

SECTION 11: BIBLIOGRAPHY

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Note on concentrated seawater dilution on the seafloor for the ocean desalination project at the AES Huntington Beach Generating Station

Submitted by:

Scott A. Jenkins, Ph. D. and Joseph Wasyl
Dr. Scott A. Jenkins Consulting
14765 Kalapana Street, Poway, CA 92064

Submitted to:

Poseidon Resources
17011 Beach Boulevard, Suite 900
Huntington Beach, CA 92647

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1) Introduction:

This is a supplement to Appendix- C (from Jenkins and Wasyl, 2004) of the now-approved City of Huntington Beach Re-circulated Environmental Impact Report on the Ocean Desalination Project at the AES Huntington Beach Generating Station, referred to herein as the REIR (2005). Extreme event model scenarios of brine discharge in Appendix C have not been exceeded by ocean and atmospheric conditions occurring since certification of the REIR, and consequently it is still a valid and up-to-date report in that respect. This supplemental hydrodynamic report evaluates areas of seabed affected by elevated salinity under “stand alone” operational circumstances. If in the future, the Huntington Beach Power Station were to cease the use of once-through cooling; or if the power plant were to permanently alter their cooling system's historical operations and reduce its long-term seawater intake; the proposed desalination facility would intake water directly from the Pacific Ocean via the existing power plant intake pipe in order to bring in source water. Specifically, we evaluate long term operation of the

proposed desalination plant using the minimum once-through flow rate available with the existing hydraulic infrastructure that will allow the production of 50 mgd of potable water by reverse osmosis (R.O.). This production rate requires approximately 100 mgd of once-through flow rate.

Using various minimum flow rates, we consider the operational regime when the source water is unheated and has the same temperature as ambient ocean temperature ($\Delta T = 0^{\circ} C$). The objective of this supplemental hydrodynamic analysis is to determine the area of seabed around the outfall that is subjected to salinity of 40 ppt or higher. The 40 ppt threshold is based on the biological analysis of salinity tolerance found in Appendix-S of the REIR (from Graham, 2004) as well as additional studies by LePage (2004).

Altogether there are seven primary variables that enter into a solution for the simultaneous dispersion and dilution of the waste heat from the generating station and concentrated seawater from the desalination plant. These seven variables may be organized into *boundary conditions* and *forcing functions*. The boundary condition variables control the source strength (concentrated sea salts) and background conditions and include: generating station flow rates and ΔT (which we fix at the outset), ocean salinity ocean temperature, and ocean water levels. The forcing function variables affect the strength of ocean mixing and ventilation and include: waves, currents, and winds. As detailed in Appendix-C of the REIR, overlapping 20.5 year long records for each of the seven controlling variables are reconstructed. These long-term records contain 7,523 consecutive days of daily mean values between 1980 and 2000.

The hydrodynamic analysis of salinity for these unheated stand-alone operational conditions considers two sets of outcomes; 1) an extreme event analysis that extracts the worst case from long term data sets of controlling

variables; and, 2) a probability analysis of the full set of all possible outcomes given by the period of record of the controlling variables. The extreme events are rare with a recurrence probability of less than 1 %.

2) Extreme Event Analysis:

Minimal ocean mixing conditions become the dominant set of environmental processes in defining worst case for the stand-alone conditions of this supplemental study. Following the statistical search criteria in Appendix-C of the REIR for extracting worst case mixing conditions, the following set of parameters are used to initialize the hydrodynamic model for the extreme event analysis:

1. AES intake flow rate = 152 mgd
2. Desalination production rate = 50 mgd
3. Combined discharge = 102 mgd
4. Ocean salinity = 33.52 ppt
5. End-of pipe combined discharge salinity = 49.9 ppt
6. Discharge temperature anomaly, $\Delta T = 0^{\circ}$ C (unheated)
7. Discharge density anomaly, $\Delta \rho / \rho = 0.88$ % (unheated)
8. Wave height = 0.16 m
9. Wave period = 8 sec
- 10) Wave direction = 255°
- 11) Wind = 0 knots
- 12) Tidal range = Syzygian spring/neap cycle
- 13) Daily maximum tidal current = 8.7 cm/sec

