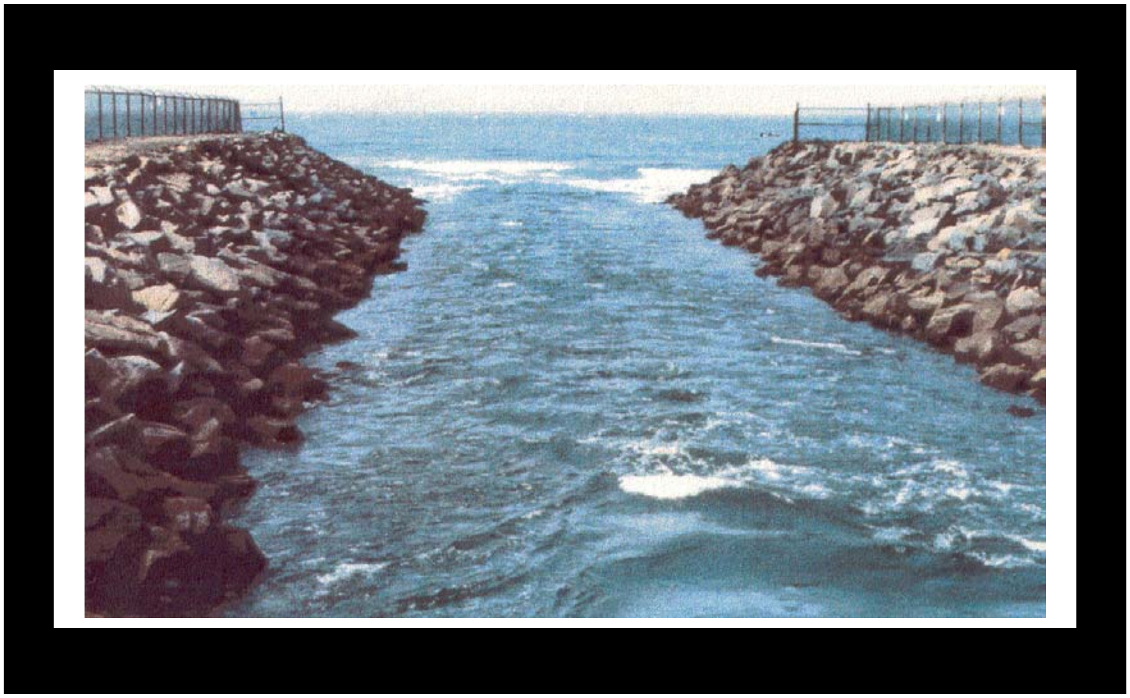
MARINE BIOLOGICAL CONSIDERATIONS RELATED TO THE REVERSE OSMOSIS DESALINATION PROJECT AT THE ENCINA POWER PLANT, CARLSBAD, CA



by:

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Executive Summary

Poseidon Resources proposes to construct and operate a reverse osmosis (RO) desalination plant at the Encina Power Station (EPS) in Carlsbad, CA. The EPS is adjacent to Aqua Hedionda Lagoon, a natural coastal estuary that has been altered by dredging since 1952. Lagoon water is used for once-through cooling in the power plant's steam condenser units; the rate of cooling-water use averages about 576 million gallons per day (mgd). After circuiting through the power plant, the warmed seawater is piped to a receiving pond that opens into an outfall channel that empties into the surf zone of the Pacific Ocean.

The proposed Carlsbad Seawater Desalination Plant will supplement the water supply of the City of Carlsbad and other areas by converting a fraction of the EPS cooling-seawater return discharge into freshwater. Desalination will divert approximately 100 mgd of the warmed seawater (i.e., after it has passed through the condensers) to the RO system. About 50 mgd of freshwater can be produced from 100 mgd of seawater. As a result of the RO process about 50 mgd of seawater with approximately twice (2x) the original salt content, will be produced and this will be returned to the cooling seawater outflow line downstream of the RO diversion point. The 2x seawater will become diluted by mixing with the outflow seawater during passage through the pipe and out of the discharge channel.

The average ocean salinity offshore of the EPS is 33.5 parts per thousand (ppt). Addition of the RO seawater concentrate to the power-plant discharge will cause a slight increase in the ocean salinity in a small area beyond the outfall-channel jetties. This report considers the potential effects of this salinity increase on the marine biota living in the discharge flow field. This report contains:

1) An appraisal of the environmental conditions and the status of the marine biological communities in the vicinity of the discharge.
2) An analysis of a comprehensive hydrodynamic study (included as an attachment to the project EIR) modeling the dispersion and dilution of the warm, elevated salinity discharge.
3) An analysis of findings of whole-effluent toxicity tests on local marine organisms using blends of water from the EPS discharge and concentrated seawater produced by the small demonstration desalination project currently operating on the grounds of the EPS.
4) An evaluation of laboratory tests of elevated-salinity exposure effects on the health or survival of local marine invertebrates and fishes that naturally occur in the discharge area.

Analysis of the marine habitat status in the discharge area reveals the following facts:

- The kelp bed, rocky and sandy bottom, and intertidal habitats occurring in the vicinity of the EPS discharge are in a healthy state and have species diversity and abundances comparable to other sites located not within the discharge area.
- The seafloor and littoral water habitats occurring near the EPS discharge are not home to any endangered marine species.
- The Zone of Initial Dilution (ZID, which is a 1000 ft [308 m] perimeter extending into the ocean from the end of the discharge-channel jetties) does not contain any "environmentally sensitive" habitats such as eel grass, surf grass, or kelp beds.

The finding of this report is that the proposed Carlsbad Seawater Desalination Plant is not expected to have a significant impact on the aquatic life in the vicinity of the EPS discharge. This conclusion is based on the following suite of facts.

1. Extent of the salinity increase:

- Hydraulic models of the combined RO and EPS discharge dispersal show that a zone of elevated salinity will extend from the discharge channel and encompass both the water column and benthic habitat.
- The extent of the salinity elevation will vary depending on "in-pipe dilution ratio" (i.e., cooling water flow : desalination concentrate flow) and the ocean conditions affecting mixing of the discharge and the receiving water.
- Under average EPS operating conditions (termed historical average conditions), the cooling water flow rate is 576 mgd. With the desalination plant, 100 mgd of this water will be diverted to the RO facility, leaving a net flow of 476 mgd for mixing and dilution of the 50 mgd of 2x RO concentrate that will enter the cooling-water flow stream (i.e., an "in-pipe" dilution ratio of 9.5).
- Under average operating conditions, the maximum salinity increase that will occur at the outer edge of the ZID is about 3 % above ambient (34.4 ppt vs. 33.5 ppt) in the water column and about 1.5 % above ambient (34.0 ppt vs. 33.5 ppt) on the bottom.

II. Marine organisms will be able to tolerate the predicted salinity increase:

- Fishes, plankton, and other pelagic organisms that encounter elevated salinity in the discharge region will have very low exposure times (in the order of several hours).
- Most of the kelp, invertebrates, and fishes living at Encina have broad geographic distributions that extend to areas where salinities as high as 36-38 ppt and occasionally as high as 40 ppt naturally occur. These organisms thus have intrinsic capacities to tolerate the slight localized salinity elevations that the models predict for the discharge field.
- The scientific literature indicates that for most marine organisms to experience adverse salinity effects, including mortality, they would need to be continuously exposed to salinities of between 37 and 41 ppt for a period of 24 to 48 hours or longer.
- Tests of the salinity tolerances of using marine organisms that live in and near the EPS discharge area indicate that species including fishes, abalone, sea urchins, sand dollars, crabs, and anemones can tolerate salinities as high as 37-39 ppt for extended periods of time.

The marine organisms living near the EPS outfall jetties and adjacent areas are part of a biologically and climatologically unique ecological region called the

Southern California Bight (SCB). The SCB is an open embayment extending from Point Conception, CA into Baja California, Mexico and 125 miles offshore. Biologically, the SCB is a transition-zone species assemblage set between two larger and diverse biological provinces; one in the cooler waters to the north and the other in the warmer waters to the south. SCB organisms comprise a mix of species, some from the cooler, northern- and some from the warmer, southern- regions.

Physical, biological, and oceanographic factors all affect the total SCB biomass and cause year-to-year variation in the number of species occurring within the SCB and in areas such as offshore from the EPS. While ocean temperature, current patterns, and upwelling affect nutrient and food supplies and the arrival of planktonic animals to coastal areas, biological variables such as recruitment and habitat availability determine ecosystem-species composition, diversity, and biomass. The young stages of most marine plants, invertebrates, and fishes living in coastal waters at Encina and throughout the SCB begin life as drifting plankton and their survival into the next life stage requires that they encounter an appropriate habitat containing sufficient space for them. Thus, evaluation of either local or regional habitats with respect to their biodiversity, the abundances of different types of organisms or their ages, body sizes, and growth rates must always be made in the context of the large-scale factors influencing these, whether along the Encina coast or throughout the entire SCB.

The discharge of heated seawater by the EPS has been a necessary and permanent coastal oceanographic feature for more than 50 years of continuous power plant operation. The heated water forms a mainly surface-occurring plume that fans out from the outflow channel and drifts south with the prevailing longshore surface current. The plume's gradual rate of thermal dilution depends upon both the EPS discharge rate (volume) and the physical factors affecting the mixture of the discharge with the receiving waters.

Regulations and the NPDES (National Pollutant Discharge Elimination System) permit issued by the Regional Water Quality Control Board governing cooling-water discharge by the EPS require procedures to protect receiving-water organisms, such as limiting the temperature difference between discharge water and ocean water temperature (delta T). Also required are regular environmental monitoring and biological surveys to verify minimal thermal effects. The finding documented by surveys at Encina is that the EPS thermal discharge is not adversely affecting the marine community.

The Poseidon Resources Corporation used computer models to describe the dispersion and dilution of the combined Carlsbad Seawater Desalination Plant and EPS discharge into the receiving waters. The most important variable in the discharge assimilation model is the power plant's cooling-water flow rate, which determines the "in-pipe-dilution ratio" of the 2x concentrated RO seawater. This ratio is calculated as:

$$\frac{\text{Total EPS Flow} - \text{RO Water Flow}}{\text{RO Concentrate Return Water Flow}}$$

Based on the power plant's historical average flow of 576 mgd and a 50 mgd RO production rate, the ratio would be:

$$\frac{(576 - 100)}{50} = 9.5$$

Another important variable in the receiving-water dispersion model is the series of interactive coastal ocean conditions (e.g., temperature, salinity, water level, tides and tidal currents, wave height) and weather factors (wind speed) affecting ocean vertical mixing and thus the dilution of the combined thermal and saline discharge.

The computer models examined how ranges of EPS flow and coastal oceanographic variables would affect discharge dispersal. The cases modeled bracketed the spectrum of possible discharge scenarios, from historical average conditions of EPS flow, with a constant delta T, and average receiving-water dispersion capacity, to the relatively rare historical extreme conditions, when EPS flow was low and its discharge could be either heated (i.e., power generation occurring) or unheated (no power generation), and ocean conditions were sub-optimal for discharge dispersal.

These models show that increasing the discharge-seawater salinity by the addition of the 2x RO concentrate will elevate its density and that the heated, more saline discharge will sink faster than presently occurs with the heated-only discharge. Sinking increases heat dispersion, which will occur more rapidly than salinity mixing. Thus, a zone of slightly elevated salinity will form in the water column and over the seabed offshore from the discharge channel and it will shed a progressively diluted plume along the coast, most often in a southerly direction.

Under historical average conditions the offshore increase in salinity and temperature associated with a 50 mgd RO operation will have a relatively small area. Salinity will be highest and temperature warmest in the discharge channel but these differences will quickly dissipate with ocean mixing. At the edge of the ZID (extending 1000 ft. beyond the jetties), an area of about 40 acres, the maximum temperature elevation would not be more that 1.0°C, both on the seabed and in the water column. Because the combined heated and more saline discharge is denser than the receiving water, it will sink, thus reducing the "thermal footprint" on the water's surface. Under present operating conditions the heated only EPS discharge establishes an approximately 65 acre surface ocean layer that is 1.1°C (2°F) warmer than ambient water. For the combined heated and elevated salinity discharge the area of surface water that will be this warm will cover about 9 acres.

