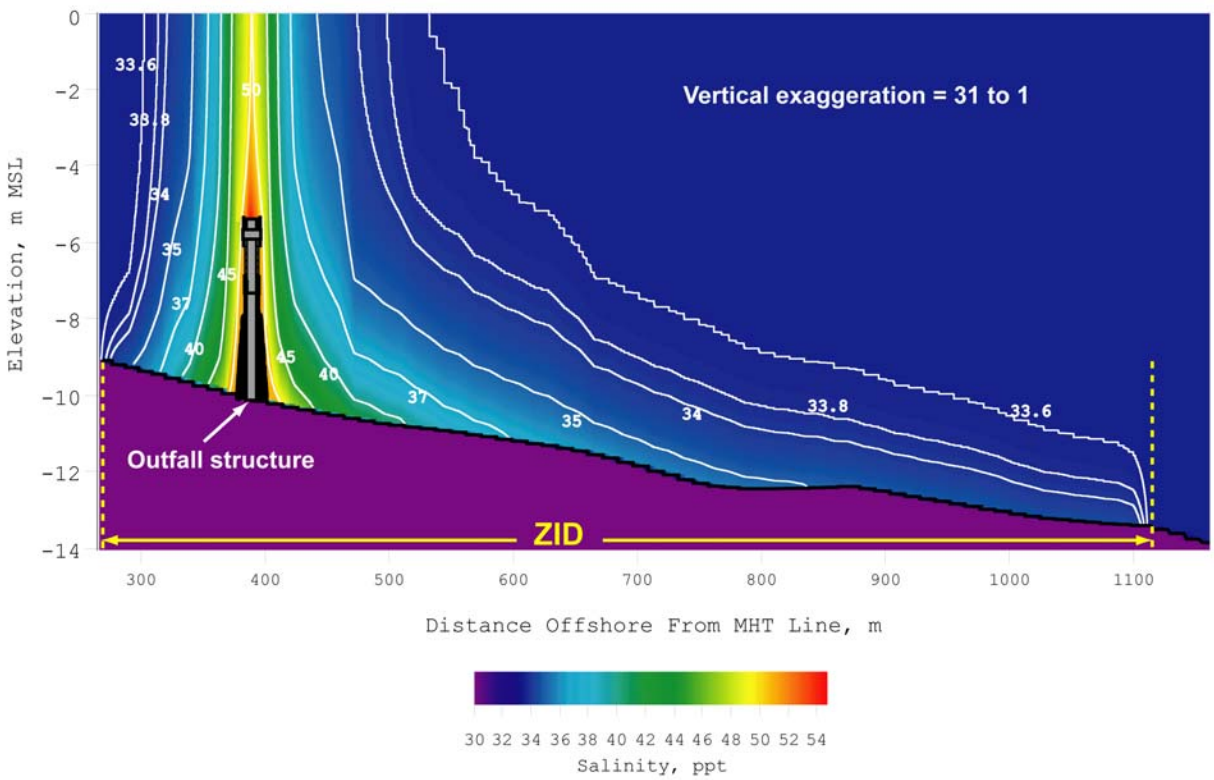
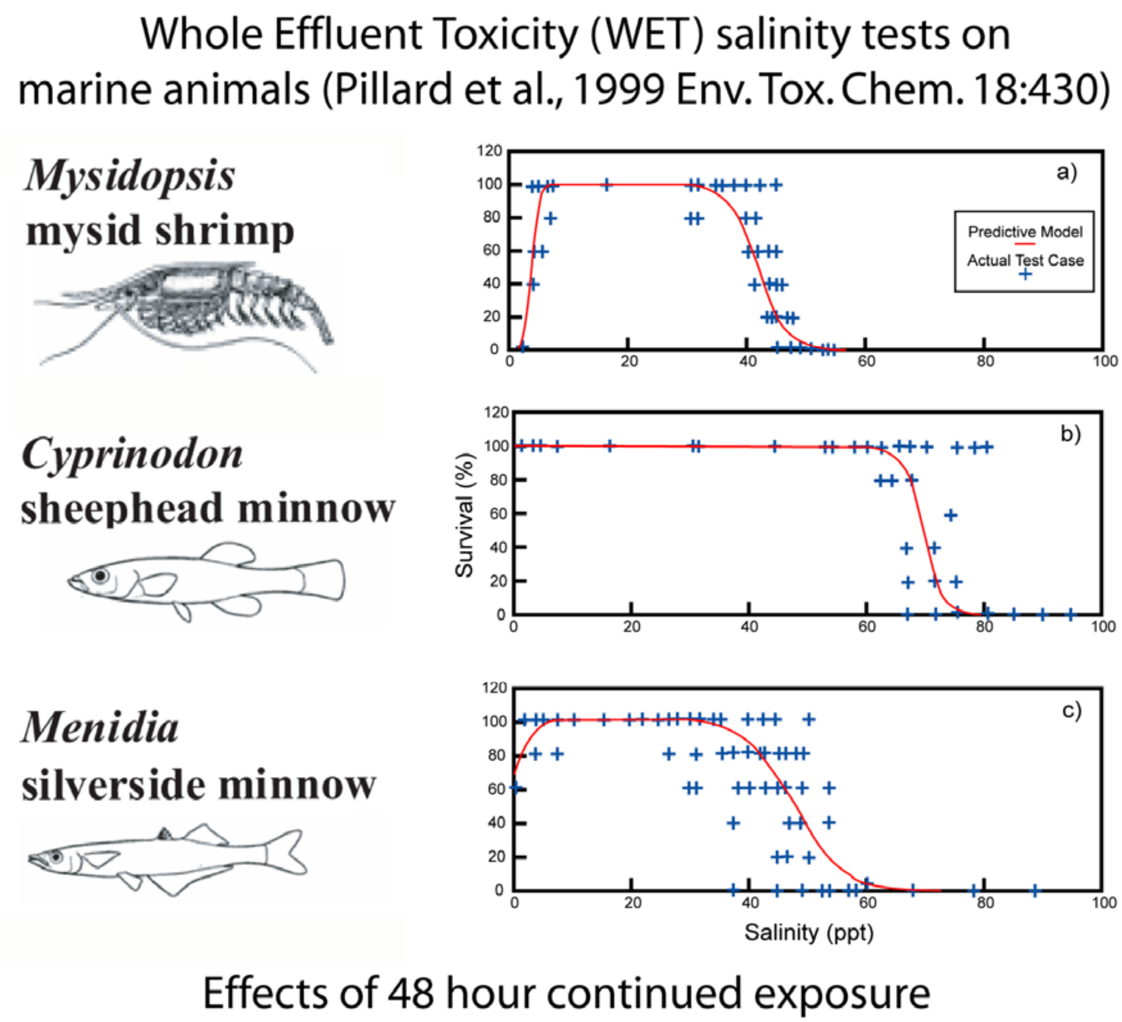


Figure 2. Cross section of salinity field used in calculation of Zone of Initial Dilution (ZID). R.O. production = 50 mgd under un-heated low-flow conditions (intake flow rate = 126.7 mgd, ΔT = 0) at the Huntington Beach outfall.
Source: Dr. Scott Jenkins

Another example of the use of a sophisticated CFD far field model is the near-field salinity dispersion analysis for the Tampa Bay seawater desalination project that was completed by the Danish Hydraulic Institute using their proprietary model. The purpose of this analysis was to evaluate the near-shore salinity elevation in a shallow embayment adjacent to the plant discharge. The far-field modeling of discharge plume dissipation in the Tampa Bay was completed by the University of South Florida using their three-dimensional hydrodynamic circulation model, specifically developed for this application.

Time of Elevated Salinity Exposure. Assessment of the biological impacts of elevated salinity requires integration of hyper-salinity test data and discharge models. Hyper-salinity testing evaluates the combined effects of both the magnitude of the salinity increase and the duration of exposure to it, and these data can be integrated with models to show the distribution and concentration of the discharge plume over the seabed (benthic habitat) and in the water column (pelagic habitat). Figure 3 shows the 48-hour hyper-salinity tolerances determined for three coastal species not occurring in Santa Monica Bay. The objective of this type of testing is to define, in a statistically robust manner, the exposure salinity which 50% of the test organisms can survive for the specified time. Data for a benthic species, the mysid shrimp, indicate a 48-hour, 50% survival of over 40 ppt. However, the data additionally show this shrimp experienced some mortality at salinities just above 36 ppt, which is near the threshold of the proposed "10% Rule" for discharge effects. In terms of the potential hyper-saline discharge effects in the water column, Figure 3 shows the silverside minnow, a pelagic species, has a 48-hour, 50% survival of over 40 ppt, but that some mortality also occurred at lower salinity. In the pelagic environment, a fish that swims into hyper-salinity plume could sense and then avoid it by swimming away. Most benthic organisms would not be able to use avoidance behavior.