Using these parameters, the hydrodynamic model simulates the maximum salinity levels during tranquil ocean conditions wherein ambient mixing is minimal. The low mixing conditions as listed above are a one time occurrence in the period of record, but are run in the model as a 30-day long simulation to insure a steady state worst case. By perpetuating these low mixing conditions for 30 continuous days, the recurrence interval is one month every 13 to 31 years (page C-133 of Appendix-C, REIR). While interacting with these unusually quiet receiving waters, the RO units would withdraw approximately 100 mgd from the 152 mgd source water flow and return 50 mgd of concentrated seawater to the discharge stream. The resulting combined discharge from the plant outfall would be 102 mgd at salinity of 49.9 ppt. The unheated discharge is heavier than the ambient seawater, with a change in specific volume of - 0.88%. The choice of 152 mgd for the intake flow rate was the result of numerical experiments with the hydrodynamic model aimed at achieving certain water quality objectives discussed in Section 5.

The 30 day average of the model simulation of bottom salinity is plotted in Figure 1 for the unheated 152 mgd scenario with worst case mixing boundary conditions as listed above. Bottom salinity decreases with increasing distance from the outfall according to the color bar scale in the upper right hand corner of the figure, where the ambient background ocean salinity is 33.52 ppt. The 40 ppt salinity contour is too small to illustrate, but encloses 0.7 acres. All the contours are asymmetric about the outfall with the 40 ppt contour having an average radius of 100 ft.

All the bottom salinity contours display this same general down-drift (southeastward spreading) distribution for the 30 day averages due to ebb-dominance of the tidal currents (see Figure 4.3 on page C-137 of Appendix-

C, REIR). An ellipse (type-b ellipse with major axis shore-parallel and discharge source alternating between the two foci) is a reasonable geometric approximation of the plume. Throughout the 30-day time step progression of model solutions, the ellipse changes its eccentricity and swaps foci with the discharge source between ebb and flood tide. The eccentricity is larger during ebb tide (more alongshore spreading, southeastward), and smaller during flood tide (less alongshore spreading, northwestward) because the tidal currents are ebb-dominated toward the south. During slack water, the eccentricity of the ellipse goes to zero as the plume becomes a circle. The best approximation for the area that is perpetually exposed to 40 ppt or greater during the 30 day progression is a circle whose radius sweeps out an area equivalent to that inside the 30-day average of the 40 ppt contour. The average radius of the 40 ppt contour is given in the tenth row of Table 1 at the end of the conclusions (Section 6) of this technical note.

Figure 1 represents a worst case assessment of the amount and distribution of bottom habitat area exposed to salinity of 40 ppt or higher during stand-alone operations (unheated $\Delta T = 0^{\circ}$ C). The maximum seabed salinity found anywhere inside the 40 ppt contour in Figure 1 is 44.2 ppt on the rock footing of the outfall tower. Because the worst-case mixing conditions and unheated stand-alone operations are both historically rare, the joint probability of the Figure 1 scenario has a recurrence probability of about 0.04% to 0.1%.

