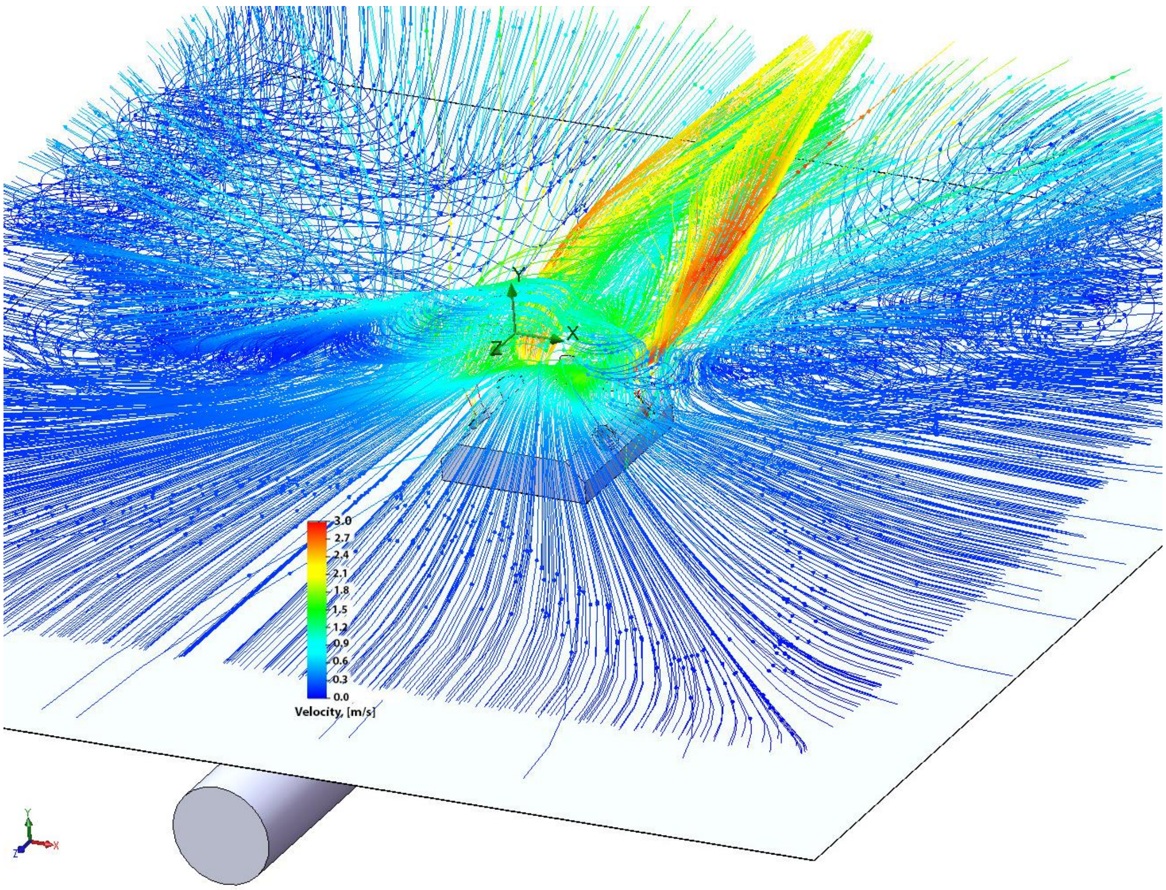
Initial Dilution in a Quiescent Ocean Due to Discharges of Concentrated Seawater from the Huntington Beach Desalination Facility (HBDF)



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ABSTRACT: The amended California Ocean Plan defines a new water quality objective for salinity of dense brine discharges as follows: "*Discharges shall not exceed a daily maximum of 2.0 ppt above natural background salinity to be measured as total dissolved solids (mg/L) measured no further than 100 meters (328 feet) horizontally from the discharge*. *There is no vertical limit to this zone*" (SWRCB, 2015).