Source: Dr. Scott Jenkins

Figure 3
Mortality Of Three Keystone Marine Species In Response To Salinity Variation; Where Mortality Is Quantified In % Survival On Vertical Axis In Response To Salinity In Parts Per Thousand (ppt) On Horizontal Axis.

Far-field dispersion/dilution models are useful in quantifying effects of the hyper-saline water column on the eggs and larvae of fish and other species and plankton which, because they drift with the current, will of necessity pass through the discharge plume. Figure 4 gives an example of the exposure-time modeling results for two potential operating points of a 50 MGD desalination facility from Appendix C of the certified REIR (2005) for the Huntington Beach Desalination Project. The 126.7 MGD intake flow rate operating point (red line) discharges 55.4 ppt end-of pipe, while the 253.4 MGD intake flow rate operating point (green line) discharges 41.8 ppt end-of pipe. Despite the fact that neither operating condition utilizes a diffuser, Figure 4 shows that the exposure times of drifting organisms to salinities in excess of 36 ppt is very brief. This result is due to the influence of the local ocean currents interacting with the hydrodynamics of the discharge plume, a complex interaction that the coupled modeling tool of Visual Plumes/SEDXPORT is well suited to resolve.

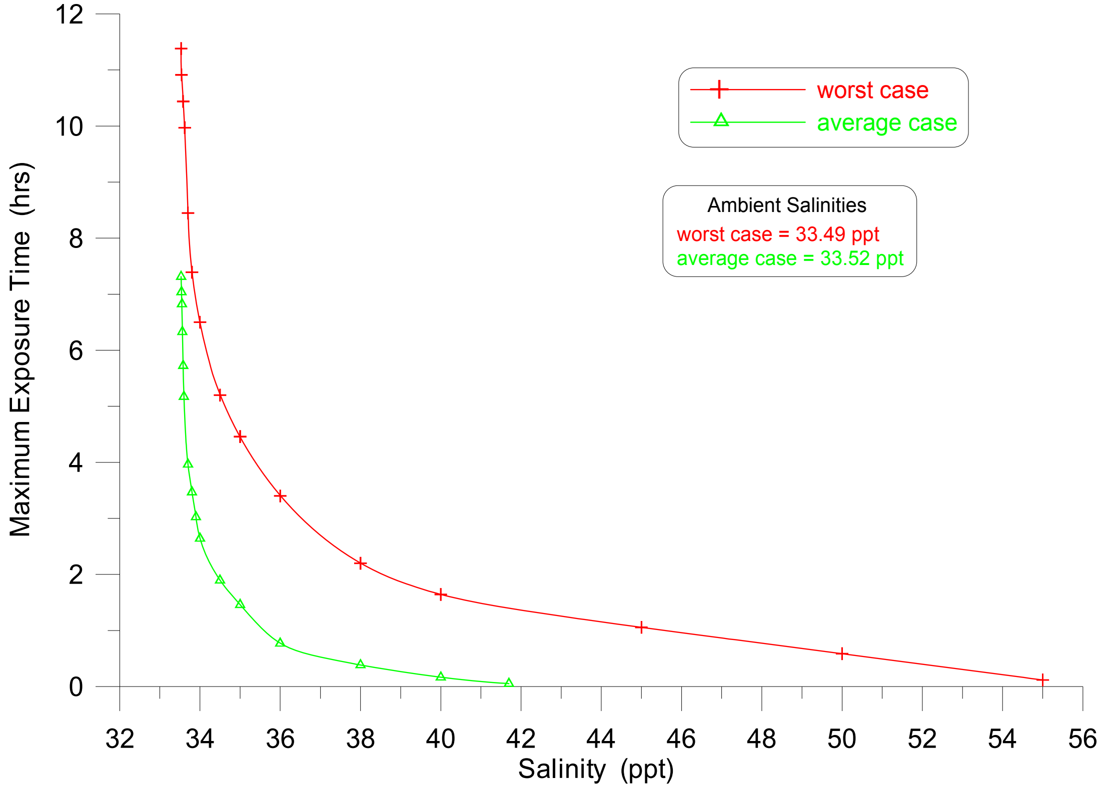


Figure 4. Maximum exposure time of a drifting organism passing through the discharge plume of concentrated seawater from the AES Huntington Beach outfall for worst case conditions (red, plant flow rate = 126.7 mgd) and average case conditions (green, plant flow rate = 253.4 mgd).

Source: Dr. Scott Jenkins

Modeling the distribution and concentration of the discharge plume over the seabed (benthic habitat) and in the water column (pelagic) will show how hyper-salinity exposure will be affected by physical processes such as currents, bottom topography, and discharge water density. Figure 5 shows the bottom salinity modeling results for the same two potential operating points used in Figure 4 for the 50 MGD desalination facility from Appendix C of the certified REIR (2005) for the Huntington Beach Desalination Project. Note that the bottom dispersion of the hyper-salinity footprint in Figure 5 is greatly constrained in the cross-shore direction by the effects of gravity acting on the heavy brine plume. On the other hand, the bottom expression of the plume is greatly extended in the along-shore direction by the coastal bottom currents. The 126.7 MGD intake flow rate operating point (red line) subjects about 15.6 acres of seabed to salinity in excess of 36 ppt, while the 253.4 MGD intake flow rate operating point (green line) subjects only about 6.8 acres of seabed to salinity in excess of 36 ppt. Again, this level of modeling detail obtained by Visual Plumes/SEDXPORT is the result of a complex interaction between the gravity flow tendencies of the heavy brine plume and the coastal current field.

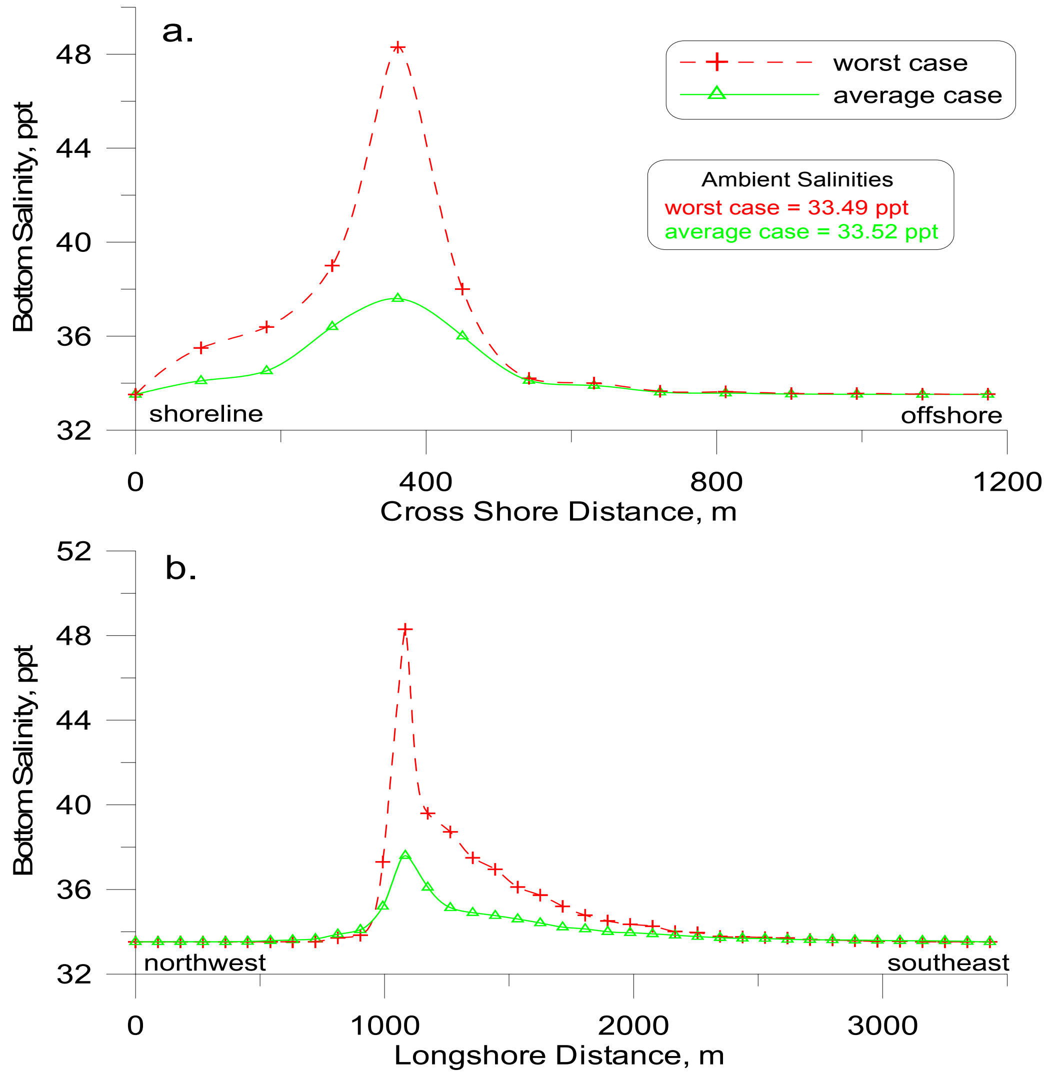


Figure 5. Thirty day average of bottom salinity for worst and average case months along: a) crossshore profile (Section A), b) longshore profile (Section B).
Source: Dr. Scott Jenkins

Effect of Source Water Conditioning Additives

Desalination plants use many of the same additives (treatment chemicals) applied for source water conditioning in conventional drinking water treatment plants and, therefore, have similar side-stream discharge water quality. The long-term track record of environmentally safe operation of surface water treatment plants in the US using many of the same water conditioning additives is a testament to the fact that if properly handled and utilized, such additives do not pose environmental challenges when regulated within the existing NPDES permitting process.