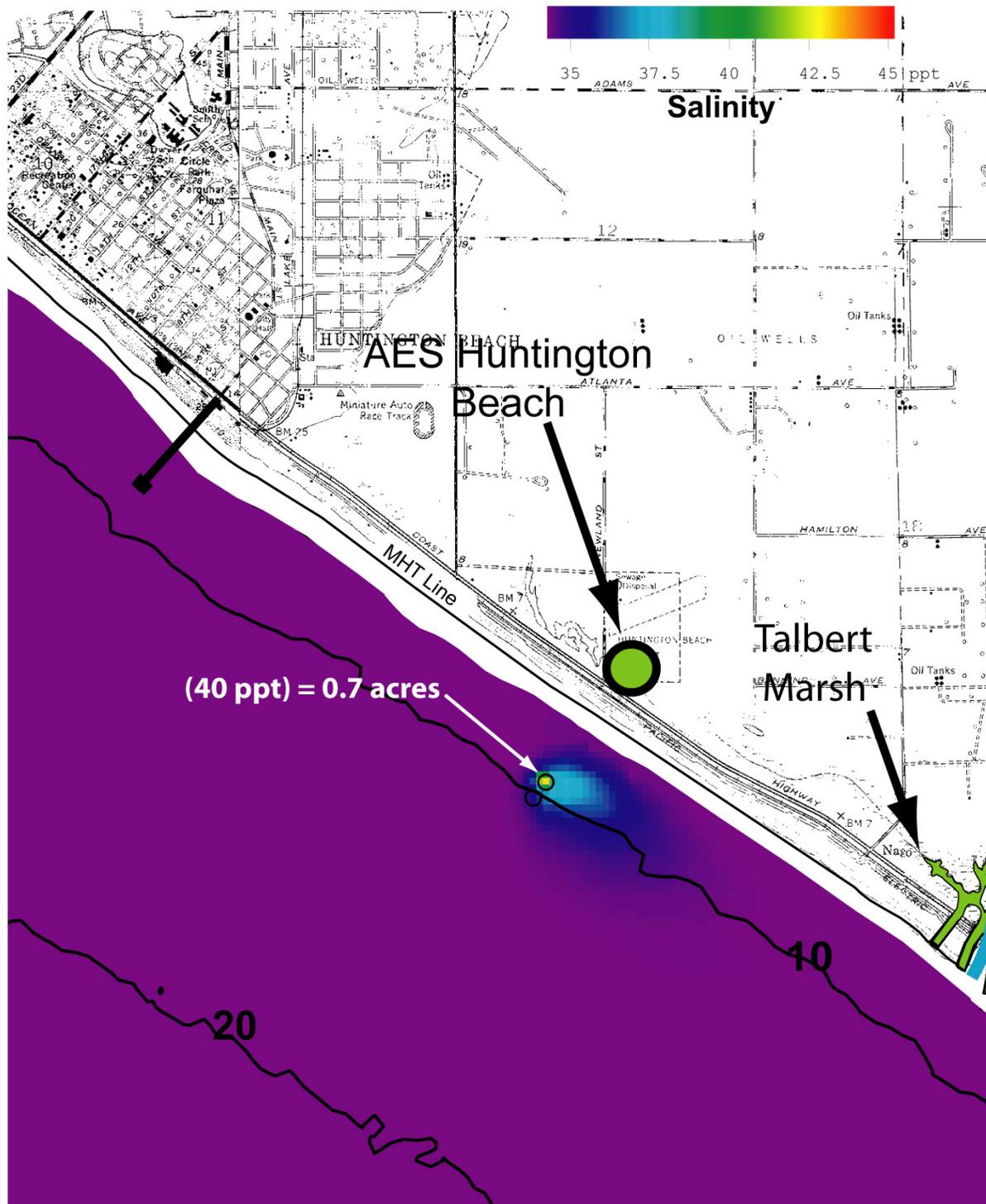


Figure 1. Bottom salinity for standby conditions: $\Delta T = 0^\circ \text{C}$; R.O. production = 50 mgd, plant flow rate = 152 mgd (worst case ocean mixing). Depth contours in m MSL, salinity indicated by color bar scale in upper right corner.

3) Long-Term Probability Analysis:

The marine environment around the AES Huntington Beach Generating station has both short-term and long-term variability due to the interplay between climatic variability and certain local features associated with the physical setting, in particular the irregular shelf bathymetry. El Niño events cause significant warming and stratification of the coastal ocean around AES Huntington Beach over recurrence periods of 3 to 7 years. These warm El Niño events are superimposed on seasonal warming cycles (Figure 2c). The salinity field shows similar variability due to the same sets of climatic and seasonal mechanisms (Figure 2b). El Niño events bring floods causing river discharges of fresh water which depress the salinities of the coastal oceans in the vicinities of river mouths. Similar variations occur inter-annually as seasonal changes in wind patterns move different water masses with different salinities into and out of the Southern California Bight. Therefore, the local environment already has a natural degree of variability in temperature and salinity (Figures 2b & c) on which the activities of the generating station and desalination plants are superimposed. In the following analysis the once-through flow rates through remain constant, fixed at the minimum flow rate of 152 mgd (Figure 2a) while the remaining variables (*boundary conditions* and *forcing functions*) are allowed to change day by day according to the 20.5 year period of record (Figures 2 and 3).