Although all modeling assumed a desalination plant operation of 50 mgd, the EPS cooling-water flow rate varies with its electrical power production rate. Seawater flow through the EPS rarely stops completely (and if it did the desalination plant could not operate), however, periods of minimal flow do occur. (For example, operation of only the two pumps on Unit 4 reduces flow to 304 mgd.) In addition, there may be times when the EPS is not generating electricity, which means that, while water is still flowing, the discharge is unheated (delta T = 0). While these occurrences are very rare, modeling them helps define the potential extreme conditions resulting from a low EPS flow rate and differences in delta T. Poseidon pushed the historical extreme models further by combining scenarios for low flow and variable delta T with the occurrence of sub-optimal ocean mixing conditions. Two classes of these "historical extreme" conditions were modeled:

1) Low flow and no power generation (i.e., a zero delta T) with sub-optimal mixing, termed "Unit 4 historical extreme, unheated."
2) Low flow with a heated discharge (i.e., power generation), with sub-optimal mixing termed "Unit 4 historical extreme, heated."

The models show that the mix of 50 mgd of 2x concentrate with a heated discharge (254 mgd net flow, mixing ratio of 4.1) will sufficiently dilute of the combined discharge to result in outer edge ZID bottom salinities of 36.3 ppt or lower and water-column salinities of about 34.9 ppt. With a zero delta T, however, this mixture does not readily mix with the receiving water and requires a greater distance for dilution to occur; at the outer edge of the ZID bottom salinity would be 38.2 ppt and a water-column salinity 35.2 ppt.

Although the co-occurrence of such a low EPS flow rate and sub-optimal mixing conditions is not likely, these historical extreme models demonstrate the central importance of EPS water flow in achieving the levels of RO-stream dilution required for effective receiving-water mixing and for minimizing adverse environmental effects. Using, for example, the EPA suggested guidelines of ambient + 4 ppt (33.5 + 4 = 37.5 ppt) as a conservative limit for ensuring minimal salinity effects on marine organisms, then a 304 mgd (254 net) heated flow approaches the lower limit for the flow rate needed to adequately dilute the 50 mgd RO concentrate. However, as noted above, the occurrence of such a low EPS flow is rare and its co-occurrence with sub-optimal mixing conditions is extremely unlikely.

A suite of biological facts support the conclusion that slight increases in salinity modeled for the combined thermal and RO discharge will not be large enough to have a significant biological impact on the marine species or communities living near the EPS. With respect to temperature, the thermal increase currently experienced by Encina marine organisms is not affecting them and the models show that the combined operation of the Carlsbad Seawater Desalination Plant and the EPS will lessen the thermal anomaly experienced by organisms in the discharge area.

Most of the organisms living near the EPS also occur in areas of the SCB where salinity can be greater. Also, the natural geographic distributions of most of the species at Encina, including the Representative Important Species, extend south to near the tip of Baja California where both coastal temperatures and salinities are as high or higher than those modeled for the combined discharge. In addition, some of these species, or ones very closely related to them live in the upper part of the Gulf of California where salinities are 36-38 ppt and can be as high as 40 ppt. Thus, many of the species living at Encina naturally experience a salinity range comparable to or greater than that predicted for the combined discharge.

While comprehensive salinity tolerance information does not exist for all the species living in the Encina area, the available data indicate that organism salinity tolerances will be far in excess of the salinity levels predicted by the 50 mgd desalination-dispersion models. For marine organisms similar to those living at Encina, adverse salinity effects, including mortality require continuous exposure to salinities between 37-41 ppt for 24-48 hours or longer. Under the historical average conditions of EPS operations, the 2x RO discharge would raise the end-of-pipe salinity to about 36.7 ppt and the maximum salinity beyond the discharge channel would occur just offshore of it and would be about 36 ppt. From that point the surf and offshore mixing will rapidly dilute the discharge. At the ZID, both bottom and water column salinity would be within 1 ppt of ambient ocean water. The models further show that historical extreme conditions of a combined heated and RO flows as low as 304 mgd (254 mgd net flow) would also result in outer ZID bottom and water-column salinities below 37 ppt. Moreover, such extreme flow scenarios have a very low probability of occurrence and an even lower probability of co-occurrence with the historical extreme ocean and weather conditions causing sub-optimal mixing.

Further, Poseidon now operates a small RO demonstration facility at the EPS and use of its RO concentrate seawater in "salinity tolerance tests" confirms previous assessments showing that standardized salinity bioassays with kelp, a larval invertebrate, and a larval fish indicate no effect of prolonged exposure to 36 ppt. Laboratory studies testing the long-term survival of different species in higher salinities also show routine tolerance of continuous exposure to salinities up to 39 ppt (higher salinities have not been tested) for as long as 19 days.

Additional evidence supporting the conclusion that there will be no discharge-salinity effect is provided by the results of a field study sponsored by the State of Florida and conducted on the Island of Antigua (West Indies). This study is reviewed in Appendix 1 of this report. It featured experimental assessment of an RO discharge on corals and other organisms living in a tropical reef lagoon. Observations before and for 6 months following the introduction of the discharge of 1.8 mgd of undiluted (57 ppt) RO concentrate indicated no effect on either the organisms living around the point source or those that came into the area.

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1.0 Introduction

This report evaluates potential environmental effects resulting from the operation of Poseidon's proposed 50 million gallon per day (mgd) Carlsbad Seawater Desalination Plant at the Encina Power Station (EPS) in Carlsbad, CA. This plant will use reverse osmosis (RO) for desalination. RO works by pumping seawater, under high pressure, through salt-filtering membranes. The freshwater product will supplement the water supply of the City of Carlsbad and other regions. The RO process results in an approximately equivalent volume of doubly concentrated (2x) seawater that will be disposed of by combining it with the power plant's cooling water and discharging the mix into the Pacific Ocean. This report considers the potential effects of a salinity increase on the marine organisms living in the discharge flow field.

1.1 The Encina Power Station

The Encina power station's five steam turbine generator units are cooled by a once-through seawater flow system. The EPS is situated next to Agua

Hedionda Lagoon, the water of which is used for cooling. Withdrawn water is pumped through coarse filters and debris screens and then through the generator condenser units. The heated water is discharged into a pond and flows through an “across the beach” channel that empties into the Pacific Ocean surf zone.

The amount of cooling water used by the EPS depends upon the number of generators that are operating. At times when no or little power is being generated flow can be as low as 127-157 mgd (times of low and zero flow are very rare). Increased electric power production brings more units on line and increases water flow.

1.3 The Carlsbad Seawater Desalination Plant

Poseidon’s proposed 50 mgd RO facility will utilize the power plant’s cooling seawater stream; access to this water will be downstream of the condenser units (i.e., after it is warmed, but before discharge). The RO plant will take approximately 100 mgd to make 50 mgd of freshwater and return about 50 mgd of approximately 2x concentrated seawater to the EPS seawater discharge line downstream from the RO intake. Mixing with the heated outflow water will dilute the 2x seawater during progression through the pipe and along the seawater outflow channel.

2.0 Marine Species and Communities Occurring Near the Encina Power Station

a. The Southern California Bight. All of the marine species living near the EPS have geographic ranges extending well beyond the coastal waters of Southern California. They are part of a broad assemblage of species living within a biologically and climatologically unique region called the Southern California Bight (SCB). Geographically, the SCB is an open embayment that extends 455 miles along the coast from Point Conception, CA (34°33'N, 120 °28'W) in the north to Cabo Colnett, Baja California, Mexico (30°57'N, 116°20'W) in the south. The SCB also extends 125 miles to the west, thus encompassing the Channel Islands and part of the California Current (Figure 1).

The SCB encompasses about 22,000 square miles, has an irregular submarine topography featuring northwest-southeast oriented basins, troughs, banks, and ridges, and the channel islands located 12 to 70 miles from the shoreline. The average SCB depth is between 700 to 1000 m (2300-3250 ft). Water circulation is generally counter-clockwise with a northerly flow at most coastal locations (Jackson, 1986; Jenkins and Wasyl, 2001, 2005). Ocean current flow is induced by topography and by eddies from the California Current that combine with north-flowing coastal and offshore waters to form the Southern California Countercurrent. The SCB has a high upwelling index between April

Figure 1

and August, but geostrophic or wind-driven flows can occur year round (Carlucci et al., 1986). Seasonal surface water temperatures are coolest in December – March and warmest in August – December, with an annual range of 12-19^{o}C. Salinity variations are minimal (average salinity is 33.5 parts per thousand, ppt) and the upper 100 m (325 ft) of the water column is well mixed and well oxygenated (>50% saturated) (Jackson, 1986).

b. Environmental factors affecting SCB organisms. The SCB marine biota is defined as an intermediate or transitional zone (ecotone) between organisms living in the cooler-water habitat to the north and those in the warmer-water habitat to the south. Accordingly, the SCB has a mixture of species, some from the cooler, northern- and some from the warmer southern-regions. Because SCB water temperatures are intermediate with respect to those to the north and south, the SCB organisms must have the capacity to adapt to a slightly warmer (if they are from the north) or cooler (if they are from the south) thermal environmental range (Graham, 1970).

Temperature therefore exerts a major influence on the distribution of SCB and most marine organisms (Graham, 1970; 1971). Seasonal changes in water temperature, as well as the warming associated with an El Niño will affect relative organism abundances and species composition throughout the SCB. El

Niño warming can eliminate the cool-water elements of the biota within the SCB and permit warm-water adapted organisms to expand their geographic distributions north into the coastal waters of Central California where it is normally too cool for them to occur (Fields et al., 1993). Fishes and crustaceans (crabs, shrimp, isopods) are groups that commonly make El Niño-related range expansions. Moreover, El Niño and seasonal warming can also bring more tropical species into the SCB from the south (Fields et al., 1993).

Biological and oceanographic factors also influence organism distribution and abundance in the SCB and this must be kept in mind when the status of a population within a small area like the Encina nearshore environment is being considered (MEC, 2004). Not only can there be seasonal or climatically induced migrations into the area, long-term climatological cycles can also have an effect. It is known that declines in the kelp habitat, resulting from nearly 20 years of continued ocean warming have caused a reduction in the kelp associated species, including many sportfishes (Tegner and Dayton, 1987, MBC Applied Environmental Sciences, 2000). Warming has also eliminated some of the cooler adapted species that can exist in the SCB (Quast, 1968; Horn and Allen, 1978). Love et al. (1998) concluded that rising temperatures have led to the nearly complete disappearance of the blue, olive, brown, gray, and bocaccio rockfishes (*Sebastes*) from rocky reefs in the SCB. El Niño conditions also reduce the amount of coastal upwelling and in turn, the nutrient supplies needed for productivity by phytoplankton and kelp (Carlucci et al., 1986; Jackson, 1986; DeMartini and Roberts, 1990). Also, through its effect on the food chain (plankton) and on the habitat in which organisms can live (kelp stands), El Niño can further affect recruitment (i.e., the seasonal addition of young-of-the-year organisms) of fishes and invertebrates into SCB habitats.

However, in addition to seasonal and El Niño induced changes, the relative abundances of species of kelp, invertebrates, and fishes, living within the SCB and along the Encina coastline are also determined by a number of factors affecting recruitment success (Graham, 2000, 2002). Recruitment is defined as the arrival of young-of-the-year organisms to an area in which they can live to adulthood. While it is essential for sustaining ecosystem diversity, recruitment is affected by factors such as temperature, sedimentation, primary production, drift mortality, substrate availability, and pollution. Regarding drift mortality, the young of most invertebrates and fishes have a drifting or planktonic phase during early development and they must metamorphose from this into a juvenile stage that is able to find an appropriate place to take up its life. [Kelp reproduction also involves a drifting (zoospore) stage; these must encounter a rocky surface for attachment.] Most of the fishes inhabiting the SCB and the area around Encina spent their early development as larvae that drifted in the currents [exceptions include live-bearing sharks and rays and a few bony fish families, surfperch and rockfish]. Thus, the life histories of most fishes, marine invertebrates, and most kelp species depend upon successful negotiation through a planktonic life phase. For the animals, survival of first the egg and then the larval-life phase depends on the largely random processes of:

1) encountering sufficient quantities of food (phytoplankton and smaller zooplankon) in the open water to sustain development and,
2) at the appropriate time in metamorphosis, fortuitously encountering a vacant habitat that is also favorable for settling from the plankton and growing to adulthood.

c. Encina coast biota and habitat features. San Diego Gas and Electric Co. (SDGE, 1972) initiated biological reconnaissance of the Encina marine biota in early 1970s. Regular studies have been conducted over the past 30 years (EA Engineering, Science, and Technology, 1997). Since 1991 MEC Analytical Systems has carried out semi-annual assessments of receiving-water status. This includes aircraft “fly-overs” to obtain infrared images of the discharge plume’s temperature and distribution and to estimate the relative area occupied by the kelp beds. MEC’s work at the water’s surface includes temperature-depth profiles and dive-transect censusing of kelp, macroinvertebrates, and fishes at fixed sites within and beyond areas touched by the warm seawater dispersal plume (MEC, 2004).