If the desalination plant pretreatment side-streams are discharged along with the concentrate, the blend may contain elevated turbidity, total suspended solids and biochemical oxygen demand. As indicated previously, for conventional granular media pretreatment systems, often, iron-based additives (coagulants) such as ferric salts are used for source water conditioning (particle coagulation for enhanced removal). Depending on their dosage, iron additives could discolor the pretreatment side-stream, which, when blended with concentrate, may also change the color of the desalination plant discharge. Therefore, the desalination plant pre-treatment side-streams are typically either processed at the desalination plant site in a separate solids handling system (typical for large plants), or discharged to the nearby sanitary sewer for further treatment at a wastewater plant (common practice for small plants). Most membrane pretreatment based systems do not use a coagulant and therefore are not challenged with the discharge discoloration issue.

Acids and scale inhibitors are often added to the desalination plant source water to facilitate the salt separation process. Typically, these additives are rejected by the reverse osmosis membranes and are collected in the concentrate. However, such source water conditioning compounds are applied at very low concentrations and their content does not alter significantly the water quality and quantity of the concentrate. The environmental implications of the use of such additives are typically well tested before their use, and only additives that are proven harmless for the environment and approved by pertinent regulatory agencies are actually applied for seawater treatment. All chemical additives used at both desalination and conventional water treatment plants in the US are of food grade purity (NSF certified) and are approved for human consumption.

CONCENTRATE MANAGEMENT ALTERNATIVES

Currently, the most commonly used methods for seawater desalination concentrate management include: surface water discharge to the ocean; discharge to sanitary sewer; and subsurface discharge through exfiltration wells and galleries. Discharge to sanitary sewer and exfiltration wells are typically practiced for small size desalination plants only. Options for discharging concentrate to surface water include:

- Direct discharge through new outfalls;
- Discharge through existing wastewater treatment plant outfalls; and
- Discharge through existing power plant outfalls (collocation).

Discharge through New Outfalls

New plant outfalls are designed to dissipate plant concentrate within a short time and distance from the point of its entrance into the surface water body in order to minimize environmental impacts. The two options available to accelerate and enhance the concentrate mixing process are to either rely on the naturally occurring mixing capacity of the near-shore zone (e.g., tidal movement, near-shore currents, wind), or to discharge concentrate beyond the near-shore zone and to use diffusers which release concentrate at high velocity towards the ocean surface in order to improve mixing.

The near-shore tidal zone is usually a suitable location for concentrate discharge when it has adequate capacity to receive, mix and transport desalination plant discharge into the open ocean. This salinity threshold mixing/transport capacity of the tidal zone can be determined using hydrodynamic modelling. If the salinity discharge load is lower than the tidal zone threshold mixing/transport capacity, then concentrate discharge to this near-shore zone is significantly more environmentally compatible and cost effective than the use of constructing long, open outfalls equipped with diffuser systems.

For example, the sites of the 85 MGD Ashkelon Desalination Plant (Figure 6), and the 92 MGD Hadera Desalination Plant (Figure 7) in Israel were specifically selected for their vicinity to coastal locations with very intensive natural near-shore tidal mixing, which eliminated the need for construction of lengthy outfalls and costly outfall diffuser structures.

Source: Water Globe Consulting

Figure 6 – 85 MGD Ashkelon Desalination Plant Near-shore Discharge

Although tidal (surf) zone may have a significant amount of turbulent energy and often may provide better mixing than an end-of-pipe type diffuser outfall system, this zone has limited capacity to transport and dissipate the saline discharge load into the open ocean. If the mass of the saline discharge exceeds the threshold of the tidal zone's salinity load mixing and transport capacity, the excess salinity would begin to accumulate in the tidal zone and could ultimately result in a long-term salinity increment in this zone. For such conditions, the construction of a new outfall structure with diffusers is often the concentrate discharge system of choice. The diffuser system provides the mixing necessary to prevent the heavy saline discharge plume from accumulating at the bottom in the immediate vicinity of the discharge. The length, size and configuration of the outfall and diffuser structure are typically determined based on hydrodynamic modelling for the site-specific conditions of the discharge location.

Source: IDE

Figure 7 – Near Shore Discharge of 92 MGD Hadera Desalination Plant

Key advantages of constructing new discharge outfalls include accommodating practically any size desalination plant and providing for more freedom in selecting plant location, as compared to the other discharge alternatives which rely on the use of existing wastewater treatment plant or power plant outfalls. The key disadvantage is that it usually is the most costly alternative for disposal of concentrate from medium and large size SWRO plants. Construction of new ocean outfalls with a diffuser structure is commonly used worldwide and is the concentrate discharge alternative of choice for the seawater desalination plants in Australia constructed to date (Perth I, Gold Coast and Sydney discharging over 140 MGD of concentrate), the Australian plants under construction (Adelaide, Perth II and Melbourne – with total discharge volume of over 260 MGD), and for many plants in Spain, the Middle East, Africa, South America, and the Caribbean.

Discharge through Existing Wastewater Treatment Plant Outfalls

The key feature of this combined discharge method is the benefit of accelerated mixing that stems from blending the heavier high-salinity concentrate with the lighter low-salinity wastewater discharge. Depending on the volume of the concentrate and how well the two waste streams are mixed prior to the point of discharge, the blending may allow for reducing the size of the wastewater discharge plume and diluting of some of its constituents. This approach was first permitted in California for the Santa Barbara Desalination Plant in 1994 and has been proposed for the Marina Coast desalination project on the Monterey Peninsula, as well as for the Santa Cruz and Dana Point desalination projects in California.

Similarly, a number of large desalination plants worldwide co-discharge their concentrate through existing wastewater treatment plant (WWTP) outfalls. For example, the concentrate from the 40 MGD Beckton desalination plant in London, England is effectively blended with secondary effluent from the Beckton Wastewater Treatment Works at a dilution ratio of 1:50 and discharged to the Thames River.

The largest plant in operation at present which practices co-discharge of desalination plant concentrate and wastewater effluent is the 50 MGD Barcelona SWRO facility in Spain (see Figure 8). Co-disposal with WWTP effluent is also used at the 30 MGD Fukuoka SWRO plant, which is the largest SWRO plant in Japan.

Source: Degremont

Figure 8 – Barcelona Seawater Desalination Plant

Key considerations related to the use of existing WWTP outfalls for direct seawater desalination plant concentrate discharge are: (1) the availability and cost of wastewater outfall capacity; (2) the need for modification of the outfall system of the existing wastewater treatment plant due to altered buoyancy of the concentrate-wastewater mix; and (3) the compatibility of the diurnal variation wastewater treatment plant discharge flows in relation to the discharge from the desalination plant.