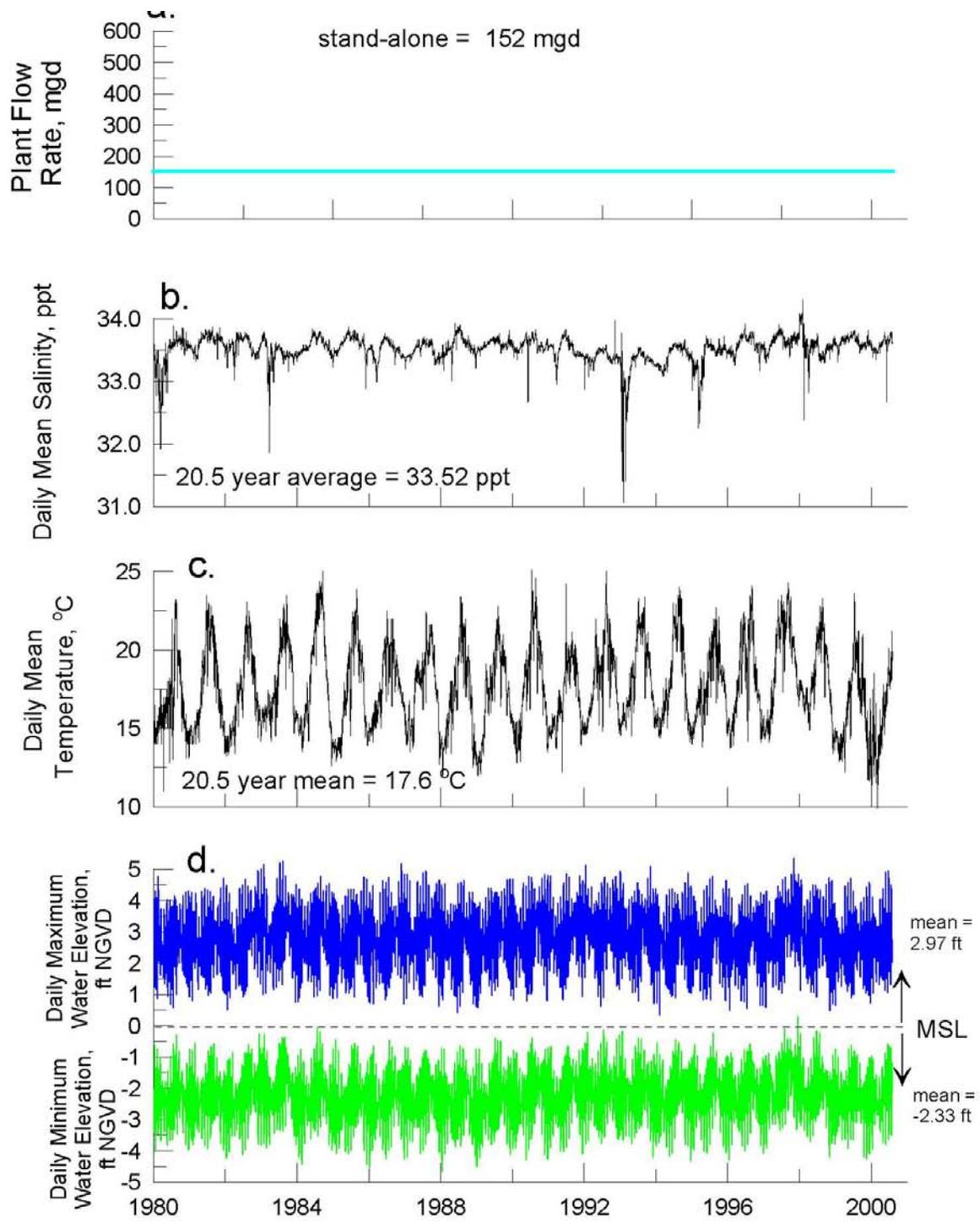


Figure 2. Controlling environmental variables for brine dilution, boundary conditions: a) plant flow rate b) daily mean salinity, c) daily mean temperature, and d) daily high and low water elevations. [data from MBC, 1980-2001; OCSD, 1993, 2000; SIO, 2001]