Inventories of the marine organisms and habitats near the EPS demonstrate that there are no endangered species or areas of Special Biological Significance. The semi-annual surveys document a recurrent pattern of seasonal changes in relative abundance of certain species but do not indicate any biological effects associated with the thermal effluent from the EPS (MEC, 2004). The report by EA Engineering, Science, and Technology (1997) states that the EPS is in full compliance with regulations governing its cooling water discharge.

Figure 2 shows outer coast habitat features relevant to this analysis. It is based on descriptions provided by EA Engineering, Science, and Technology (1997) and the surveys and benthic relief compilations from side-scan sonar data contained in Le Page and Ware (2001). The coastline has 50-70 m (162.5-227.5 ft) wide beaches backed by 12-24 m (39-78 ft) remnant marine terrace bluffs. Within 100 m (325 ft) of the usually sandy shore, and over depths ranging from 1-2 m (3.3-6.6 ft), the warm discharge from the EPS is well mixed by wave action and longshore transport and generally drifts south along the shoreline (Jenkins and Wasyl, 2005, Figs. 7 and 8). Due to this mixing and transport, the area of the Carlsbad State Beach immediately south of the Plant is known locally as “warm beach.” Immediately offshore, the ocean bottom is sandy with

Figure 2

scattered low-lying rocky outcroppings, some of which extend out to deeper water. Seasonal storms, waves, and different rates of longshore sediment transfer affect the thickness of sand in the shallow littoral and sublittoral areas. This ranges from exposed cobble consisting of 2-12 cm (1-5 inch) diameter stones in winter to a 0.3-1.0 m (0.9-3.3 ft) thick sand layer in the summer (EA Engineering, Science, and Technology, 1997; Jenkins and Wasyl, 2005).

In deeper waters, rocky areas may also be covered seasonally by sand (Le Page and Ware, 2001). In areas where this does not occur, the rocks provide sites for kelp growth. In coastline waters, longshore currents driven by winds and ocean swells generally move water in a southerly direction at average velocities of 3-5 cm/sec (32-60 ft/h) (EA Engineering, Science, and Technology, 1997; Jenkins and Wasyl, 2001, 2005). Further offshore, the ocean bottom slopes gently, reaching approximately 180 m (585ft) depth 2.4 km (1.48 miles) offshore. The steeply sloped Carlsbad submarine canyon occurs about 3 km (1.85 miles) directly offshore from the EPS. The canyon's contours affect coastal wave patterns, internal wave formation, and current flow, and the canyon is a conduit for vertical water transport to during upwelling (Jenkins and Wasyl, 2001, 2005).

2.1 Encina Organisms, Coastal Habitat Classifications, and Biological Assessment

Detailed species lists for different habitats were compiled by SDGE (1972). EA Engineering, Science, and Technology (1997) identified principal coastal habitats near the Encina plant: Intertidal (both sandy shore and tidepools), Subtidal Sand, Rock Outcrop/Kelp Beds, Water Column.

a. Intertidal. The beach habitat consists mainly of wave-swept sandy shores. There is seasonal loss and replenishment of sand, with the exposure of a cobble substrate in the winter, and the associated grinding and instability of the substrate inimical to its infauna (organisms living within the substrate). In addition to physical factors (wave intensity, tidal exposure, temperature, and desiccation) affecting sandy beach organisms, sediment grain size is also an important determinant of their abundance. This community is therefore characterized as sparse and patchily distributed. Most taxa present have pelagic larval forms, which may mean that new recruits arrive annually in longshore currents.

Species common to the sandy beach include: Air-breathing pill bugs (*Alloniscus perconvexus*), an isopod (*Tylos punctatus*), the amphipod beach hopper (*Orchestoidea californiana*), the mole crab (*Emerita analoga*), the opossum (mysid) shrimp (*Archaeomysis maculata*), the polychaete worm (*Euzonus mucronata*), the bean clam (*Donax gouldi*), and the pismo clam (*Tivela stultorum*). EA Engineering, Science, and Technology (1997) indicated (page 5-31) a lower number of species and biomass in an area about 150 m (488 ft) downcoast from the discharge where water temperature varies considerably and can be as much as 5°C warmer than ambient.

Fishes in the sandy beach habitat include California grunion [*Leuresthes tenuis*, which spawns seasonally (March-July) in the sand beneath the highest series of waves at the crest of nocturnal spring tides], the northern anchovy (*Engraulis mordax*), topsmelt (*Atherinops affinis*), barred surfperch (*Amphisticus argenteus*), walleye surfperch *(Hyperprosopon argenteum*), queenfish (*Seriphus politus*), and California corbina (*Menticirrhus undulatus*).

About 1000 m (3250 ft) downcoast of the discharge channel, just beyond the open sandy beach (and in the vicinity of where Cannon Road intersects Carlsbad Boulevard) is the rocky intertidal habitat, Terra Mar. This area is subject to continued physical disturbance, periodic air exposure, and a wide range of temperatures. Organisms living in this habitat are tolerant of a range of physical conditions. Comparative surveys of the rocky intertidal species at Terra Mar and other locations indicate that the overall species composition has remained the same over the years, even with the addition of EPS Units 4 (1973) and 5 (1978). As reported by EA Engineering, Science, and Technology (1997), about 10-15 species account for 95% of the organisms inventoried and the bulk of the biomass present each year. This report also stated that organism distribution and abundance are largely independent of the EPS thermal discharge.

b. Subtidal sand. The sand areas beyond the surf zone are also subjected to seasonal stripping and sand replenishment, however, the frequency and intensity of this action declines with depth. Nevertheless, and similar to shallower sand habitats, the unstable nature of this habitat leads to a spatially and temporarily heterogeneous assemblage of organisms.

Species listed by EA Engineering, Science, and Technology (1997) as associated with the Encina subtidal sand habitat include: a polychaete (*Prionospio pygmaeus*), a proboscis worm (*Carinoma mutabilis*), a sea spider (pycnogonid) (*Callipallene californiensis*), two crustaceans (*Megaluropus* sp. and *Leptocuma forsmani*), and the sand dollar (*Dendraster excentricus*). Polychaetes are the most abundant followed by arthropods. Fishes found in this habitat include: the speckled sanddab (*Citharichthys stigmaeus*), northern anchovy (*Engraulis mordax*), queenfish (*Seriphus politus*), sand bass *(Paralabrax nebulifer*), white croaker (*Genyonemus lineatus*), horneyhead turbot (*Pleuronichthys verticalis*), and California halibut (*Paralichthys californicus*). Pelagic fishes occurring slightly further offshore include: northern anchovy

(*Engraulis mordax*), deepbody anchovy (*Anchoa compressa*), queenfish (*Seriphus politus*), topsmelt (*Atherinops affinis*), and walleye surfperch (*Hyperprosopon argenteum*). The calanoid copepod (*Arcartia tonsa*) is also abundant in this area.

EA Engineering, Science, and Technology (1997) reports a total of 234 taxa occurring in this habitat and indicates most were uncommon, not present throughout the year, and when present were patchily distributed. There were also no spatial patterns or distribution trends indicating any effect of the power plant's warm discharge on the benthic community.

c. Rock outcrops and kelp beds. Kelp forests are the most conspicuous subtidal habitats in the vicinity of the Encina discharge. Kelp are macroalgae that, using root-like "holdfasts," secure themselves to rocks and grow toward the surface. In the Encina coastal habitat and many other southern California coastal areas, kelps most commonly occur in 20-60 ft deep waters (North et al., 1993).

1. Habitats. The rocky outcroppings at Terra Mar extend offshore to form the hard-bottom substrate for a large kelp stand. There are three kelp beds in the Encina area. These are named the Southern Kelp Stand (SKS), North Kelp Stand (NKS) and Control Kelp Stand (CKS) (EA Engineering, Science, and Technology, 1997). SKS occurs offshore from Terra Mar and is the only kelp bed in the vicinity of the EPS that is regularly, but only partially contacted by its

heated seawater discharge (Figure 2). The extent of this contact is summarized as follows: the 3°C (above ambient) surface isotherm extends to the northeast third of the SKS approximately 1% of the time**,** the 2°C surface isotherm extends into the northeast corner of the SKS about 25% of the time**,** the 2°C surface isotherm encompasses the entire SKS only 1% of the time [EA Engineering, Science, and Technology, 1997)]. Regions of the rocky outcropping supporting the SKS are also subject to seasonal burying and exposure by sand, which can affect kelp abundance and the numbers and diversity of animals living in the kelp understory and on the rocky reefs.

NKS occurs approximately 1000 m (3250 ft) north of the EPS discharge channel (Figure 2) and is rarely contacted by the discharge [i.e., it is inside the +1°C surface isotherm about 5% of the time, but never encompassed by the +2°C surface isotherm (EA Engineering, Science, and Technology, 1997)]. Even with a very low incidence of contact with the heated seawater return, recent observations of the NKS by Le Page and Ware (2001) indicate that this kelp bed undergoes periodic changes in area. These workers reported variations in the size of the surface canopy in early 1997, and that no kelp were at this site in March and September 2000. The control kelp stand (CKS) is located 4 km south of the discharge channel and entirely beyond the range of the outfall's thermal plume. MEC (2004), which conducts semi-annual surveys at NKS, SKS, and

CKS, has also documented the recurrent history of kelp bed expansion and contraction in relation to ocean conditions, pointing out that these occur independently of EPS activities.

2. Algal biology and diversity. The most common kelp species at Encina is the giant kelp *Macrocystis pyrifera.* This plant can reach a length of 150 ft and grows to the water surface and then along it, held there by gas-filled bladders at the base of each blade. Dense clusters of giant and other kelp species, with thick fronds extending upward from the rocks give rise to the "kelp forest" appearance. On the surface, fronds (stipes and blades) of many plants become entangled into a surface canopy or mat that shades the underlying seafloor. Other macroalgae grow up under the canopy to occupy mid-depths of the kelp forest. EA Engineering, Science, and Technology (1997) lists the following kelp species at Encina: *Eisenia arborea* (southern sea palm)*, Egregia laevigata* (feather boa kelp)*, Laminaria farlowii* (oar weed)*, Cystoseira osmundacea* (bladder chain), all of which are brown algae. Also, present are "turf algae" growing within a short distance of the seafloor. Among genera found at the Encina kelp beds are *Dictyota flabellata,* a brown alga and *Rhodymenia californica*, a red alga. All of these plants are included in the MEC (2004) algal list of 16 varieties occurring at their study sites (Table 1A).

Since the mid 1950s, kelp beds along the southern California coastline have been monitored for their area extent and relative health. These beds fluctuate in size mainly in response to the episodic oceanographic conditions of El Niño and La Niña. El Niño, which brings warm, nutrient-poor water up from the south, adversely affects kelp beds. Additional El Niño effects on kelp come from larger than normal freshwater runoff associated with increased rains and a greater number of storms. Other factors influencing kelp abundance include turbidity, large waves, and changes in the available substrate**.** Turbidity effects are largely attributable to anthropogenic factors (dredging, runoff from coastal construction sites, and damaged watershed). Changes in substrate, for example, the seasonal covering of rocky areas by sand, also affects kelp abundance, however, a greater effect is exerted by weather-related factors such as wave strength and direction and coastal currents (North et al., 1993; MBC Applied Environmental Sciences, 2000).

Kelp reproduce by alternation of generations. In the case of *Macrocystis*, mature kelp plants, called sporophytes, release zoospores (flagellated spores that swim), which attach to exposed rocks and germinate. Germination involves formation of a tube through which the spore contents move into a new cell. These attached microscopic growths are termed male and female gametophytes. Sperm released by the male gametophyte finds its way to and fertilizes the egg

produced by a female gametophyte. The sporophyte grows from this site, often over the female gametophyte. Full development of the sporophyte can require 1-2 years. All of these reproductive steps are temperature dependent and also affected by environmental factors that include sunlight, sedimentation, ocean conditions, and the presence of animals that will eat the young plant stages.