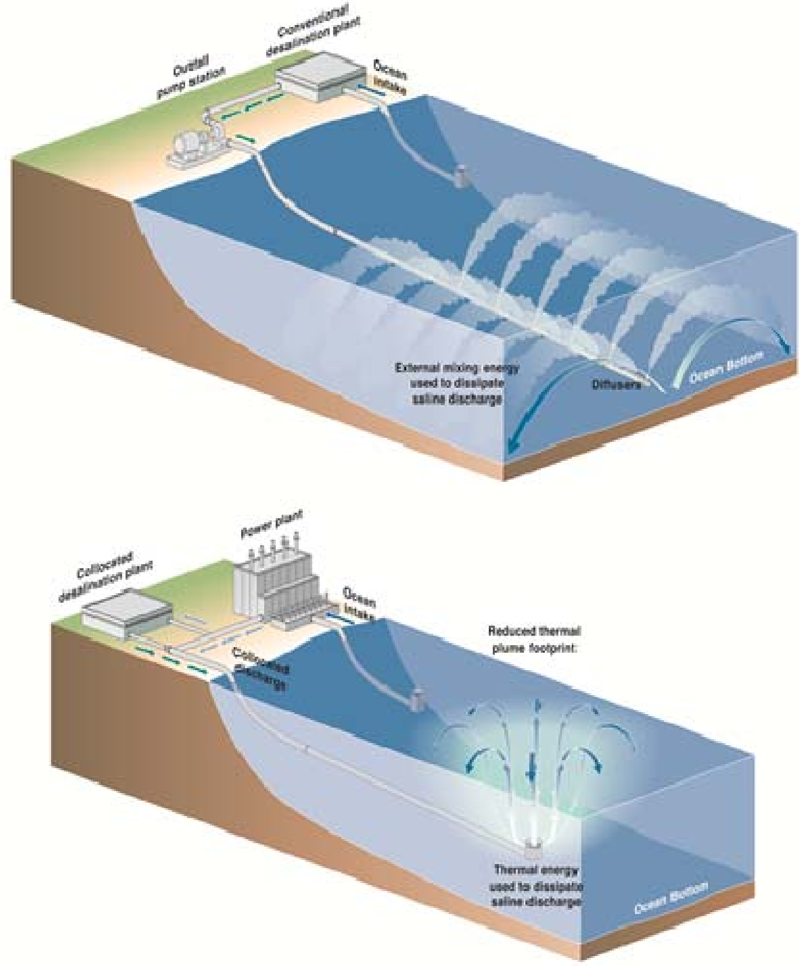
The key advantage of wastewater treatment plant co-discharge is that it avoids substantial costs and environmental impacts associated with construction of a new outfall for the desalination plant. Mixing of the negatively buoyant wastewater discharge with the heavier than ocean water concentrate, promotes 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, metals, organics and pathogens in seawater concentrate are typically at significantly lower levels than those in the wastewater discharge, which helps with reducing their discharge concentrations in the combined WWTP effluent.

Often, desalination plants are operated at a constant production rate and, as a result, they generate concentrate discharge with little or no diurnal flow variation. On the other hand, wastewater treatment plant availability for dilution of the desalination plant concentrate typically follows a distinctive diurnal or daily variation pattern. Since adequate protection of aquatic life typically requires a certain minimum concentrate dilution ratio to be maintained at all times, the amount of concentrate disposed by the desalination plant (and therefore, the plant production capacity) may be limited by the lack of adequate hydraulic capacity of wastewater plant effluent for blending during periods of low wastewater effluent flows (i.e., at night). In order to address this concern, the desalination plant operational regime and capacity may need to be altered to match the WWTP effluent availability patterns or a diurnal concentrate storage/equalization facility may need to be constructed at the desalination plant. Alternatively, the desalination plant could collect additional saline source water to dilute the concentrate when needed.

Collocation with Existing Power Plants

Collocation involves using the cooling water discharge of an existing power plant as both the source of saline water for production of fresh water and as dilution water for mixing with the desalination plant concentrate. For collocation to be viable, the power plant cooling water discharge flow must be greater than the proposed desalination plant intake flow, and the power plant outfall configuration must be adequate to avoid entrainment and recirculation of concentrate into the desalination plant intake. Special consideration must be given to the effect of the power plant operations on the cooling water quality, since this discharge is used as source water for the desalination plant.

The power plant thermal discharge is lighter than the ambient ocean water because of its elevated temperature. Consequently, the discharge tends to float on the ocean surface. The heavier saline discharge from the desalination plant draws the lighter cooling water downward and thereby engages the entire depth of the ocean water column into the heat and salinity dissipation process and accelerates its mixing and blending into the ambient seawater. For comparison, new off-shore outfalls would have to rely on a complex diffuser structure to eject the concentrate upwards in order to achieve similar vertical directional movement and mixing path of the concentrate (see Figure 9).



Source: Water Globe Consulting

Figure 9 – Comparison of Concentrate Mixing Patterns of Collocated and New Outfalls

It should be pointed out that the concentrate mixing benefit of collocation would no longer be available if and when the collocated power plant discontinues using once-through cooling in order to comply with proposed amendments to Section 316 (b) of the Clean Water Act federal regulatory requirements for reduction of the environmental impacts associated with plant intake operations. If such a modification occurs, the concentrate mixing effect of the warm water would need to be compensated by either diluting the concentrate with additional ambient seawater or by modifying the existing power plant outfall structure and installing appropriate diffuser structures.

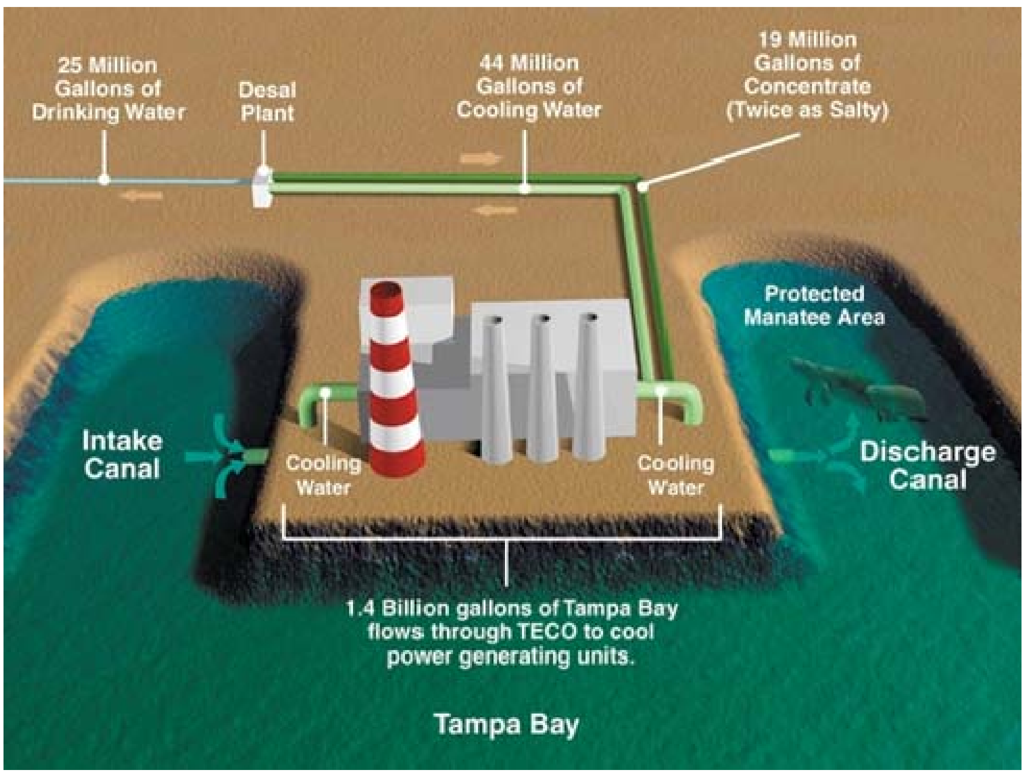
Opponents of collocated seawater desalination plants often present the argument that if a coastal power generation plant discontinues its once-through cooling practices, the seawater desalination project at this location would no longer be viable. On the contrary, the desalination facility will retain the significant and primary cost-benefit of collocation: avoidance of the need to construct a new intake and outfall and, instead, only modifying the existing outfall infrastructure to accommodate a diffuser type of system. The capital cost savings from the use of the existing power plant intake and outfall facilities are typically 10 to 50% of the total plant construction costs.

CONCENTRATE DISCHARGE CASE STUDIES

Around the world, seawater desalination has a comprehensive track record of successful operation and environmentally safe performance. The project concentrate disposal case studies presented below illustrate worldwide experience with concentrate management for large seawater desalination projects.

Tampa Bay Seawater Desalination Plant

Collocation with a power station in a large scale was first proposed for the Tampa Bay Seawater Desalination Project in 1999. Since then, collocation has been considered for numerous plants in the US 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 (TECO)'s Big Bend Power Station (Figure 10).



Source: Water Globe Consulting

Figure 10 – Tampa Bay SWRO Plant Collocation Schematic

The TECO power generation station discharges an average of 1.4 billion gallons of cooling water per day, of which the desalination plant takes an average of 44 MGD to produce 25 MGD of fresh drinking water. The 19 MGD desalination plant concentrate is discharged to the same

TECO cooling water outfalls downstream from the point of seawater desalination plant intake connection.

In this case, the source seawater is treated through fine screens, coagulation and flocculation chambers, a single stage of sand media followed by diatomaceous filters for polishing, and cartridge filters before the SWRO system with a partial second pass. The spent filter backwash water from the desalination plant is processed through lamella settlers and dewatered using belt filter presses. Treated backwash water and concentrate are blended and disposed through the power plant outfalls under a NPDES permit administered by the Florida Department of Environmental Protection.

Environmental monitoring of the desalination plant discharge has been ongoing since the plant first began operating in 2002[4]. The desalination plant discharges 19 MGD of concentrate of salinity from 54 ppt to 62 ppt, which 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 power plant discharge, the blend of concentrate and cooling water has a salinity level which is well within 2 ppt of the ambient bay water salinity.