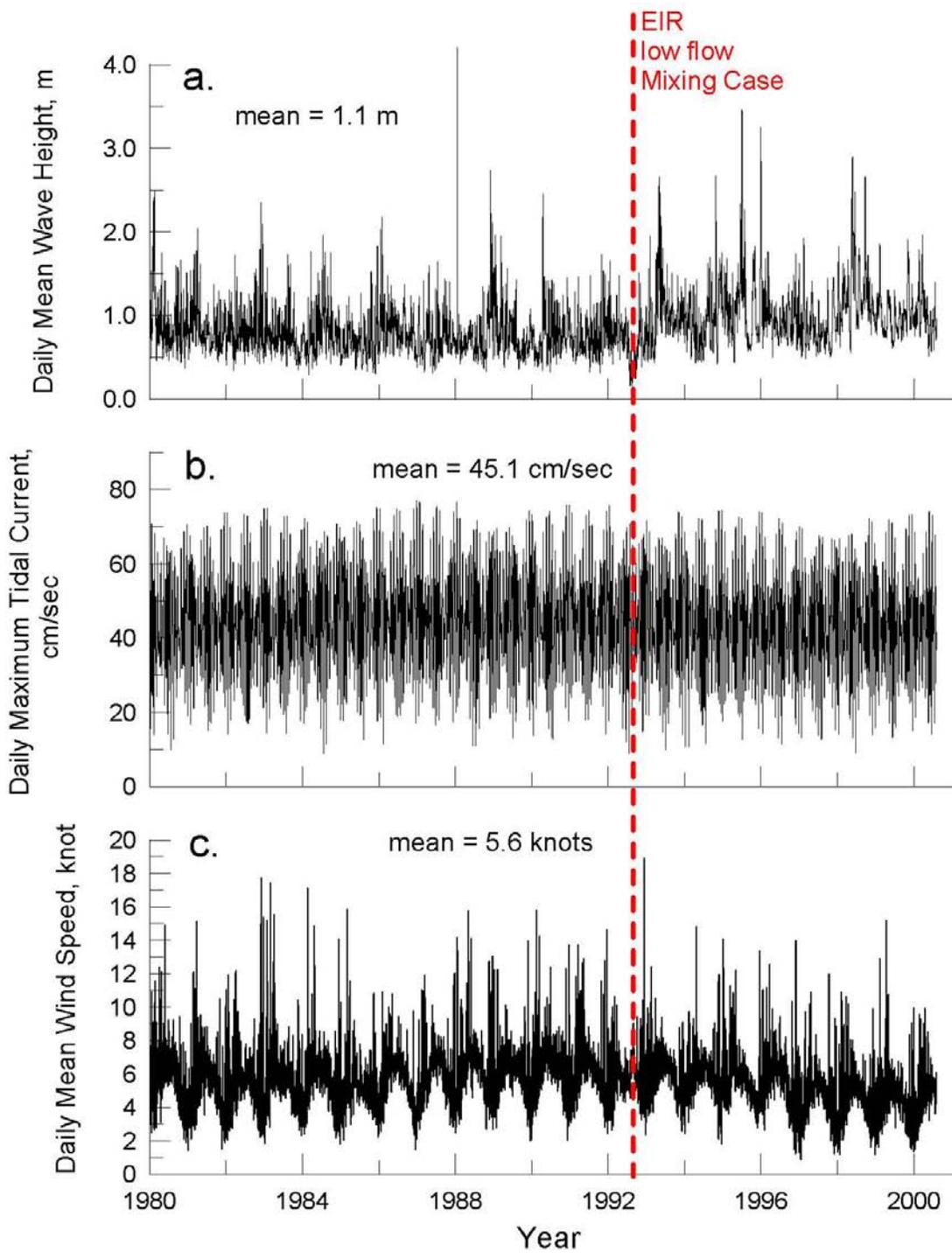


Figure 3 20.5 year record of forcing for the Newport Littoral Cell [centered at Huntington Beach, CA]. a) daily mean wave height (CDIP), b) daily maximum tidal current velocity (Station 8d), and c) daily mean wind (Station 8d). [data from CDIP, 2001; SIO, 2001; NWS, 2001; App.C, REIR, 2005]

The ocean forcing functions (Figure 3) that will mix and carry away the heat and concentrated seawater are likewise modulated by El Niño events, seasonal changes in weather patterns and by diurnal and semi-diurnal changes in tidal stage. The waves, currents and winds used to specify the worst-case mixing conditions in Section 2 is shown by the red dashed line in Figure 3. The historic boundary conditions from Figure 2 and the forcing functions from Figure 3 were sequentially input into the model, producing daily solutions for the salinity field discharged from the stand-alone operations of the desalination plant (circulating sea water at 152 mgd and producing product water at 50 mgd). The input stream of seven controlling variables from Figures 2 & 3 produced 7,523 daily solutions for the salinity field around the outfall. A numerical scan of each of these daily solutions searched for the locus of points on the sea floor having salinity of 40 ppt, and then calculated the area inside the closed contour formed by those points. The acreages inside the daily 40 ppt solution contours were then entered into histogram bins at 0.25 acre increments for ultimately assembling a probability density function and cumulative probability from the 7,523 outcomes.