3. Kelp bed fauna. Kelp beds are ecologically important because they provide refuge for many species. Marine biological investigations spanning a long period of time fully document the importance of kelp beds in enhancing coastal biodiversity (Tegner and Dayton, 1987; DeMartini and Roberts, 1990). Biological surveys of the Encina coast (EA Engineering, Science, and Technology, 1997; Le Page and Ware, 2001) list the following animals associated with the kelp forest and its rocky substrate: Invertebrates; the dominant species is the polychaete (*Dioptra ornata*), also present are sea fans (*Muricea californica*, and *M. fructicosa*), a sea anemone (*Anthopleura elegantissima*), the tunicate (*Styela montereyensis*), the dog or Kellets whelk (*Kelletia kelletii*) and the sea urchins (*Stronglyocentrotrus franciscanus* and *S. purpuratus*). Also abundant are encrusting species (bryozoans, other tunicates, sponges and hydrozoans). The MEC (2004) kelp surveys include all of these taxa and list the regular occurrence of 32 macroinvertebrate species (Table 1B).

EA Engineering, Science, and Technology (1997) reported no changes in the major constituents of the kelp bed fauna over the extended period of monitoring the EPS heated seawater outflow, including the nearly 20 years (1978-1997) since Unit 5 went on line. That report does indicate a significant inverse relationship between proximity to the discharge area and the density and abundances of both sea anemones and polychaetes. However, the magnitude of these two negative correlations is not large and can be contrasted with the finding of no distance-occurrence correlations for several other taxa (whelk, snails, sea fan, clam) subjected to the same analysis; all of which suggests subtle effects of substrate differences rather than a power-plant thermal discharge effect (EA Engineering, Science, and Technology, 1997, page 5-35 and table 5-6).

Fishes associated with kelp include: kelp bass (*Paralabrax clathratus*), sand bass (*P. nebulifer*), black surfperch (*Embiotica jacksoni*), kelp surfperch (*Brachyistius frenatus*), white surfperch (*Phaenerodon furcatus*), black surfperch (*Embiotica jacksoni*), California sheephead (*Semicossyphus pulcher*), rock wrasse (*Halichoeres semicinctus*), senorita (*Oxyjulis californica*), topsmelt (*Atherinops affinis*), and many others (Turner et al., 1964; Quast, 1968; Allen and DeMartini, 1983; Larson and DeMartini, 1984; DeMartini and Roberts, 1990; Graham, 2000). MEC (2004) lists 7 of these same species among its designation of the 11 species most common in the kelp beds (Table 2). Among these, the kelp bass occurs in most survey areas while the senorita is most abundant. Table 3 contains MEC data documenting recurring trends in both the number of species and total fish abundances during both the fall and spring diver surveys.

d. Open water column. Pelagic fishes and invertebrates and both phyto- and zooplankton frequent the open coast area offshore of the EPS. Phytoplankton are very small and usually single celled plants that live suspended in the water column and are thus affected by ocean currents and turbulence. Phytoplankton are the open ocean's principal primary producers, meaning that, by means of photosynthesis, they covert solar energy into energy containing organic molecules that sustain life and form the basis for pelagic food chains. Phytoplankton and kelp are the main energy production sources in coastal waters. The most common forms of phytoplankton in local waters include diatoms, dinoflagellates, and the reproductive stages of the kelp (see above).

Zooplankton are small animals that also drift with ocean currents. They range in size from single celled animals (most common are protozoans), to fairly large shrimp. Phytoplankton are the main food supply of zooplankton. There are two zooplankton categories, holo- and meroplankton. Holoplankton are the zooplankton that spend their entire lives in the plankton. Copepods are

holoplankton, and one species *Acartia tonsa* is the most abundant zooplankton species in Encina waters. Meroplankton are animals that spend part of their early life as plankton but then settle out by metamorphosing into the juvenile or sub-adult body form. Principal among the meroplankton are the larvae of crustaceans (crabs, barnacles), mollusks (whelks, clams), and echinoderms (urchins, sand dollars), and fishes. The relative abundance of these groups varies seasonally. As a group, zooplankton are the main food supply for benthic filter and particulate feeding invertebrates (e.g., barnacles, clams, polychaetes, anemones) and planktivorous fishes (northern and deep body anchovy).

Fishes in the open-ocean habitat include some species important to the commercial and sportfishing industries. A number of fishes targeted by sportfishers occur in kelp beds or the waters adjacent to them: chub mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*), sand bass (*Paralabrax nebulifer*), kelp bass (*Paralabrax clathratus*), yellowtail (*Seriola dorsalis*), barracuda (*Sphyraena argentea*), ocean whitefish (*Caulolatilus princeps*), halibut (*Paralichthys californicus*), and many others (Le Page and Ware, 2001).

e. “Representative Important Species” at Encina. Reviewers of earlier receiving-water surveys specified use of the Representative Important Species (RIS) criteria. RIS was developed by the Environmental Protection Agency for the purpose of focusing impact assessments on selected representative species that could be assumed to reflect the status of species within a "balanced indigenous community." Accordingly, EA Engineering, Science, and Technology (1997) identified one kelp species, six macroinvertebrate species, and seven fish species living on the Encina coastline as qualifying for RIS status and evaluated them in relation to the Plant's discharge. The RIS designated for the Encina Power Plant are:

Giant kelp	*Macrocystis pyrifera*
Mysid shrimps	*Archeomysis maculata, Metamysidopsis elongata*
Polychaete worms	*Euzonus muconata, Scolelepis acuta, Prionospio pygmaeus*
Mole crab	*Emerita analoga*
California halibut	*Paralichthys californicus*
Cheekspot goby	*Ilypnus gilberti*
Walley surfperch	*Hyperprosopon argenteum*
Queenfish	*Seriphus politus*
Kelp bass	*Paralabrax clathratus*
California grunion	*Leuresthes tenuis*
Northern anchovy	*Engraulis modax*

This species assemblage is largely typical of that occurring in other kelp habitats in the SCB (Quast, 1964).

2.2 Encina Environmental and Habitat Assessment

No endangered or at risk species occur in Encina waters and none of the coastline has been designated as an area of Special Biological Significance. Whether based on the different habitat assessments or on RIS criteria, the findings of the EA Engineering, Science, and Technology (1997) report are that no species and none of the habitats within the warm EPS flow field have been adversely affected by it. This includes macroinvertebrates, the benthic interstitial fauna, and fishes living in the coastal waters around the EPS. With respect to benthic invertebrates, the report categorically states (page 5-35)

> "The mix of species and trophic structure of the nearshore benthic invertebrate community is similar to that observed at other locations along the southern coast of California. No biologically significant changes have occurred in the nearshore benthic community over time since Unit 5 began commercial operation and no significant spatial differences associated with the thermal plume have been observed except in a very small area in the immediate vicinity of the end of the discharge channel. Any such localized effects would have no impact on the overall benthic community and the utilization of components of that community by higher trophic levels along the southern coast of California."

3.0 Dispersal and Dilution Models for the Combined Power and RO Plant Discharge

Jenkins and Wasyl (2001, 2005) applied the U.S. Navy Coastal Water Clarity Model to analyze the dispersal and dilution of the combined power plant and RO discharge from the EPS. The objective was to model how differences in discharge characteristics (salinity, temperature, density, and flow rate) interact with variations in ocean mixing processes to affect discharge dispersal. Maps showing these effects on the discharge plume's salinity and temperature profiles in the nearshore environment enable estimates of both the **magnitude** of the changes and **duration** of the periods that the organisms would be exposed to them. The accuracy of these models has been verified by independent analysis (Grant, 2003, Jenkins and Wasyl, 2005) and by findings in agreement with previous works: 1) indicating a less than 1% probability that any of the EPS discharge would drift north and enter the Aqua Hedionda lagoon (EA Engineering, Science, and Technology, 1997) and, 2) suggesting that, because of a greater density, the saltier combined RO and seawater discharge would sink (CA Coastal Commission, 1993).

The models require three important inputs: 1) oceanographic data quantifying the capacity of the receiving waters to mix and dilute the discharge, 2) data on EPS flow rate together with the temperature differences between the discharge and receiving water (delta T), and 3) the volume of RO byproduct that is formed. Table 4 lists the different oceanographic and climate variables and explains their effect on models for the mixing and dispersion of the discharge.

For the oceanographic data, Jenkins and Wasyl (2001, 2005) used a 20.5 year (1980-2000) time-series for five factors, average ocean mixed layer temperature (^{o}C) and salinity (ppt), average wave height (meters), average wind speed (knots), and maximum tidal current velocity (cm/second). These interact with one another to influence discharge dispersal by affecting vertical mixing and longshore water flow (Table 4). A joint probability analysis rooted in the separate occurrence frequencies of each factor over the 20.5-year period was used to combine them in a way that would describe: 1) an average capacity for dilution and dispersal by the receiving waters (historical average receiving water conditions) and, 2) a sub-optimal capacity for dilution and dispersal (historical extreme case).

Analysis of a 20.5-year record of the EPS cooling-water flow rate defined: 1) average flow (historical average) and, 2) a low flow rate (i.e., extreme case low flow rates). Two values of power-plant delta T were used: 1) 5.5°C, which is the delta T mandated by the EPS operation permit and, 2) a 0°C delta T, which would occur during when the EPS was pumping water but not generating power. All models assumed of an RO 2x seawater discharge of 50 mgd.

Table 5 shows the flow, oceanographic, and RO variables used to model the historical average case. Also shown in the Table is the "in-pipe dilution ratio" for the 2x concentrated seawater RO return flow, calculated as:

$$\frac{\textbf{EPS Flow (mgd)} - \textbf{Flow into the RO plant (100 mgd)}}{\textbf{RO Concentrate Return Water Flow (50 mgd)}}$$

Table 4. Summary of the combinations of ocean and climate factors used by Jenkins and Wasyl (2005, Table 1) to define the 20.5 year time-series combinations for both historical average and sub-optimal receiving water conditions.

Variable	**Search Criterion**	**Functional Importance**
Salinity	Maximize	Higher salinity causes higher RO byproduct salinity and density
Temperature	Maximize	Higher temperature lessens density and increases thermal stress
Water Level	Minimize	Lower water levels cause less dilution in the outflow channel
Waves	Minimize	Smaller waves reduce mixing and inshore dilution
Currents	Minimize	Weaker currents retard mixing
Winds	Minimize	Weaker winds lessen surface mixing

Table 5. Data from Jenkins and Wasyl (2001, table 2) showing boundary conditions for forcing functions governing the combined RO and heated seawater discharge from the EPS under historical average conditions for flow and receiving water characteristics.

Model Factor	Historical Average
EPS Flow Rate (mgd)	576
Average Mixed Layer	
Temperature (°C)	17.60
Salinity (ppt)	33.52
Average Wave Height (m)	0.86
Average Wind Speed (knots)	5.33
Maximum Tidal Current	
Velocity (cm/sec)	29.43
*Combined Heated and RO (50 mgd) Discharge Salinity	36.71
**In-pipe-dilution ratio	9.5

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* End-of-pipe (= end of flow channel) estimate

** Ratio = $\frac{\text{Total EPS flow (mgd) - 100 (mgd) Flow to RO facility}}{\text{50 (mgd) 2x seawater return flow}}$

At an average flow of 576 mgd and a 50 mgd RO production rate, the ratio is (576 – 100 / 50) = 9.5.

Modeling of the historic extreme case for discharge dispersal assumed the co-occurrence of both a low EPS flow rate and sub-optimal ocean mixing (Jenkins and Wasyl, 2005). The operation of the two cooling water pumps on Unit 4 (304 mgd total flow) was used as the low flow model. Further, depending upon whether Unit 4 was or was not generating power, the delta T value used in the modeling was either 5.5° C or 0°C. The historical extreme modeling parameters for Unit 4 are:

Flow (mgd)		**Cooling : RO outflow**		**Receiving Water**
Total	**Net (-50 mgd)**	**delta T**	**"In-pipe dilution ratio"**	**Conditions**
304	254	unheated	4.08	sub-optimal
304	254	heated	4.08	sub-optimal

3.1 Model Findings I: Historical Average Conditions.

a. Temperature. Presently the EPS only discharges warm water and this forms a lens along the ocean surface that drifts downcoast with the prevailing coastal flow (Jenkins and Wasyl, 2001, figure 3.23, MEC, 2004, figures 4-6). When the RO concentrate is added, the discharge will submerge. Under historical average conditions (Figure 3) the plume will drift downcoast as it sinks. This will cause a greater extent of bottom warming than occurs within the water column and will thus expand the thermal contours along the bottom. The warmest temperatures will occur in waters near the discharge channel. However, whether along the bottom or in the water column, the average temperature increase is small (Figure 3). At the edge of the ZID (i.e., the perimeter 1000 ft away from the end of the discharge channel encompassing an area of about 40 acres) the maximum bottom and water-temperature elevation would be about 1^{o}C above ambient.

b. **Salinity.** Figure 4 shows model-determined historical average bottom and depth-averaged (water-column) salinities. The maximum salinity in the discharge channel will be about 36.7 ppt (9.6% above ambient). Because this discharge is denser than the receiving water it will sink, causing salinity contours to expand more along the bottom. The maximum ocean salinity (36 ppt) will occur on the bottom just outside the discharge channel, and will decrease as the plume drifts downcoast. Thus, no benthic area will experience salinities in excess of 36-37 ppt and maximum salinity at the outer edge of the ZID will be about 34.4 ppt (Jenkins and Wasyl, 2005). Water-column salinities will be less; 34.4 just beyond the discharge channel opening and about 34 ppt at the edge of the ZID.