The environmental monitoring program in the area of the desalination plant discharge is implemented by Tampa Bay Water independently from the desalination plant operator, American Water-Acciona Agua, in fulfillment of the plant's discharge permit requirements. Overall objectives for the monitoring program are to detect and evaluate effects of discharge through comparison to a control area and time periods defined by facility operation (pre-operational, operational, and off-line periods).

The plant discharge permit requires additional supplemental sampling to be performed as part of Tampa Bay Water's hydrobiological monitoring program. Water quality and benthic invertebrate monitoring includes fixed and random sites, and is focused on areas most likely to be affected by the discharge including the power plant discharge canal, and areas of Hillsborough Bay and the middle of Tampa Bay near the mouth of the canal (Figure 11). A small embayment adjacent to the discharge canal is also monitored. The letters "I" and "D" on Figure 11 indicate TECO intake and discharge canals, while the letter "A" stands for Apollo Bay – a shallow embayment in the vicinity of the discharge. Areas designated by rectangular areas A, B and C, are the prime sampling areas, while D and NAB zones have been added for supplemental monitoring. NAB stands for Near-shore zone of Apollo Bay. A control area considered representative of ambient background bay water quality conditions has been used for comparison. For fish and seagrass, data collected by other government agencies monitoring in the vicinity of the Desal facility have been used to evaluate potential changes. In addition, the discharge permit also requires monitoring of chemical constituents to ensure that water quality in Tampa Bay is protected.

[4] McConnell, R. (2009), "Tampa Bay Seawater Desalination Facility – Environmental Impact Monitoring", Proceedings of 2009 Annual WateReuse Symposium, Seattle, WA, September.

Monitoring of the desalination facility began in April of 2002. The desalination facility first began operating in 2003. Since then, it has operated at varying production levels until being taken off-line for remediation in May 2005. The facility came back on-line in March 2007. Evaluation of monitoring data from the period of 2002 to 2008 shows that even during periods of maximum water production (29 MGD), changes in salinity in the vicinity of the discharge were within or below the maximum thresholds (less than 2 ppt increase over background) predicted by the hydrodynamic model developed during the design and permitting phases of the facility. Review of monitoring data to date indicates that the plant operation does not have any adverse impacts on Tampa Bay's water quality and abundance, or diversity of the biological resources near the facility discharge.

While benthic assemblages varied spatially in terms of dominant taxa, diversity, and community structure, the salinity did not vary among monitoring strata. Also, the observed spatial heterogeneity of marine life distribution has been found to be caused by variables not related to the discharge from the desalination facility (e.g., 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.

Source: Tampa Bay Water

Figure 11 – Monitoring Areas of Tampa Bay Desalination Plant Discharge

Antigua Desalination Plant Discharge Study

In 1998 the Southwest Florida Water Management District and the University of South Florida have completed a study entitled "Effects of the Disposal of Seawater Desalination Discharges on

Near Shore Benthic Communities"[2]. The purpose of this study was to identify the environmental impact of discharge from an existing desalination plant on the benthic, plant and animal communities that inhabit the discharge area. The selected test site was located at a 1.8 MGD seawater desalination plant in Antigua, the Caribbean. The discharge salinity of this plant is 57 ppt.

The desalination plant outfall extends approximately 300 feet (100 m) from the shore and does not have diffusers – the concentrate exits the open pipe directly and is mixed by the kinetic energy of the discharge and the ocean tidal movement. The salinity within 3.0 feet (1.0 meter) from the point of discharge was measured to be in a range 45 to 50 ppt.

The research team has developed six transects extending radially from the point of discharge and has completed two monitoring studies of the condition of the marine organisms encountered along the six transects within a 6-month period including: seagrass; macro algae; benthic microalgae; benthic foraminifera; and macro-fauna. The results of these studies indicate that the desalination plant discharge did not have a detectable effect on the density, biomass and production of seagrass. In addition, the discharge did not have a statistically significant impact on the biomass and the numerical abundance of the benthic micro-algal community, benthic foraminifera and macro-fauna (polychaetes, oligochaetes, bivalves, gastropods, pelagic fish, anemones, worms, sea stars and other species inhabiting the discharge).

Gold Coast Desalination Plant, Australia

This 45 MGD desalination plant is located in South East Queensland, Australia in an area which is a renowned tourist destination (see Figure 12).

Source: WaterSecure

Figure 12 – Gold Coast Seawater Desalination Plant

The desalination plant has been in operation since November of 2008 and employs an open intake, granular media pretreatment filters, and a reverse osmosis desalination system. The Gold Coast plant is a stand-alone facility, which discharges concentrate with salinity of 67 ppt through a multiple diffuser system. The zone of initial dilution of this plant is 360 feet x 960 feet (120 meters x 320 meters).

The Gold Coast plant discharge diffusers are located at the ocean bottom and direct concentrate upwards into the water column to a height of approximately 30 feet (see Figure 13).

Source: WaterSecure

Figure 13 – Discharge of the Gold Coast Seawater Desalination Plant

According to a recent publication presented at the 2009 World Congress of the International Desalination Association[5], the aquatic habitat in the area of Gold Coast Desalination Plant discharge is sandy bottom, inhabited primarily by widely scattered tube anemones, sipunculid worms, sea stars, and burrowing sponges.

For 18 months prior to the beginning of the desalination plant operations, the project team has completed baseline monitoring to document the original existing environmental conditions, as well as flora and fauna in the area of the discharge. Figure 14 depicts plant intake and outfall configurations as well as the location of the reference sites used for comparison.

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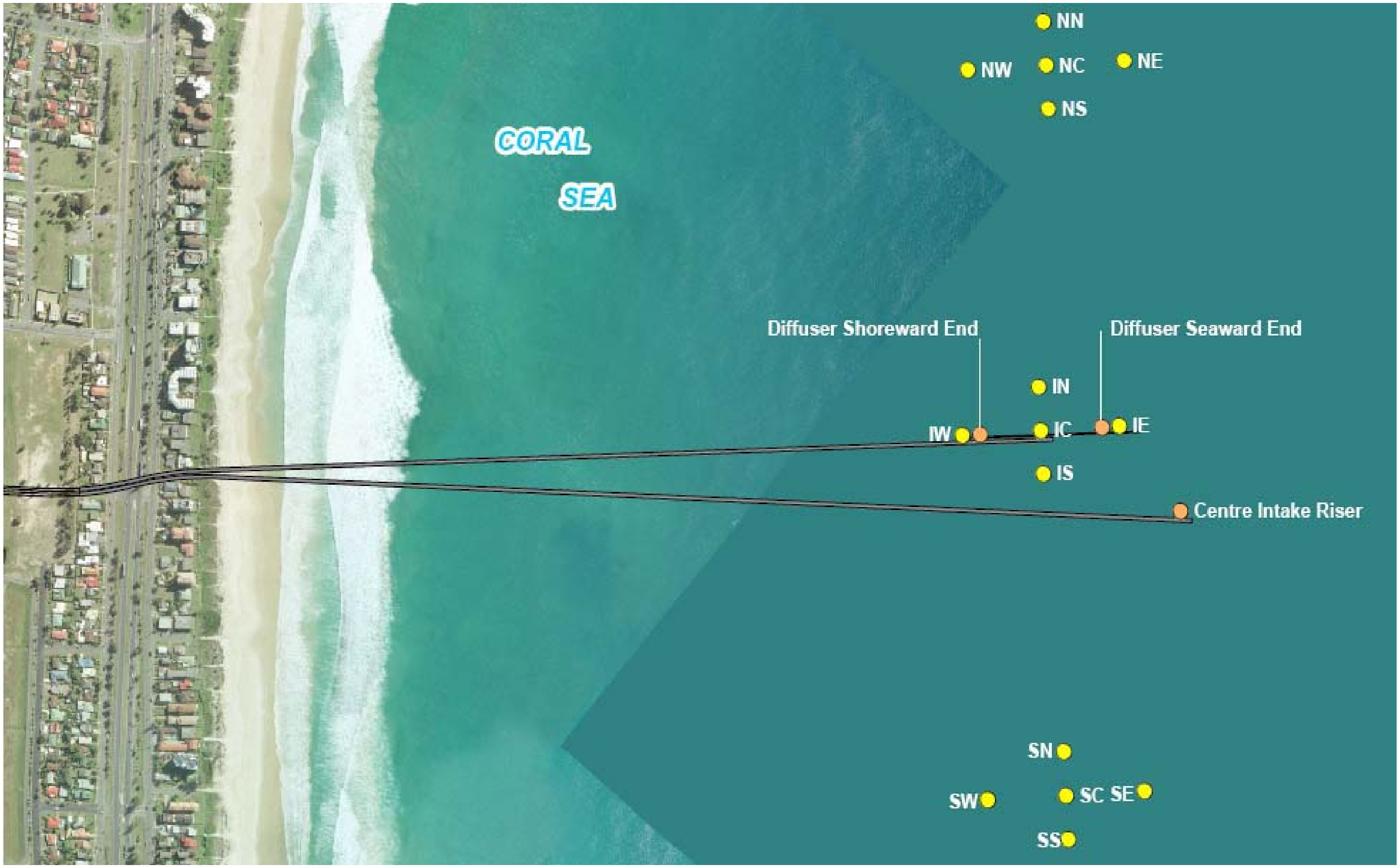
[5] Cannesson, N. (2009), "Community, Environmental and Marine Impact Minimization at the Gold Coast Desalination Plant", International Desalination Association, Biennial Conference, IDAWC/DB09-242, Dubai, UAE, November 7-12.