Figure 4 gives the histogram of acreage inside the 40 ppt bottom salinity contour for the 152 mgd stand-alone operating scenario. The median of the 7,523 daily solutions is 0.21 acres, and there were no outcomes greater than 0.72 acres, consistent with the extreme event analysis in Section 2 (Figure 1). In fact the worst case outcome from Figure 1 is so rare its histogram bar in Figure 4 is less than a line width, consistent with the estimated recurrence probability of about 0.04% to 0.1%. The locus of red bars in Figure 4 represents the probability density function according

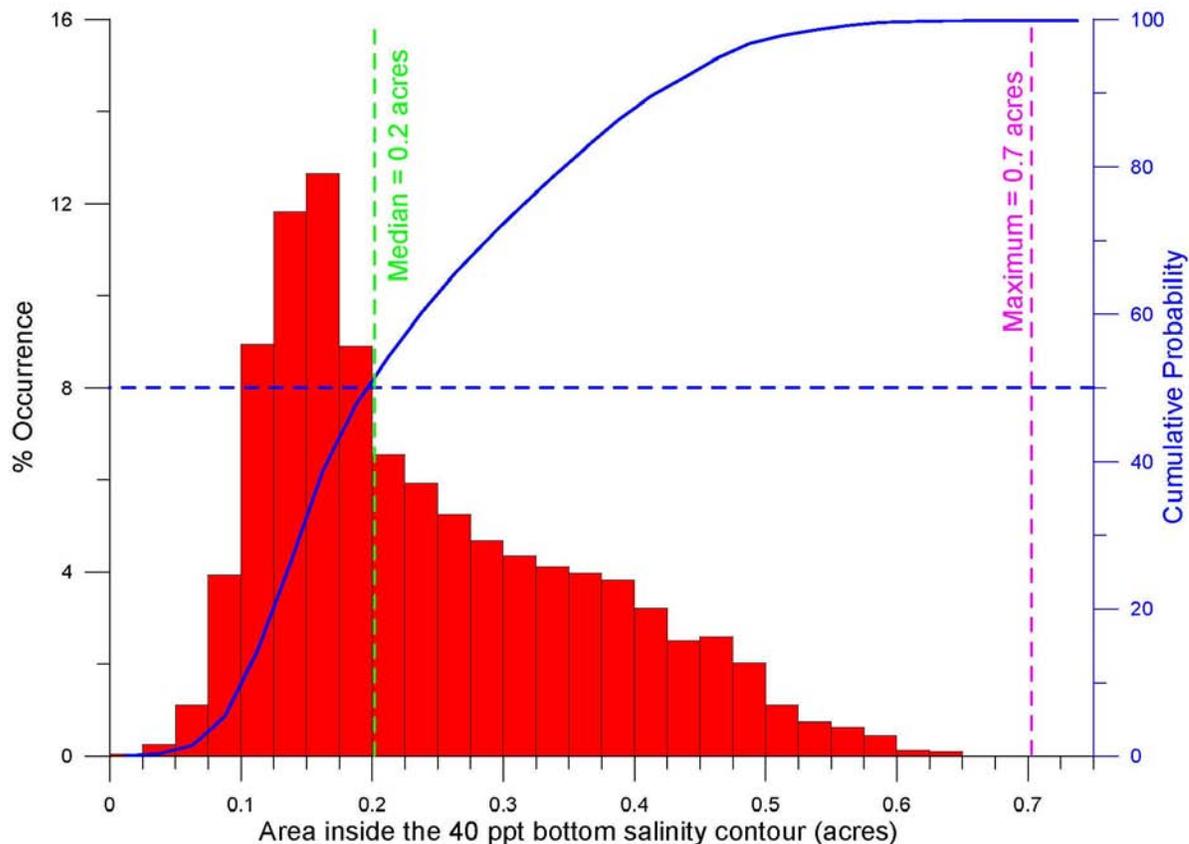


Figure 4. Histogram of acreage enclosed by the 40 ppt bottom salinity contour for desalination production rate of 50 mgd and intake flow rate = 152 mgd with $\Delta T = 0^\circ \text{C}$. Percent occurrence based on historic observations of ocean forcing and water mass properties 1980-200 (7,523 daily outcomes).