Figure 3. Historical average case EPS flow and receiving-water conditions (delta T =5.5^{o}C). Average bottom temperature (left) and depth-averaged temperature (right) contours of the concentrated seawater discharge for RO = 50 mgd, Plant total flow rate = 576 mgd, net discharge 526 mgd, ambient ocean surface temperature = 17.6^{o}C, 23 May 1994. (Jenkins and Wasyl, 2005).

Figure 4. Historical average case EPS flow and receiving-water conditions (delta T =5.5°C). Average bottom salinity (left) and depth-averaged salinity (right) contours of the concentrated seawater discharge for RO = 50 mgd, Plant total flow rate = 576 mgd, net discharge 526 mgd, ambient ocean salinity = 33.52°/oo, 23 May 1994. (Jenkins and Wasyl, 2005).

3.2 Model Findings II: Historical Extreme Cases

The historical extreme cases evolve from much lower EPS flow rates with a lower “in-pipe dilution ratio,” and combine these with sub-optimal receiving water conditions for mixing. Also, the discharge can be either heated or unheated, which differentially affects density and sinking rate and thus ocean mixing. Figure 5 compares the historical average bottom salinity contours with those modeled for the heated and unheated hypothetical extreme cases. Relative to historical average conditions, the bottom salinity contours resulting from the Unit 4 historical extreme, heated discharge will have a higher channel salinity and establish much larger bottom and depth-averaged salinity contours. The effect of the heated discharge is very evident in Figure 5; by slightly lessening the density difference with ambient water, the heated discharge mixes more completely with the receiving water than does the unheated discharge, resulting in a smaller area of the bottom having an elevated salinity. Table 6A and B compare the resultant outer ZID salinity values for the three discharge scenarios and show salinity dilutions in relation to different habitats within the discharge area (see Figure 2 and section 4.1).

Figure 5. Comparison of bottom salinities for the historical average (top left) and the two historical extreme cases that were modeled [i.e., Unit 4 historical extreme, heated (lower left), vs unheated (right)] cases. (Note: The historical extreme cases assume both low EPS flow and sub-optimal receiving water conditions for discharge mixing.) (Data from Jenkins and Wasyl, 2005.)

Table 6A. Comparison of the estimated outer ZID bottom and water-column salinities under historical average case conditions and the two historical extreme case scenarios that coupled low flow and sub-optimal mixing with either a heated or unheated discharge (delta T). (Data from Jenkins and Wasyl, 2005.)

Flow Scenario	delta T	ZID Salinities (ppt)	
(mgd/net mgd)*	(^oC)	Bottom	Water Column
576/551*	5.5	34.4	34.0
304/254	5.5	36.3	34.9
304/254	0	38.2	35.2

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* net mgd = total mgd - 50 mgd

6B. Maximum bottom (b) and mid-water column (mw) salinities (ppt) at different outflow locations modeled for the historical extreme and average case conditions as described in the text. (Data from Jenkins and Wasyl, 2005). (Note: ambient ocean salinity is 33.5 ppt and the distances from the ZID to different habitat zones in the discharge area.)

		304 mgd				576 mgd	
		heated		unheated		heated	
Feet	Location	b	mw	b	mw	b	mw
0	End of Pipe*	40.5	40.5	40.5	40.5	36.8	36.8
500	½ ZID	**	**	39	**	35	**
1000	ZID	36.4	35	38.2	35.3	34.4	34.2
2000	Closest Distance from the discharge jetties to the North Kelp Stand						
2500	Distance from jetties to Terra Mar						
4000	Distance from jetties to the Middle of the NKS						

* = End of channel
** = no data

3.3 Model Interpretations

Jenkins and Wasyl (2001, 2005) modeled how average and hypothetical extreme conditions would affect the mixing and dispersal of the combined heated and elevated salinity discharge associated with the EPS and the Carlsbad Seawater Desalination Plant. The models enable visualization of the thermal and salinity contours that will form by adding the 50 mgd RO concentrate to the Encina discharge under average and extreme conditions with respect to flow and receiving water mixing, and also show the effect of a heated vs unheated discharge. The models demonstrate the central importance of total EPS flow on the discharge dispersal and assimilation; primarily through its effect on the "in-pipe-dilution" of the seawater concentrate, but also through its effect on delta T. The models also permit comparisons of the discharge at different points along its route, from "end-of-pipe" (end of channel) to the outer edge of the ZID (Table 6).

Figure 6 plots the outer ZID values for bottom salinity under the historical average (34.4 ppt, dashed green line) flow case and the Unit 4 historical extreme case (unheated, 38.2 ppt). The histogram reflects the range of outer ZID salinities determined by modeling iterations that operated on slightly different from historical average combinations of EPS flow rate and receiving water

Figure 6. The range of outer ZID salinities modeled for the historical average (vertical dashed green line) and the historical extreme (blue dashed line) cases and for various combinations of different flow rates and receiving water mixing conditions (histograms) determined from the 20.5 year time series. See text for other details. (Data from Jenkins and Wasyl, 2005.)

conditions. The blue line in Figure 6 shows the statistical probability of occurrence of the different flow regimes based on the 20.5 year sampling paradigm used by Jenkins and Wasyl (2005). The following statements aid interpretation of this line in relation to the salinity ranges that have been modeled for RO-operation effects on the discharge. First, there is zero probability that discharge salinity would drop below 33.5 ppt, which is ambient. Second, historical average salinity, the result of average flow and average receiving water conditions, has a 50% occurrence probability. Next, the probability that outer ZID salinity during RO operations would be 37 ppt or less is about 98%, which means more extreme outer ZID salinities would occur very rarely. As explained in Jenkins and Wasyl (2005) the historical extreme co-occurrence of both a low flow and sub-optimal ocean mixing conditions has a very low (zero in Figure 6) occurrence probability.

4.0 Analysis: How Will the Combined RO and Heated Water Discharge Interact With the Marine Biota?

Of concern in assessing the combined discharge effects on the Encina marine biota is whether or not the salinity and temperature changes are sufficient to affect the basic biological processes of the organisms experiencing them.

These processes include but are not limited to: feeding, growth, metamorphosis, gamete formation and production, locomotion and predator escape, metabolic and physiological activities, adjustments to tidal, lunar, and daily cycles, and many others.

Evaluation of combined RO and thermal discharge effects entails consideration of the **extent** of the salinity and temperature changes the organisms will experience. In this context, "**extent**" has two components, the **magnitude** of the change (i.e., the ^{o}C or ppt departure from ambient) and its **duration**.

4.1 The Extent of the Salinity and Temperature Change

a. Magnitude. Figure 7 displays the bottom salinity contours for historical average flow conditions in relation to the biotic distribution and benthic habitat relief shown in Figure 2. This shows that the plumes do not contact the north kelp stand (NKS) or the Agua Hedionda Lagoon channel. The models show that there will be a permanent area of elevated salinity extending from the discharge channel to offshore. Under historical average conditions, which can be expected to occur most of the time, this area and its salinity gradient will both be small; the discharge channel salinity would be 36.7 ppt. Across the ZID, an area of about 40 acres bottom salinity ranges from 34.6 to 36.7 ppt.

Figure 7. Major substrate and life zone offshore from the EPS shown in relation to bottom salinity contours predicted by historical average discharge case for flow rate and receiving water condition. Salinity data from Jenkins and Wasyl, (2005); substrate and life zone map from Le Page and Ware (2001).

4.2 Existing Discharge Standards for Salinity

The California Ocean Plan (SWRCB 2001) does not specify requirements or water quality objectives concerning RO concentrate discharge. EPA (1986) policy on discharge-effects related to salinity acknowledges that fishes and other aquatic organisms are naturally tolerant of a range of dissolved solids concentrations (in this case salinity) and must be able to do this in order to survive under natural conditions. Also, marine species are tolerant of variations in salinity. EPA (1986) recommendations state that, to protect wildlife habitats, salinity variation from natural levels should not exceed 4 ppt when natural salinity is between 13.5 and 35 ppt. As applied to the Carlsbad Seawater Desalination Plant, discharge scenarios that do not permanently elevate salinities above 38 ppt (i.e., 4 ppt + the upper range of salinity for the area, about 34 ppt, see Jenkins and Wasyl, 2005, figure 1) would appear effective in not adversely affecting the marine organisms living in the discharge flow field. The modeling done by Jenkins and Wasyl (2001, 2005) shows that the most prevalent EPS operation modes and the offshore environmental conditions would not result in situations that exceed this limit.

4.3 The Encina Marine Organisms Can Adjust to and Tolerate the Predicted Temperatures and Salinities

Arguments based on a diversity of scientific facts will be now be developed in support of the conclusion that the Encina biota will not be adversely affected by the **magnitude** and **duration** of the elevated salinities and temperatures associated with the combined RO and thermal discharge modeled for historical average and historical extreme cases, including the infrequent periods of EPS power production at a flow rate of 304 mgd.

4.4 Temperature

The temperature increases modeled for the combined discharge flow field are in the range of those that occur presently in the heated-only Encina discharge. The models show that some of the SKS and the adjacent biota will be touched by the combined discharge. The 30-year monitoring history at Encina (SDGE, 1972; EA Engineering, Science, and Technology. 1997; MEC, 2004) documents the absence of a significant biological effect of this magnitude of a thermal increase on local organisms. There is no basis for concluding that the thermal effects of the combined RO and heated discharge will have a different effect. Moreover, with desalination less of the EPS heat load will actually enter the ocean (i.e., the heat in 100 mgd of water will be dissipated to the atmosphere during the RO process). Also, because the combined RO and heated discharge will sink, the area of the thermal footprint will be less (Jenkins and Wasyl, 2005).

There is an abundance of physiological and natural history data documenting the biological effects of temperature on organisms, their thermal tolerances, and their ability to adapt to temperature changes. (Consider, for example, that all organisms living at Encina must be able to adapt to a winter - summer temperature range of from about 12 to 19°C.) Experimental data, some of which were obtained to answer basic questions about power-plant thermal discharge effects on SCB species, are readily accessible and are reviewed in an earlier report (Graham, 2002). The findings of those studies are consistent with the contention that the thermal changes that will occur under the historical average conditions, and during intervals of operation under historical extreme conditions as described above (Jenkins and Wasyl, 2005) are of insufficient magnitude to affect the biota.

4.5 Salinity Tolerance

a. Mechanism. Figure 8 illustrates the mechanisms underlying the above-described EPA (1986) principles governing the ability of marine

Figure 8. Salinity adaptations of marine invertebrates, fishes, and other organisms.

organisms to tolerate salinity change (Graham, 2002). This graph plots a range of ocean salinities against the amount of salts (and organic solutes) in the body (tissues) of invertebrates and algae, fishes, mammals and birds. The diagonal "equality line" in Figure 10 indicates similar "ocean" and "organism" salinities. Marine invertebrates generally have about the same amounts of salts and other solutes in their tissues as are in the ocean. If the ocean salinity goes up or down, their tissue solute (salinity) levels follow this change. Kelp also do this as do both zoo- and phytoplankton. All of these organisms are termed isosmotic (i.e., the "same" osmotic or solute pressure as seawater) and, because their tissue-solute levels change with seawater salinity, they are called "osmoconformers" (Graham, 2002). Fishes, birds, and mammals are different. They have about 1/3 the level of solutes in their body tissues as are in the ocean and they regulate this, thus maintaining about the same solute level over a range of ambient salinities. This is called "osmoregulation;" birds and mammals are more proficient osmoregulators than are fishes, however, most fishes can tolerate a salinity range of several ppt. Marine animals begin to be stressed if ambient salinity changes to levels beyond the range that they can make the appropriate adjustments (by osmoconformity or osmoregulation) without affecting their bodily functions.

b. The natural salinity range encountered by Encina species is greater than will occur because of the RO discharge: An argument based on geographic distribution patterns. The average world ocean salinity is about 36 ppt. Throughout the SCB the ocean salinity ranges between 33 to 34 ppt. At Encina the average is 33.5 ppt; there is a small annual range and salinity decreases (due to rainfall runoff) are more common than increases (Jenkins and Wasyl, 2005, Figure 1). Salinity increases are caused by evaporation. Along coastal areas of the SCB salinities as high as 37 ppt occur in bays and other enclosed areas. Even the relative open waters of San Pedro Bay, Los Angeles Harbor can be as high as 36.99 ppt (Soule and Oguri, 1974). Many of the species that occur at Encina also live in these areas. Thus, within the SCB there are areas in which many of the organisms comprising the Encina marine biota normally experience salinities greater than those predicted for the combined discharge.