Source: WaterSecure

Figure 14 – Gold Coast Plant Location of Discharge and Monitoring Points

Once the plant began operations in November of 2008, the project team completed marine monitoring at four sites around the discharge diffuser area at the edge of the mixing zone, as well as at two reference locations 1,500 feet away from the edge of the mixing zone in order to determine environmental impacts and verify salinity projections.

The water quality and benthic infauna abundance and diversity results after the start of the 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 has practically remained the same in terms of both abundance and diversity. The Gold Coast plant has been in operation for over a year, and monitoring to date has confirmed that the plant's discharge is environmentally safe.

Perth Seawater Desalination Plant, Australia

As reported at the November 2009 World Congress of the International Desalination Association[6], the 38 MGD Perth Seawater Desalination Plant has been in continuous operation since November 2006. This plant supplies over 17% of the drinking water for the City of Perth, Australia which has over 1.6 million inhabitants (Figure 15).

Source: Water Corporation

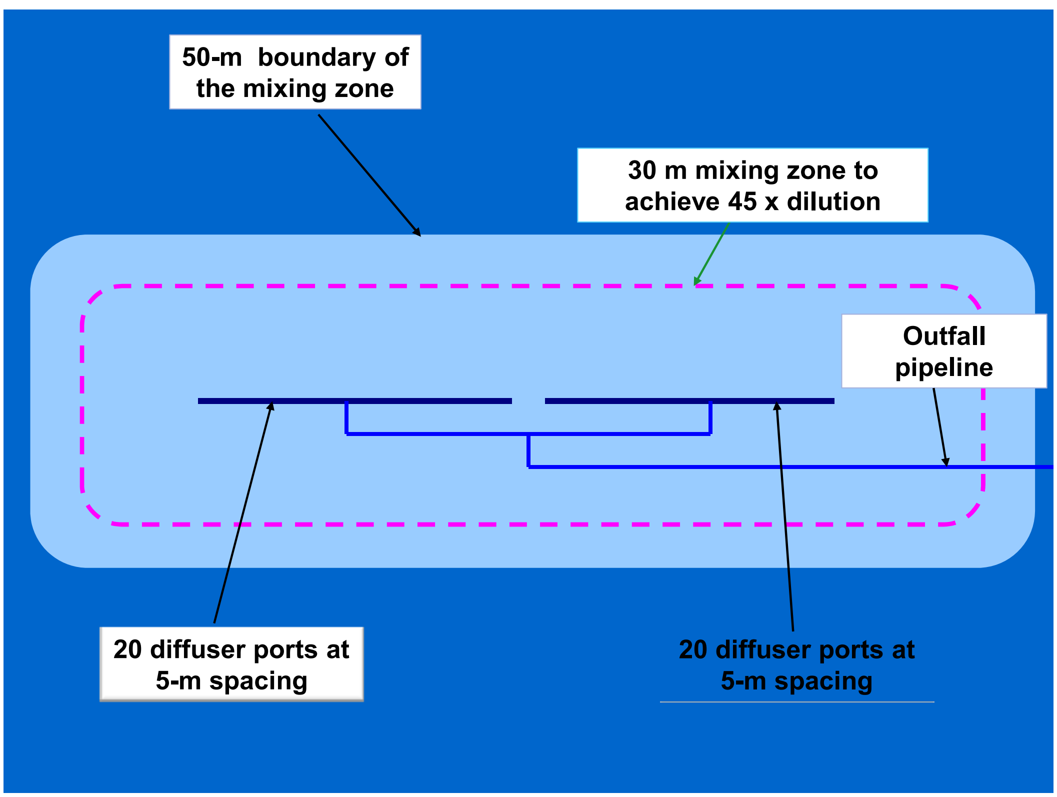
Figure 15 – Perth Seawater Desalination Plant

[6] Christie, S., Bonnelye, V. (2009), Perth, Australia: Two-year Feed Back on Operation and Environmental Impact, International Desalination Association, Biennial Conference, Dubai WC/DB09-278, Dubai, UAE, November 7-12.

The treatment facilities of the Perth seawater desalination plant are very typical for state-of-the-art desalination plants worldwide. This plant has an open intake structure extending 600 feet (200 meters) from the shore. Source seawater is pretreated using single-stage granular media filters, 5-micron cartridge filters, and a two-pass reverse osmosis membrane system with pressure exchangers for energy recovery.

Perth SWRO plant discharge is located in Cockburn Sound, which is a shallow and enclosed water body with a very limited water circulation. Cockburn Sound frequently experiences naturally occurring low oxygen levels. Since the Perth SWRO plant discharge area has very limited natural mixing, the desalination plant project team has constructed a diffuser-based outfall which is located approximately 1,500 feet (500 meters) offshore and has 40 ports along the final 600 feet (200 meters) at about 1.5 feet (0.5 meters) from the seabed surface at a 60-degree angle.

The diffuser ports are spaced at 15-feet (5 meter) intervals with a 0.7 feet (0.22 m) nominal port diameter at a depth of 30 feet (10 meters) (see Figure 16). The diffuser ports extend 1.5 feet (0.5 meters) from the floor. Diffuser length is 480 feet (160 meters). The outfall is a single GRP pipeline with a diameter of 63 inches (1600 mm).



Source: Water Corporation

Figure 16 - Perth SWRO Plant Discharge Configuration

This diffuser design was adopted with the expectation that the concentrate plume would rise to a height of 25.5 feet (8.5 meters) before it begins to sink due to its elevated density. The outfall structure was designed to achieve a plume thickness at the edge of the mixing zone of 7.5 feet (2.5 meters) and, in the absence of ambient cross-flow, to extend to approximately 150 feet (50 meters) laterally from the diffuser to the edge of the mixing zone (see Figures 16 and 17).

Extensive real-time monitoring was undertaken in Cockburn Sound since the plant began operating in November 2006 to ensure that the marine habitat and fauna are protected. This monitoring includes continuous measurement of dissolved oxygen levels via sensors located on the sandy bed of the Sound. Visual confirmation of the plume dispersion was achieved by the use of 14 gallons (52 liters) of Rhodamine dye added to the plant discharge. The dye was reported to have billowed to within approximately 9 feet (3 meters) 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 0.94 miles (1.5 kilometers) – well within the protected deeper region of Cockburn Sound which is located approximately 3.1 miles (5 kilometers) from the diffusers.