to the scale of % occurrence on the left hand side of Figure 1, while the blue curve is the cumulative probability according to the scale on the left hand side. Inspection of the cumulative probability function in Figure 4 reveals that 90% of the outcomes resulted in less than 0.4 acres inside the 40 ppt bottom contour.

4) Plume Exposure Time for Drifting Organisms:

Pelagic organisms drifting in the nearshore currents can be carried through the discharge plume along trajectories governed by the *Lagrangian drift*. The Lagrangian drift is the mean motion of a particle that would be observed by following that particle along its drift trajectory. The drift rates of an organism passing through the plume are calculated as described on pages C-157-162 of Appendix C of the REIR. Here we supplement that analysis to consider the stand-alone worst case whereby the power plant is not generating and the desalination plant is utilizing 152 mgd of unheated source water flow with $\Delta T = 0^{\circ} C$.

The maximum exposure time of a drifting pelagic organism passing through the discharge plume for the unheated 152 mgd stand-alone operational case with worst case mixing is plotted as a black line in Figure 5. Salinity in the inner core of the discharge plume does not exceed 49.9 ppt, for which exposure time of a drifting organism is 9 minutes. Exposure to the outer core where salinities are nominally 45 ppt, is 39 minutes, and about 1.9 hours along the outer fringes of the outer core where salinities decline to 38 ppt. The exposure time is 1.4 hrs at 40 ppt. In the salt wedge where salinities range from 33.58 ppt to 34 ppt, exposure times never exceed 9.3 hours.

5) Discussion of Water Quality Objective:

The stand-alone operational simulations at 152 mgd intake flow rate are based on achieving sufficient in-the-pipe dilution so that salinity does not exceed 40 ppt, beyond 100 ft from the discharge tower. This result is aimed at meeting the 0.3 TUa objective of Requirement III.C.4(b) of the *California Ocean Plan* (even though concentrated seawater is not a toxin), as it would