In addition, all of the species living near the EPS have geographic distributions that extend beyond the SCB. Practically all of the species living at Encina occur in coastal waters down along the southern part of Baja California. In addition to being warmer, these waters have higher salinities (34.5 ppt) that become even higher in shallow, enclosed areas (Hickey, 1993). Further, a number of the same species living at Encina or species very closely related to them also live in the Northern Gulf of California where salinity generally ranges from 35 to 36 ppt, but can be as high as 39-40 ppt in shallow areas (Reynolds et al., 1976; Brusca, 1980).

Thus, the natural geographic distributions of a number of the Encina species extend into habitats where salinity (also temperature) exceeds the average salinity at Encina and is comparable to the RO salinity increase that has been modeled for the discharge area. For this reason the Encina biota should be largely unaffected by the RO plant operation.

4.6 Comparative Salinity Tolerances

As suggested by Figure 8, salinity intolerance results when ambient changes exceed an organism's ability to maintain the internal (tissue) salinity levels required for normal function. While salinity tolerance studies have not been performed on all species at Encina, relevant observations have been made for a few of them. Data for species closely related to those living at Encina are also informative.

Determination of the salinity tolerance of an organism is done by exposing sufficient numbers of them (for statistical purposes) to different test salinities for a specific period of time and assessing percent survival. More recently the LC_{50} methodology has been used. LC_{50} is a standardized, statistically robust analytical method having environmental water quality applications, such as assessing the toxicological effects of substances dissolved in polluted water. By placing small groups of a test species in a series of different salinities (with adequate control tests) for a specific time, the salinity that would lead to 50% population mortality can be calculated or interpolated. Thus, tests of tolerance and LC_{50} statistics specify the combination of both the test salinity level and exposure time that prove lethal. This conforms to the analysis (Section 4.0) of the Encina RO discharge in terms of both its **magnitude** and **duration**.

Here are salinity LC_{50} data for three species commonly used in standardized bioassays (Pillard et al., 1999).

Common name	Scientific name	LC_{50}	Test period
Mysid shrimp	*Mysidopsis bahia*	43	48 hours
Sheephead minnow	*Cyprinodon variegatus*	70	48 h
Silverside minnow	*Menidia beryllina*	44	48 h

These three species occur in estuaries where salinity can be quite variable and this explains their high salinity tolerances, even with 48 hours of exposure. These salinities far exceed all of the values modeled for the combined RO and EPS discharge by Jenkins and Wasyl (2001, 2005).

Here are data for species similar to those living along the Encina coastline.

a. Invertebrates. Invertebrates are generally slow moving and most of them live on the bottom or within the substrate and will thus need to endure the permanent salinity increases resulting from RO operations.

1. Roundworms. Roundworms (nematodes), live in marine substrates. Tests on four species (Forster, 1998) determined that two of them *Axonolaimus paraspinosus* and *Sabatieria punctata*, both of which live in the intertidal zone, could live in 2x seawater (about 70 ppt) for 48 hours. The other two species (*Daptonemia oxycera* and *Cervonema tenuicaida*), which live in deeper water, had 10-20% mortality after 24 – 48 hours exposure to 2x seawater:

Species	Percentage of test group not surviving in 2x salinity after:				
	1	8	12	24	48 hours
A. paraspinosus	0	0	0	0	0
S. punctata	0	0	0	0	0
C. tenuicauda	0	0	0	10	10
D. oxycerca	0	0	10	20	20

The 2x seawater salinity required to cause mortality of some of the test animals (but, note that LC_{50} was not reached for any of these worms) are much more severe that has been modeled for the combined Encina discharge where, even though the models show a permanent elevated salinity zone will develop, it will be very small.

2. An isopod. Isopods are small, short-lived crustaceans found in marine substrates. The adult females brood their young. A study (Charmantier and Charmantier-Daures, 1994) of *Sphaeroma serratum* of different ages showed that 96 hours of continuous exposure to salinities above 55 ppt (young) and as

high as 70 ppt (adults) was required to cause mortality. These salinities far exceed the levels modeled for the Encina coastline.

3. Hermit crab. Blaszkoski and Moreira (1986) found that, over the course of 16 days (at 30°C) *Pagurus criticornis* (hermit crab) larvae grow and metamorphose equally well in 25 and 35 ppt, but at 45 ppt fewer larvae progress beyond development stage II (about 5 days). Thus, chronic exposure lasting several days at salinities much higher than those predicted for the Encina RO discharge are required to impede this hermit crab's larval development. Hermit crabs also live in the Encina waters, however, no planktonic larva at Encina will experience the salinity extremes reported in the above study.

b. Fishes. In contrast to invertebrates, most fishes are fairly mobile. Fishes occur throughout the water column and also live on the bottom. Fish can sense temperature and salinity. They may swim into areas where temperature (and salinity) exceed preferred levels, spend a brief time, and then swim back out. Thus, the mobility of fishes and their ability to sense and avoid localized conditions would be part of the natural behavioral responses expected for species around the Encina discharge.

How then do fish salinity tolerances compare to the predicted conditions at Encina? Here are data for four species.

1. The sargo. A study of the sargo (*Anisotremus davidsonii*) by Brocksen and Cole (1972) and Lasker et al. (1972) showed:

- Optimal salinity for juvenile feeding and growth determined over 14 days exposure is 33-45 ppt.
- Adverse effects on feeding and growth were seen at greater than 45 ppt exposure (14 days).
- Salinities greater than 40 ppt adversely affect developing eggs and larvae after about 70 hours exposure.

2. The bairdiella croaker. Investigation of bairdiella, *Bairdiella icistia* (Brocksen and Cole, 1972; Lasker et al., 1972; May, 1974, 1975a,b) revealed the following facts:

- For juveniles, 14 day tests indicated the optimal salinity for feeding and growth is 33-37 ppt.
- Adverse effects begin at greater than 45 ppt (14 days).
- Salinities greater than 40 ppt adversely affect developing eggs and larvae after about 14 hours exposure.

Lasker et al. (1972) further showed that bairdiella egg fertilization could occur normally up to 45 ppt and that 24-hour development proceeded normally in 48 ppt and proceeded normally for 72 hours in 45 ppt.

3. Grunion. For the California grunion (*Leuresthes tenuis*) (Reynolds et al., 1976) determined:

- Prolarvae (i.e., larvae with a yolk sac, up to about 4 days old) have an upper salinity tolerance LC_{50} of 41ppt after 24 hours exposure.
- 20-30 day old larvae tolerate a maximum of 40 ppt for about 18 hours.
- In these studies both test groups tolerated more extreme salinities for shorter periods.

4. Topsmelt. *Atherinops affinis* can be acclimated to live in 90 ppt in San Francisco Bay (Carpelan, 1955).

These details about invertebrate and fish salinity tolerance show that for a diversity of organisms, including species that live in the SCB or are closely related to them, the extent of exposure: that is, the **magnitude** and **duration** required for a toxic salinity effect to occur greatly exceeds the range of conditions that marine organisms will experience in the Encina seawater discharge area under the flow scenarios having the greatest likelihood of occurrrence.

c. Additional observations about salinity, with reference to the Encina Representative Important Species or species similar to them.

1. Giant and other kelp species. *Macrocystis* normally occurs along the Baja California coast where it experiences higher ambient salinities (North and Zimmerman, 1984) than will occur in the combined discharge. In tests of the effects of RO and treated sewage outfall water, Bay and Greenstein (1992/1993) found that exposure of *Macrocystis* blades to elevated salinities of 38.5 ppt and 43 ppt did not affect either the spore generation rate or the length of the germination tube (explained in Section 2.1c).

In a review of algal salinity tolerance, Kirst (1989) states "most algae exhibit remarkable physiological potential --e.g., *Porphyra umbilicalis* grew optimally in a range of 7-52 ppt and survived without cell division in salinity 6-times that of sea water." Kirst also states that, provided an algal species has optimal conditions of light and temperature, it can tolerate a broad range of salinities. Blinks (1951) wrote "Some plants are remarkably tolerant of salinity variations, and most algae can stand salinity ranges of from 0.5 to 1.5 seawater for a matter of hours or even days."

2. Mysids. Mysids are small shrimp-like crustaceans. They are also known as opossum shrimp because the female has a brood pouch that holds up to 60 developing young. Mysids (*Archeomysis* and *Metamysidopsis*) occur at Encina. Both will experience the discharge salinity because they move up and down the water column. There are no salinity tolerance data for these mysids. However,

tests with the Florida estuary mysid *Mysidopsis bahia,* (Section 4.6), show its 48 hour LC_{50} is 43 ppt (Pillard et al., 1999).

3. Mole crab. The sand or mole crab **(***Emerita analoga*) ranges from Alaska to Baja California. It lives in the upper 10 cm of the sandy beach surf zone and uses long antennae to filter food from water surging over the beach. Mole crabs living on the beaches at Encina is will experience the combined RO and heated discharge. There are no data on the salinity and thermal tolerance ranges of *E. analoga*. However, because its distribution extends south into Baja California, it is predicted that the mole crab will easily tolerate the modeled discharge conditions. For the Atlantic mole crab *E. talpoida*, Bursey (1978) found that it tolerated salinities up to 40 ppt and withstood temperatures as warm as 25°C for 9 hours and 30°C for 6 hours.

5.0 Bioassays With Product Water from the Poseidon RO Demonstration Plant Now Operating at Encina

Since early 2003, Poseidon has operated a small (36,000 gallons per day) RO unit at the EPS. This plant enables the testing of RO methods specific to the area and the ocean water. It has also been used in bioassay testing of marine organism responses to mixtures of the 2x concentrate seawater and seawater. Currently, a display aquarium at the site holds a variety of local marine species at about 36.2 ppt. Specimens in the tank include the barred sand bass, California halibut, red sea urchins, and green abalone (Le Page, 2005).

California Ocean Plan toxicity requirements for the RO plant's discharge are also being met using the demonstration facility's 2x concentrate seawater in tests with local marine species. Tests done for Poseidon by MEC Analytical Systems (Carlsbad, CA) used RO 2x concentrate diluted with seawater to a salinity of 36 ppt in standard bioassays on three species.

1) *Macrocystis pyrifera*, giant kelp, germination and growth (48 hours).
2) *Atherinops affinis*, topsmelt, 7 day survival using 10-day old larva.
3) *Haliotis rufescens*, red abalone, embryonic development over 48 hours post fertilization.

Bioassay results are on file with Poseidon and MEC. They indicate no effect of RO concentrated seawater in cases where it had been diluted to 36°/oo using local seawater. In cases where the 2x concentrate had been diluted to 36 ppt using distilled water, red abalone eggs failed to develop properly over 48 hours, implying that the relative amounts of different types of salts in the water were not in chemical equilibrium with the test organisms.

These findings largely agree with earlier bioassays done by Bay and Greenstein (1992/1993, a SCCWRP sponsored study) who studied the toxicity of mixes of brine (obtained from a variety of sources) and seawater and other waters including secondary effluent wastewater. These workers conducted standard bioassays using giant kelp, amphipods, and fertilized sea urchin eggs.

- Their 48 hour test of spore germination and germ tube length (described in Section 2.1 c.2) using *Macrocystis pyrifera* indicated no effect of salinities ranging from 34.5 to 43 ppt.
- Elevated salinity tests with the amphipod *Rhepoxynius abronius* showed no effect on survival of 10 day exposure to salinities ranging from 34.5 to 38.5 ppt.
- Tests of sea urchin (*Strongylocentrotus purpuratus*) fertilization also showed no effect over 48 hours exposure to various concentrations of brine (from the RO facility at Diablo Canyon) and diluted with seawater.