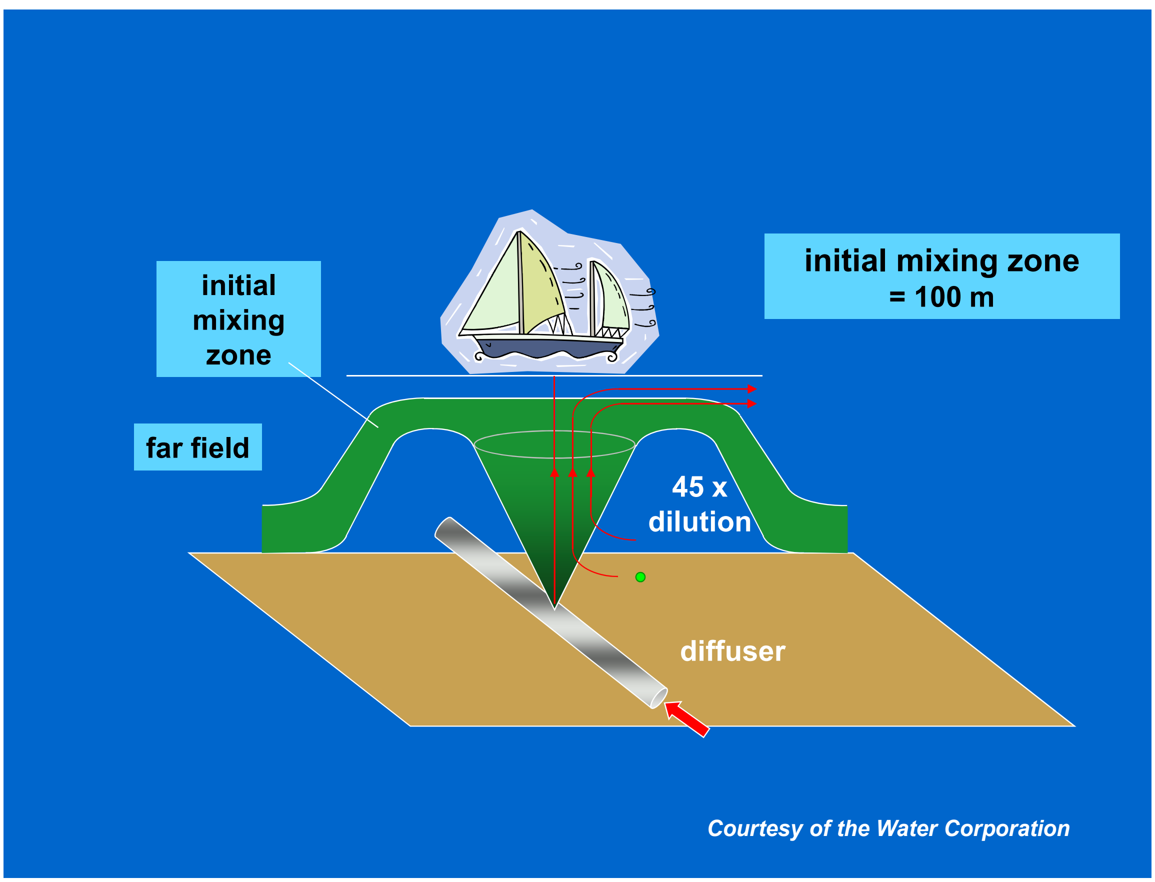


Figure 17 - Perth Desalination Plant Mixing Zone

In addition to the dye study, the project team has completed a series of toxicity tests with a number of species in larval phase to determine the minimum dilution ratio needed to be achieved at the edge of the zone of initial dilution:

- 72-hour macro-algal germination assay using the brown kelp *Ecklonia radiate*;
- 48-hour mussel larval development using *Mytilis edulis*;
- 72-hour 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 to be achieved at the edge of the zone of initial dilution in order to protect the sensitive species listed above 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 has also completed two environmental surveys of the desalination plant discharge area in terms of macro-faunal community and sediment (benthic) habitat[7,8]. The March 2006 baseline survey covered 77 sites to determine the spatial pattern of the benthic macro-faunal communities, while the repeat survey in 2008 covered 41 sites originally sampled in 2006, as well as five new reference sites. Some of the benthic community survey locations were in the immediate vicinity of the discharge diffusers, while others were in various locations throughout the bay. The two surveys have shown no changes in benthic communities that can 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, which is well within the naturally occurring salinity variation[9].

Figure 18 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 conductivity (shown on Figure 18) and salinity is 0.78, the plant discharge salinity varied between 64.5 ppt (88 mS/cm) and 56.2 ppt (72 mS/cm).

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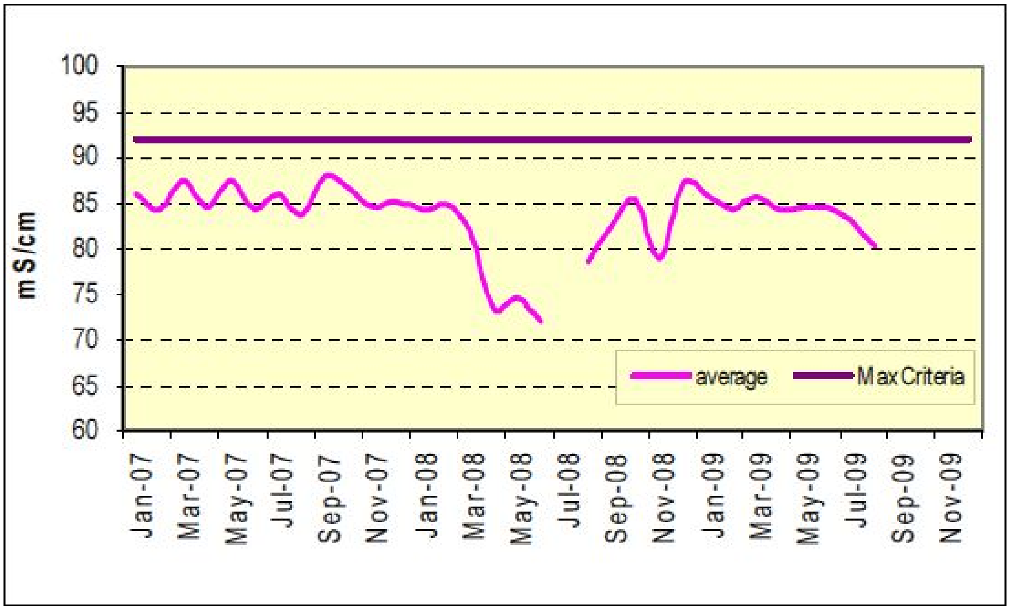
[7] Okel, P.N., J. P. Antenucci, and J. Imberger (2007), Field Investigation of the Impact of the Perth Seawater Desalination Plant Discharge on Cockburn Sound During Summer, Centre for Water Research, University of Western Australia, Perth.

[8] Oceanica Consulting (2009), Perth Metropolitan Desalination Plant – Cockburn Sound Benthic Macrofouna Community and Sediment Habitat, Repeat Macrobenthic Survey.

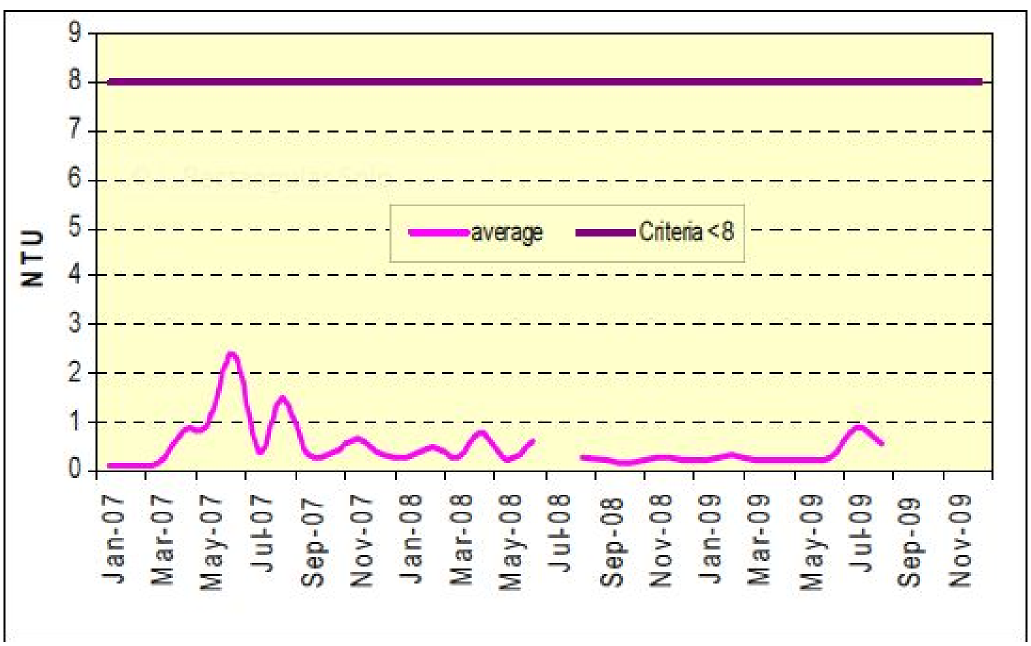
[9] Christie, S., Bonnelye, V. (2009), Perth, Australia: Two-year Feed Back on Operation and Environmental Impact, International Desalination Association, Biennial Conference, Dubai WC/DB09-278, Dubai, UAE, November 7-12.



Source: Water Corporation

Figure 18 – Perth Desalination Plant – Discharge Conductivity

Dissolved oxygen 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 5.0 mg/L. Similarly, concentrate pH was between 7.2 and 7.6, which was well within 10% of the ambient ocean water pH. Discharge turbidity for the same period (January 2007 to September 2009) was always less than 3 NTU (see Figure 19).



Source: Water Corporation

Figure 19 – Perth Desalination Plant – Discharge Turbidity

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 to a landfill.

Pictures of the discharge diffusers taken approximately one year after the plant operation (see Figures 20 and 21) show that despite the high salinity of the concentrate (56.2 ppt to 64.5 ppt), the area around the discharge diffusers is abundant with marine life rather as opposed to being a dead zone.

Source: Water Corporation

Figure 20 – Perth Desalination Plant Diffuser with Swimming Fish

Source: Water Corporation

Figure 21 – Seahorse Inhabiting Perth Desalination Plant Diffuser

Figure 21 is especially significant since it shows that seahorses (which are known to be sensitive to varying marine water quality conditions) inhabit the zone of initial dilution of the Perth desalination plant.