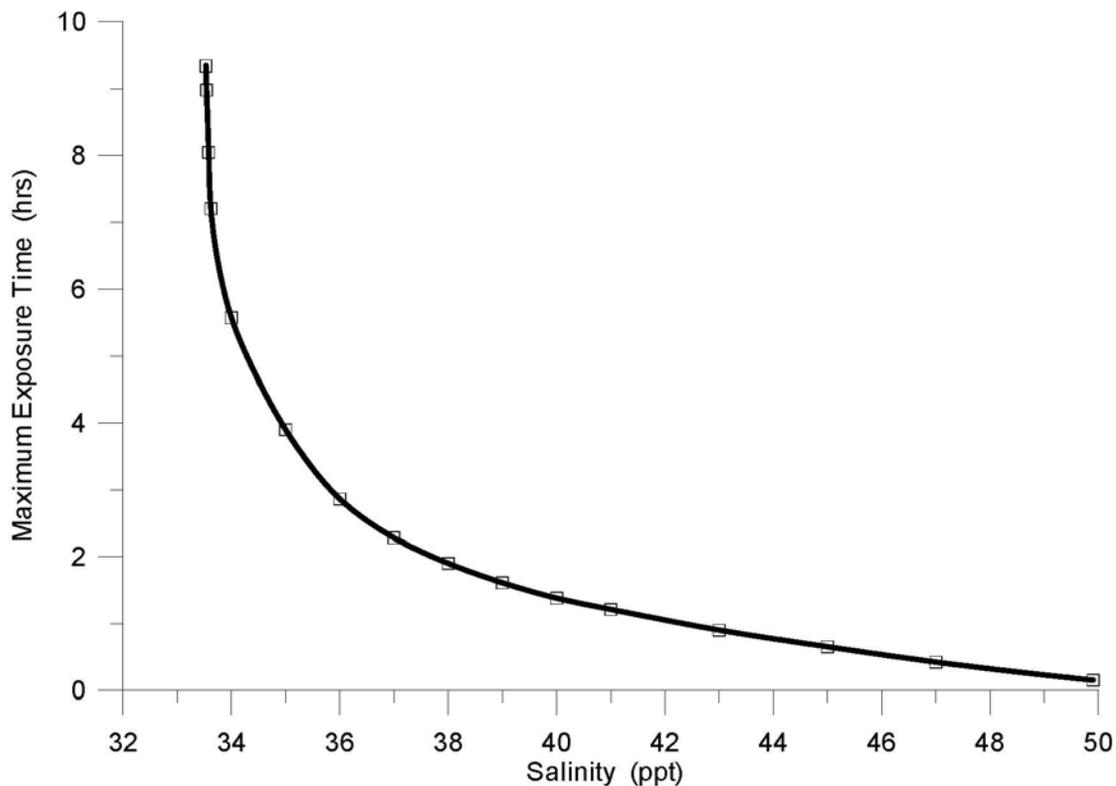


Figure 5. Maximum exposure time of a drifting organism passing through the discharge plume of concentrated seawater from the AES Huntington Beach outfall for augmented stand-alone worst-case at $\Delta T = 0^{\circ}\text{C}$ and 152 mgd intake flow rate (black)

apply to a *Zone of Initial Dilution (ZID)* measuring 1000 ft in radius as stipulated in RWQCB (2007) for the Huntington Beach Generating Station and the co-located Huntington Beach Desalination Project. For worst case mixing conditions as defined in Section 2, intake flows would have to reach 152 mgd to meet this version of the 0.3 TUa objective. If the 152 mgd stand-alone operating point is subjected to long-term mixing conditions, then seafloor salinity remains under 40 ppt beyond 54 ft from the discharge tower. Therefore, the intake flow rate could be reduced to 144 mgd to satisfy the 0.3 TUa objective with a 1000 ft ZID under long-term mixing conditions.

6) Conclusions:

Taking various unheated minimum intake flow rates, we use a hydrodynamic model to calculate the area of seabed subjected to salinities of 40 ppt or greater. The unheated regime represents a hypothetical circumstance in which: the generating station has been permanently shut down or has altered their cooling system's historical operations and reduce its long-term seawater intake; and the desalination facility operates circulation and supplemental pumps to supply source water to the reverse osmosis (RO) units. From these hydrodynamic simulations we conclude:

- a) The unheated discharge produced by desalination using 152 mgd of intake flow results in a median outcome of 0.2 acres of sea bed being exposed to salinities of 40 ppt or greater, while 90 % of the time less than 0.4 acres of sea bed are so affected. The worst-case outcome for the 40 ppt seabed footprint was found to be 0.7 acres. The recurrence probability of this worst case outcome is estimated at 0.04% and 0.1% from historic environmental and operating conditions.
- b) Heated source water produces a smaller footprint of elevated salinity over the seafloor with lower peak salinity than that obtained with unheated source water.
- c) Unheated source water causes an insignificant increase in the time that drifting organisms are exposed to salinity exceeding 40 ppt in the water column.

The stand-alone, hydrodynamic simulations at 152 mgd intake flow rate are based on achieving enough in-the-pipe dilution so that salinity does not exceed 40 ppt beyond 100 ft from the discharge tower. This objective is aimed at meeting the 0.3 TUa objective of Requirement III.C.4(b) of the

California Ocean Plan (even though concentrated seawater is not a toxin), as it would apply to a *Zone of Initial Dilution (ZID)* measuring 1000 ft in radius as stipulated in RWQCB (2007) for the Huntington Beach Generating Station and the co-located Huntington Beach Desalination Project. From these simulations we conclude:

d) For worst case mixing conditions, intake flows must reach at least 152 mgd to meet this version of the 0.3 TUa objective; but could be reduced to 144 mgd under long-term mixing conditions in order to satisfy this objective. The 152 mgd stand-alone scenario results in a 1.4 hour exposure period for drifting organisms encountering salinity exceeding 40 ppt in the water column under worst case mixing conditions. Maximum salinity in the inner core of the discharge plume does not exceed 49.9 ppt, for which exposure time of a drifting organism is 9 minutes.

7) References:

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- LePage, S., 2004, "Salinity tolerance investigation: supplemental report for the Huntington Beach Desalination Project", submitted to Poseidon Resources, 29 pp.

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