It is very important to emphasize the latter finding on sea urchins and contrast it with other data presented in that same report. While Bay and Greenstein <u>did not find an elevated salinity effect</u> on sea urchin development when they tested brine that had been diluted with seawater, they did find that brine diluted with 24-hour composite secondary effluent wastewater (El Estero treatment plant, Santa Barbara, CA) negatively affected fertilized sea urchin egg development. This brine + wastewater result has received considerable notoriety. It is cited with an expression of concern in California Coastal Commission (1993) report on desalination. Opponents of desalination consider this finding to be a key scientific fact and evidence that sea urchins and other echinoderms cannot live successfully in areas near desalination plants. (As a group, the echinoderms [the Phylum Echinodermata includes urchins, starfish, sand dollars, serpent stars, and others] are the only major marine taxa that does not extend into freshwater.) Echinoderms are generally regarded as being less resistant to salinity change than other groups [actually, they are less resistant to seawater dilution rather than to seawater concentration].)

It is unclear why the Bay and Greenstein finding of **"no brine + seawater elevated salinity effect on sea urchin development"** has gone relatively unnoticed in the same report.

- Their main conclusion is clearly stated: "Desalination plant brine and elevated salinity did not produce toxic effects on amphipods, kelp spores, or sea urchin fertilization."
- However, their report's conclusions focus more on the brine + sewage result: "Elevated salinity and sewage effluent had significant effects on sea urchin development…." "sea urchin embryos proved to be among

> the most sensitive of marine species." "More work also needs to be done on the interactions between sewage effluent and desalination waste brine."

It thus appears that the finding of no effect of brine + salinity, the relevant dilution and environmental indicator model for the combined discharge at Encina, has either been ignored or is unknown. However, recent tests at Poseidon's small test RO facility at the EPS again confirm no effect of RO brine + seawater on sea urchins. In studies contracted by Poseidon, Mr. S. Le Page (M-Rep Consulting, Carlsbad, CA) has successfully maintained sexually mature spiny sea urchins (*Stronglyocentrotus purpuratus*) for 3 months in 36.2 ppt (range 35.7-36.4 ppt) seawater blended from demonstration plant RO water and seawater. In addition, Le Page has harvested eggs and sperm from these urchins and successfully fertilized the eggs in 36 ppt seawater (60 minute sperm activation tests). Additional laboratory testing of the long-term survival of different species in higher salinities and other bioassays demonstrate no effects of the diluted RO byproduct (Le Page, 2005).

6.0 An Ecological Monitoring of RO Discharge Effects at Antigua

Appendix I reports a study sponsored by agencies in the State of Florida that sought to conduct preliminary field studies of the effect of RO discharge on marine organisms. A group of scientists from several state and federal agencies and universities searched for a place where they could conduct a “before and after study.” They found an ideal situation on Antigua where a small 1.8 mgd RO unit was operating. This plant was discharging its RO concentrate into a storm drain that emptied onto rocks and crossed a short beach before entering a large lagoon. The team secured permission from plant operators to connect the RO discharge to an extension pipe that would carry the seawater concentrate water to a more offshore area in the lagoon where the previous RO discharge had not reached and which contained living coral and a diversity of algae, macroinvertebrates, and fishes. By conducting observations before and for six months following the pipe’s installation, these workers concluded there were no effects of the direct discharge of 1.8 mgd of seawater concentrate (57 ppt) into the study area.

7.0 Summary

This report has considered the potential effect of a 50 mgd Carlsbad Seawater Desalination Plant on the marine organisms living in the EPS discharge area. It reviewed a comprehensive hydrodynamic study modeling the dispersion and dilution of the warm, concentrated seawater discharge resulting from combined desalination EPS operations. It also reviewed the environmental conditions and the status of the marine biological communities in the vicinity of the discharge. Also considered were the findings of whole effluent toxicity tests on local marine organisms using blends of EPS cooling water discharge and concentrated seawater produced by the small demonstration desalination project currently operating on the grounds of the EPS. Laboratory tests showing no effect of elevated salinity on the health or survival of local marine invertebrates and fishes occurring in the discharge waters were also taken into account.

Investigation of the Encina marine biota show that the kelp bed, rocky and sandy bottom, and intertidal habitats occurring in the vicinity of the Encina Power Plant Discharge are in a healthy state and have species diversity and abundances comparable to other locations. The seafloor and littoral water habitats occurring near the EPS discharge are not home to any endangered marine species. The zone of initial dilution (ZID, a 1000 ft perimeter outside the discharge channel jetties) does not have any "environmentally sensitive" habitats such as eel grass, surf grass, or kelp beds.

This report finds that the proposed Carlsbad Seawater Desalination Plant is not expected to have a significant impact on the aquatic life occurring in the vicinity of the discharge flow field. Supporting this conclusion are a number of facts.

The Jenkins and Wasyl (2001, 2005) EPS flow and receiving water models enable visualization of the thermal and salinity contours that will exist when the 50 mgd RO 2x seawater concentrate is added to the Encina discharge. These show that under historical average conditions for both EPS operations and receiving-water mixing, discharge of the RO concentrate will expose local organisms to extremely small salinity increases within a small area offshore from the discharge jetties. The models further show that a combined heated and RO discharge at EPS flow rates of as low as 304 mgd results in an end-of-pipe salinity of about 37 ppt, which is diluted to nearly ambient salinity at the outer edge of the ZID. Modeling thus shows that, with adequate in-pipe dilution, flow-field salinities will be well below the maximum salinity tolerance limit of most marine organisms.

That the marine organisms living in the discharge area will be able to tolerate this range of salinity increase is supported by several facts. Fishes, plankton, and other pelagic animals that encounter elevated salinity in the discharge region will have very low exposure times (on the order of several hours). Most of the kelp, invertebrate, and fishes living at Encina have broad geographic distributions that extend to areas where salinities as high as 36-38 ppt and occasionally as high as 40 ppt naturally occur. The scientific literature indicates that for marine organisms to experience adverse salinity effects, including mortality, they would need to be exposed to salinities between 37 and 41 ppt for a period of 24 to 48 hours or longer. Tests of the salinity tolerances of using marine organisms that live in and near the Encina discharge area (Le Page, 2005) indicate that species including fishes, abalone, sea urchins, sand dollars, crabs and anemones can tolerate salinities as high as 37-39 ppt for extended periods of time (higher salinities were not tested because model predictions indicated these would not occur).

In addition, Poseidon now operates a small RO demonstration facility at the Encina Plant and "salinity tests" there confirm previous assessments showing that standardized salinity bioassays with kelp, a larval invertebrate, and a larval fish found no effect of prolonged exposure to 36 ppt. Indeed, a diversity of Encina species live perfectly well in a small aquarium with a 36 ppt salinity.

Additional evidence supporting the conclusion that there will be no discharge salinity effect is provided by the results of a field study sponsored by the State of Florida and conducted on the Island of Antigua (West Indies). The study involved experimental assessment of an RO discharge on corals and other organisms living in a tropical reef lagoon. Observations before and for 6 months following the introduction of the discharge of 1.8 mgd of undiluted (57 ppt) RO concentrate indicated no effect on either the organisms living around the point source or those that came into the area.

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APPENDIX 1.
DESALINATION DISCHARGE STUDIES AT ANTIGUA

Summary and Analysis of:

"Effects of the Disposal of Seawater Desalination Discharges on Near Shore Benthic Communities"

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Introduction

This is a review of the scientific and technical information contained in "*Effects of the Disposal of Seawater Desalination Discharges on Near Shore Benthic Communities*," a draft report, dated 1 April 1998, that was authored by Mark A. Hammond, Norman J. Blake, Craig W. Dye, Pamela Hallock-Muller, Mark E. Luther, David A. Tomasko, and Gabe Vargo.

The combined expertise of these authors is in the areas of marine biology, marine and coastal ecology, coastal engineering, and environmental science. Many of them have a professional association with the report's sponsoring agencies: Southwest Florida Water Management District, University of South Florida.

The report describes research evaluating the biological and other effects of the concentrated seawater discharge from a Reverse Osmosis (RO) seawater desalination facility located on the Caribbean Island of Antigua. This research was a fundamental aspect of the environmental pre-planning studies conducted prior to construction of a high capacity RO plant at Tampa Bay, Florida.

What is in this Report?

It describes results of a field reconnaissance of apparent biological and other effects resulting from discharge of the concentrated saline water byproduct from the Culligan Enerserve RO desalination plant operating on the Caribbean Island of Antigua. Antigua, which is in the Lesser Antilles Island chain of the West Indies, is located about 300 miles south-southeast of Puerto Rico.

RO Plant Specifications

Located on Antigua's eastern shore along Crabbs Peninsula and adjacent to Parham Harbor, the Culligan Enerserve RO plant has been operating since 1993. It has a freshwater production capacity of 1.32 million gallons per day (mgd) and uses Parham Harbor surface water [salinity 35 parts per thousand (ppt)] for its source water. The RO plant's byproduct, about 1.8 mgd of concentrated (57 ppt) seawater, is discharged into Parham Harbor.

These specifications, in addition to a discharge area that contains a healthy and diverse biological community (with many similarities to Tampa Bay) made the Antigua RO site a desirable study area. Also, and perhaps most important, the research team was able to manipulate the RO plant's discharge to suite the experimental objective of obtaining baseline data on a marine habitat's physical and biological status before and then during a period when it was exposed to the concentrated seawater discharge.

Since it began operation, the Antigua RO Plant has discharged its concentrated seawater byproduct into Parham Harbor via an elevated rectangular concrete flume extending to the water's edge (Figure 1). Depending upon tidal height (daily range in Parham Harbor is 0.25 m), this discharge either spills directly into the water or flows to the water's edge across a 3-5 m (9.8-16.3 ft) strand of exposed beach and rock.

What experiment was done?

The authors of this study received permission to temporarily change the discharge site. By installing a plywood stopper and flange over the end of the flume and there attaching a 12 inch PVC pipe, the discharge point was extended 20 m (65 ft) out into Parham Harbor. Figure 1 shows the position of the discharge pipe relative to the RO plant and a large jetty. The pipe's end was capped and a discharge port was formed by cutting a 12x12 inch (0.3x0.3 m) saddle notch on the pipe's upper side.

Diversion of the discharge was done in late March 1997. In the days (22-29 March) prior to the diversion, investigators conducted baseline, pre-salinity exposure studies of the habitat that would receive the concentrated discharge. The objectives were to census the study area and describe its water quality. It was necessary to establish that the site was biologically representative of the habitats and environmental conditions generally present in Parham Harbor. It was also important to confirm that the site was not contacted by the pre-existing RO shore-discharge plume.

Environmental effects of the newly established discharge site would be assessed by comparing the "pre-discharge" state with conditions found at three month (June 22-26) and six month (October 1-6, 1997) post-diversion site surveys.

How was the environmental survey conducted?

The discharge study area was mapped and six linear transects, extending radially 10 m (32.5 ft) out from the center (=discharge site), and at 60 degree angles from one another, were marked at one- or two-meter increments using PVC stakes and tags. As seen in Figures 1 and 2, transect lines reflect compass headings and are numbered clockwise beginning nearest to North. Transects extended both on- and offshore from the discharge site. Transects II and IV were approximately parallel to the shoreline. Water depth at the discharge-pipe opening was about 1.2 m (3.9 ft) and the opening, a rectangular (0.09m^2, 1 square foot) notch on the pipe's upper surface, directed discharge up to contact water surface. Three transects extended offshore into moderately deeper water and three went into more shallow water. Maximum water depth at the termini of the three most near-shore transects ranged from 0.7 to 1.1 m (2.3-3.6 ft). The depth range at the outer end of the three most offshore transects was from 0.8 to 2.6 m (2.6-8.5 ft). Together, the six transects define a 20x20 m (400 m^2) (65x65= 4225 square ft) area centered over the discharge-pipe opening. This study area was used to map topographical and other physical features as well as discharge-water contours.

Water quality was assessed using a Hydrolab system and by noting in particular the distribution of the three principal RO discharge "signals," increased temperature, lowered pH, and increased salinity. Monitoring was done on rising and falling tides and at different times of the day. Tidal current flows were recorded and dye was injected at the flume to observe discharge cohesiveness and distribution.

Figure 2 shows transect locations for the Hydrolab and biological sampling. The Parham Harbor study area contains a diverse assemblage of healthy marine organisms including sea grass (*Thalassia*), algae (*Dictyota*) hard (*Porites*) and soft (*Pseudoterogorgia*) corals, and an association of tropical microalgae, micro- and macroinvertebrates, and fishes. In addition to a census of the principal species in this community, the plan was to also compare the pre-diversion abundance and condition of these organisms with their status after three and six month's exposure to the concentrated seawater discharge.