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

Examples of Discharge Configurations of Spanish Desalination Plants

An independent overview of the discharges of three desalination plants in Spain (5.8 MGD Javea SWRO Plant; 18 MGD Alicante 1 SWRO Plant; and 18 MGD San Pedro Del Pinatar) was recently completed by the University of Alicante, Spain[10]. The three plants are located within 50 miles (80 kilometers) of each other (see Figure 22), and the salinity of their discharges is 68 ppt to 70 ppt.

Source: F. Y. Torquemada

Figure 22 – Location of Three Large Desalination Plants in Spain

The Alicante 1 plant is located in a turbulent, tidally influenced area exposed to intense naturally occurring mixing. This feature of the desalination plant discharge allows the Alicante plant to

[10] Torquemada, F. Y. (2009), Dispersion of Brine Discharge from Seawater Reverse Osmosis Desalination Plants, Journal of Desalination and Water Treatment, vol. 5, pp. 137-145.

operate without a measurable environmental impact even at relatively low mixing ratio of 1.5 to 5 between concentrate and ambient seawater at the edge of the zone of initial dilution.

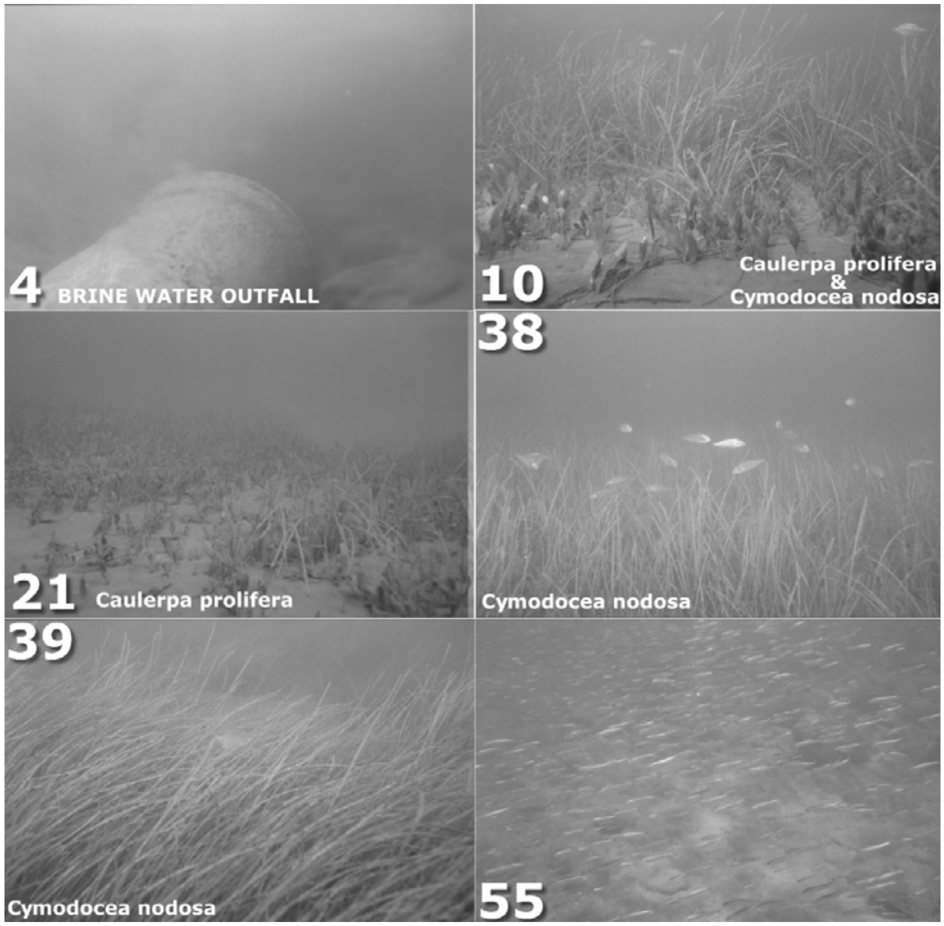
The Javea SWRO plant discharge is in an open canal which then carries the concentrate into the ocean. The concentrate from this plant is diluted in the channel from 69 ppt down to 44 ppt in a 4:1 mixing ratio. This salinity level was found to have no negative impact on the marine habitat in the discharge area. The discharge of the San Pedro del Pinatar Plant is through a diffuser located approximately 3.1 miles (5 kilometers) away from the shore at 114-feet (38-meter) depth.

All three desalination plants have been in operation for over three years. The water quality and environmental monitoring of the three discharges indicates that the size and time for dispersion of the salinity plume varied seasonally. These variations however, did not affect 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 due to its high oxygen content.

Maspalomas II Desalination Plant, Canary Islands, Spain. This desalination plant is located in Gran Canarias and has two concentrate outfalls, which extend 300 m away from the shore[11]. The outlet of the discharge outfalls does not have diffusers (see Figure 23), 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 22.5 to 24.0 feet (7.5 to 8.0 meters).

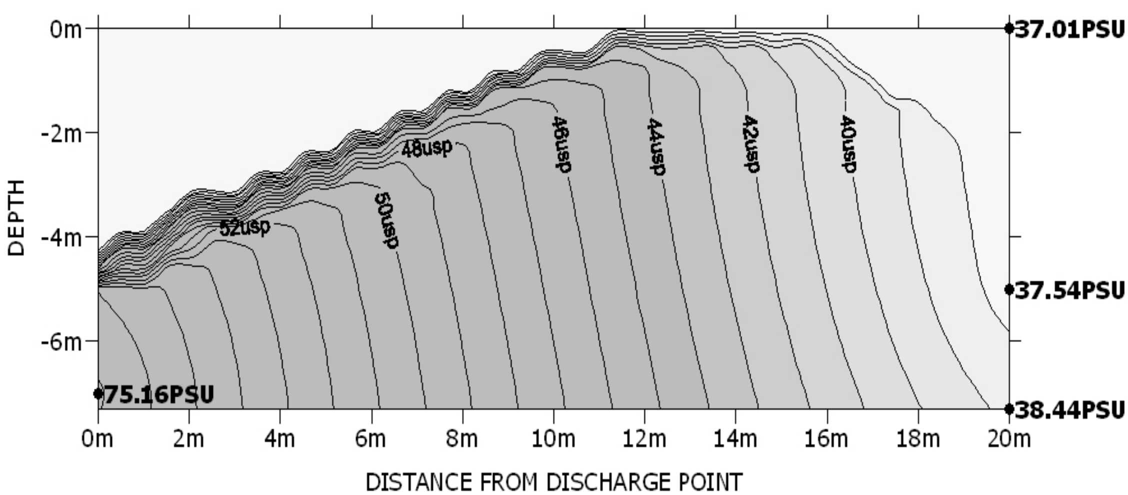
The Maspalomas discharge conditions are challenging for two reasons: (1) very high salinity of the concentrate (90 ppt); and (2) seagrass habitat for fish and other marine organisms. Due to the naturally occurring near-shore mixing, the salinity of the discharge is dissipated down to 38 ppt (38 PSU) within 20 m from the discharge point as shown on Figure 24. The salinity on this figure is presented in PSU (practical salinity units), which have the same value as ppt (parts per thousand) of salinity concentration.

[11] Talavera, J.L., Ruiz, J.J. Q. (2001), Identification of the Mixing Process in Brine Discharges Carried Out in Barranco del Toro Beach, South Gran Canarias (Canary Island), Desalination, Vo. 139, pp. 277-286.



Source: J. L. Talavera

Figure 23 – Discharge of Maspalomas SWRO Plant



Source: J. L. Talavera

Figure 24 – Maspalomas SWRO Plant – Outfall Salinity Field

The zone of initial dilution of the Maspalomas II desalination plant is a sandy bed with practically no flora. However, this zone is surrounded by seagrass beds, which based on environmental study of the discharge area, are not significantly affected by the desalination plant discharge.

CLOSING REMARKS

Long-term experience worldwide indicates that when designed and managed properly, discharges from seawater desalination plants are environmentally safe and do not result in speciation change or other negative impacts on the marine habitat in the area of the discharge. Results from recent worldwide studies also indicate that marine organisms can tolerate long-term exposure to desalination plant discharge of salinity in a range of 40 ppt to over 70 ppt.

However, salinity tolerance of marine organisms is very site specific and dependent on the type of organisms inhabiting the discharge area, their mobility, and the time of their exposure to elevated salinity. Therefore, establishing “blanket” or one-size-fits-all salinity discharge limit at a federal or state level would not provide added protection and benefits to the environment beyond those already secured by meeting site-specific whole effluent toxicity objectives contained in existing environmental discharge regulations.