Using SCUBA and snorkeling, transect surveys were done to both count individual organisms and map the distribution of sea grasses, algae, and epibenthic macroinvertebrates. Divers also took sea grass and algal samples for laboratory analysis. Substrate samples (mainly coral sand) were taken using core or "grab samplers" and small syringes (modified for coring by cutting off their tips) in order to determine the types and relative abundances of benthic microalgae (including diatoms), of benthic foraminifera (small amoeba-like single celled animals with calcareous shells), and of infaunal (i.e., living within the substrate) macro-invertebrates. Plastic settling plates (also termed fouling plates), were attached to the substrate along the transects. These plates are inert surfaces that enable censusing of the types and numbers of organisms that are recruited (i.e., planktonic plant spores or animal larvae that drift into the area, settle out of the plankton, attach to the plate and become established) over a specific period. Divers also recorded the presence of fishes and mobile invertebrates (i.e., starfish, anemones, snails) on the transects.

Collected samples were either frozen or preserved and returned to the laboratory. Substrate samples to be assayed for diatoms and foraminfera were immediately injected with a vital stain (Rose Bengal), which colored and preserved the tissues, thus making it possible to distinguish organisms living at the time of collection from their empty (dead) skeletons. In the laboratory, samples were analyzed microscopically to assess the growth status of sea grass, to count and classify the diatoms and foraminifera (and differentiating the living and dead) and enumerate and classify the infaunal macro-invertebrates. Measurement of the substrate content of the photosynthetic pigment chlorophyll a was used as a proxy estimate of substrate microalgae concentration.

What are the Report’s findings?

A. Physical conditions.

Pre-diversion water samples confirmed that water from the RO shore plume did not flow into the study area. Three features of the RO discharge water, elevated temperature and salinity and a reduced pH, were all detectable within the study area. The small differences between discharge and ambient water (discharge water was 2-3^{o}C warmer and its pH was 0.2-0.3 units lower) were rapidly dissipated by mixing. Dye injected at the flume demonstrated the discharge plume's tendency for rapid dissipation and for movement towards deeper water (because it is denser it sinks). Depending upon bottom topography and contour and current flow, divergent pH and temperature values were rarely detected beyond 2-6 m (6.5-19.5 ft) from the discharge-pipe opening.

The large difference between discharge and ambient salinity (57 vs 35 ppt) resulted in a stronger salinity "signal," which was detectable beyond the 10 m (32.5 ft) study area and distributed mainly down slope. Maximum bottom salinities, recorded in the immediate vicinity of the discharge opening, were 35-40 ppt in June and 34-38 ppt in October. Because the discharge flowed upward and contacted the lagoon surface, surface salinities were higher (35-44 ppt June, 34-43 ppt October). However, and because of strong mixing, salinities at the 8-10 m (26-32.5 ft) transect positions averaged only 0.2 ppt above ambient, with salinity increases extending farther down slope than up slope.

B. Biological status.

Studies of the sea grass beds indicated no changes in their health (as reflected in the number of "new shoots"), abundance (biomass), and growth rate (productivity) over the three survey periods. There was thus no effect of concentrated saline exposure. Also, the levels of salinity measured in the study area are well below the levels (about 70 ppt) known to cause permanent cell damage to sea grass. All sea grass plants studied in all transects showed a high degree of parrotfish bite scarring which indicated that this foraging fish frequented the study area in spite of the concentrated salinity discharge.

Algal abundance was generally variable over the three sampling periods, however, this variation is not correlated with the discharge salinity. One brown alga (*Dictyota*) did show variations in its growth rate and a weak correlation was found for its growth rate and salinity. Tissues from plants living within the study area also showed a higher concentration of nitrogen than did plants sampled from outside the study area. Reciprocal transplant studies, in which *Dictyota* specimens from within the study area were moved out and plants living outside were moved in, failed to induce a nitrogen increase in the newly introduced study area residents and there is thus not conclusive evidence for a discharge-salinity effect on *Dictyota.* It was concluded that perhaps episodic chemical imbalances associated with excessive rainwater runoff (storm culverts flow into the flume and surface runoff mixes with the RO discharge) or possibly caused by either RO membrane servicing or RO system flushing may have affected the chemistry of *Dictyota*.

A greater concentration of substrate-dwelling microalgae (as indicated by greater chlorophyll a amounts) was found in June and October compared to March. However, because there was no trend within or along the transects, this suggested that a factor other than the saline discharge had triggered the microalgae concentration increase. Diatom numbers and types did not change from pre-diversion conditions in either sampling period or along any transect.

Benthic foraminifera occurred on all substrates including sea grass blades. Their distribution and abundance varied considerably within the study area, however, comparison of the pre- and post-diversion surveys showed no differences that related to the presence of the concentrated seawater discharge. Also, because foraminifera are considered reliable indicators of habitat health state, the absence of pre- and post-diversion changes for this group suggests the habitat was not stressed.

The benthic invertebrate infauna collections totaled nearly 37,000 individuals, distributed among 339 different kinds (taxa), that included sponges, coelenterates, annelid worms, mollusks, arthropods, peanut worms, echinoderms, and chordates (tunicates). Of the 339 taxa about 10 species accounted for 52% of the infauna. These dominant organisms included seven species of annelids and one species of snail. However, there were significant differences in the infaunal assemblage (i.e., both the absolute numbers and relative abundance of the dominant species) at different times. The March and October samples each had more animals than did the June sample. These differences in infaunal invertebrate abundance and diversity did not appear affected by elevated salinity.

The June and October settling plates documented the arrival of nearly 1800 individual animals representing 12 different taxa. Bryozoans and polycheate (annelid) worms were the dominant forms with hydroids, snails, clams, and sea urchins also settling. A large influx of hydroids occurred in June but not in October. However, overall variations in the groups that settled on the plates at the different sampling times was attributed more to biological factors (reproductive season, productivity, etc.) than an elevated salinity effect. Because there was no pre-diversion settling plate data, it is unknown whether or not increased salinity excluded any species from settling.

Benthic macroinvertebrates observed by divers in the study area included hard (*Porites*) and soft (*Pseudoterogorgia*) corals, the great anemone (*Condylactus*), the cushion starfish (*Oreaster*), and the queen conch (*Strombus*). *Porites* colonies living near the discharge pipe in salinities about 5 ppt above ambient survived the entire study period. The mobile macro-invertebrates such as *Strombus* and *Oreaster* were frequently observed in close proximity to the discharge pipe.

Thirteen species of fish were recorded in the study area. The two most abundant species were the bucktooth parrotfish (*Sparisoma*) and the yellowtail snapper **(***Ocyurus***)**. More species occurred in a deeper part of the study area, about 6-10 m (19.5-32.5 ft) away from the discharge site, where there were more rocks and a greater vertical relief. There were no obvious or statistically significant effects of the saline discharge on either the macro-invertebrates or fishes in the study area or among the different observation periods. Both the fishes and mobile invertebrates appeared to move through the area independent of the salinity discharge profile. Parrotfish tooth scars on the sea grass plants in the study area confirm the regular appearance of this species.

What are the Report's Main Conclusions?

- The RO concentrate is rapidly dispersed and dissipated and salinity returned to ambient within a small distance of the discharge.

- There was not a salinity "build-up."

- The discharge area over which pH and temperature differ from ambient was much smaller than that of salinity.

- Study area transect surveys done before and then three and six months after diversion showed no discernable effect of RO discharge on the density, biomass, or productivity of the seagrass. Also, the number of seagrass shoot densities, an index of plant health and viability, did not differ before and six months after discharge diversion.

- The discharge had no effect on the feeding behavior of a major seagrass forager, the bucktooth parrotfish.

- The discharge had no effect on the abundance or the apparent health status (as indexed by chlorophyll concentration) of the benthic microalgae.

- Neither the abundance nor the diversity of the substrate-occurring diatoms was affected by the concentrate discharge.

- Benthic foraminifera were similarly unaffected by six month's exposure to the concentrated seawater discharge.

- Foraminifera are generally considered indicators of environmental quality. If the types and relative abundances of foraminifera in the study area did not change, this implies the salinity discharge was not having a large effect.

- Adverse responses to the seawater concentrate discharge, by either large invertebrates or fishes, were not observed by divers. Transect data similarly indicated no area-avoidance behavior.

- Divers commonly observed two mobile invertebrates, the queen conch and the cushion starfish within the areas of maximum salinity.

- Coral heads located within the transect area and exposed to an average salinity elevation of 4.5 ppt showed no ill effects over the entire 6 month observation period.

- Settling plates indicated the recruitment of a number of species into the area over the course of this study.

- The presence of both starfish and sea urchins in the elevated salinity study area is notable in light of the general perception that these animals (and all echinoderms) have a low tolerance for seawater salinity change.

What are the Report's most positive features?

- An experiment was conducted in which it was possible to evaluate a habitat before and after introduction of a concentrated seawater discharge from an RO plant.

- The team of expert scientists assembled for this study made careful observations of the "pre-" and "post-diversion" effects. They planned and executed a detailed sampling program to quantify the physical factors in the habitat and the response of the biota (in terms of both community structure and the relative abundances of major species) to the concentrated seawater incursion.

What are the Report's limitations?

- The sampling periods were limited to only two post-diversion observations and extended only six months post-diversion.

- This period is too short to determine how other variables such as season, rainfall, and nutrient presence and annual nutrient cycles, and biological cycles of recruitment and production influence the Parham Harbor marine community.

- Rains, for example, occur mainly in two seasons of each year (January-February) and (September-October), and a longer study period would be needed to assess this effect.

- The time limitation is further illustrated by the fact that the settling plate studies reported did not have "pre-diversion" control data. Plates gathered in June reflected study area colonization since March. Those collected in October indicated the combined settling history of six months. However, no plates were available to show recruitment between October and March and therefore a contrast between pre- and post-diversion settling cannot be made.

- Monitoring of a second "control" site, where no salinity changes occurred, would have provided important baseline data for interpretation of the possible causes of some of the small biological changes recorded within the study area.

What relevance does this Report have for proposed RO operations at the Encina Power Plant?

A. Reference Information.

1. The Antigua report reviews existing literature pertaining to RO discharge effects on marine biota, pointing out that very little is known.

2. Most of what is known is contained in technical reports and, for this reason, is not as directly accessible as data appearing in the more widely distributed journals.

B. The finding of no salinity effect.

1. The Antigua report provides a diverse number of broadly based observations documenting the lack of an effect of a rather large salinity anomaly on a tropical reef community.

2. "No effect" has also been predicted for the Encina RO discharge which will be less extreme, in terms of the salinity differences between the discharge and ambient water, than Antigua.

C. Differences in the Antigua and Encina RO plant and discharge systems.

1. The Antigua concentrate flows directly into the ocean (57→35 ppt).

2. The Encina RO concentrate will mix with power-plant cooling water and become highly diluted before entering the ocean. At a typical operating level of 576 mgd, the "in pipe" dilution ratio is 476/50 = 9.5, which

means that an approximately 67 ppt salinity will be diluted toward 37 ppt before the discharge reaches the ocean.

3. Antigua has an upward directed, surface contacting discharges, which promotes rapid water mixing. Encina empties into the surf zone which also promotes mixing.

4. The EPS discharge (average 576 mgd - 100 mgd of RO water, with 50 mgd of RO byproduct added back in) greatly exceeds that at Antigua (1.8 mgd). Not only does the dilution factor minimize the salinity effect on the environment, because of tidal and coastal currents there is a much greater volume of open and moving water surrounding the Encina discharge which will further enhance the plume dissipation.

D. Biological contrasts for Antigua and Encina

1. Antigua is tropical. Encina is temperate.

2. The Antigua Parham Harbor reef study area is complex having rocks and a notable vertical relief and a large benthic species diversity including corals, sea grass and algae.

3. The Encina Plant discharge area is also complex. It includes flat sand and surf zone habitats as well as kelp beds and rocky outcroppings.

4. Both habitats have comparable complexities with respect to types of organisms such as benthic macroinvertebrates and fishes. However, very many more species likely live in the tropical habitat.

5. The infaunal diversity at Antigua and at Encina is expected to compare favorably, however, the species list for the two habitats would differ considerably if not entirely.

6. As has been documented for the Antigua study area, it is expected that macroinvertebrates and fishes that enter the seawater concentrate discharge area at Encina will not be affected by it and will not purposely avoid the area.