A set of coupled high resolution dilution models were constructed and run to determine compliance with this new water quality objective and to establish initial dilution values for discharges of concentrated seawater and trace pollutants at the boundaries of the zone of initial dilution (ZID) under stand-alone operations of the Huntington Beach Desalination Facility (HBDF). Peer reviewed, published and USEPA certified hydrodynamic models were employed to resolve initial dilution and discharge plume trajectories under standard NPDES dilution modeling protocols (as defined in the California Ocean Plan); according to which "*Initial Dilution will be considered the process which results in the rapid and irreversible turbulent mixing of wastewater with ocean water around the point of discharge".* As such the models do not consider any additional mixing due to the action of ocean currents, waves, tides or wind. The models were initialized for quiescent ocean receiving waters at mean sea level bounded by the existing bathymetry surrounding the offshore discharge site for the Huntington Beach Desalination Facility.

The modeled HBDF desalination operating scenario was based on 56.7 mgd of concentrated seawater (brine) at a salinity of 63.1 ppt being discharged into quiescent ocean receiving waters having a natural background salinity of 33.52 ppt and worst-case month temperature salinity profiles obtained from the extensive KOMEX (2003) monitoring of the AES Huntington Beach intake and outfall, performed for the California Energy Commission. No power generation is assumed to occur within the AES Huntington Beach Generating Station and the delta-T of the undiluted brine relative to ocean water temperature is assumed to be $\Delta T = 0\ ^0C$. Two different discharge structures were studied: 1) The existing outfall tower presently used by the AES Huntington Beach Generating Station (HBGS) at latitude 33º 38' 19'' N, longitude 117º 58' 57'' W, approximately 1,500 ft (457 m) offshore from the mean lower-low water tide line at a depth of 27.9 ft (8.5 m) below mean sea level; and 2) the Alden designed 6-Jet Radial Diffuser retrofitted to the existing outfall tower at the same location. The 6-jet radial diffuser was designed to be adaptable to two potential future operating regimes, both of which were evaluated by the initial dilution models. The operations of the diffuser retrofit are expected to initially occur during what will be referred to as the *combined regime*, when the diffuser must provide excess conveyance capacity to accept once-through cooling water discharges from the Huntington Beach Generating Station (HBGS). During this operating regime, all six discharge ports of the radial diffuser will be open. Worst-case dilution during the *combined regime* occurs when the diffuser is receiving only brine effluent from the Huntington Beach Desalination Facility (HBDF) because the HBGS is operating in *stand-by mode* with no thermal discharges conveyed to the diffuser. Once the HBGS has abandoned its once-through cooling operations, the four diffuser ports that are 42 in. diameter will be capped and the diffuser will operate in a *stand-alone* regime using only the two seaward facing 30 in. diameter ports.

The Visual Plumes (UM3) and *COSMOS/ FLowWorks* matched solutions of brine discharge from the existing HBGS discharge tower find that the brine discharge plume

breaks up into four discrete meandering spreading layers that do not follow a particular shoreline normal or shore-parallel plane. At the 100 m BMZ boundary, the maxima in discharge salinity was found to be 42.0 ppt, thereby failing to satisfying the brine amendment of the California Ocean Plan, (Appendix-A of SWRCB 2015). The corresponding dilution factor is D_m = 2.48 at the 100 m BMZ boundary, where Dm is calculated based on 63.1 parts per thousand (ppt) effluent concentration at end-of-pipe. At the HBDF brine ZID, 1,900 m from the point where brine dilution achieves a steady end state, initial dilution reaches a robust D_m = 210; but the amended Ocean Plan defaults initial dilution to the smaller of Dm at the BMZ vs at the ZID. Therefore, initial dilution of HBDF brine when discharged from the existing HBGS discharge tower is merely Dm = 2.48.

The Visual Plumes nearfield dilution results for the Alden radial diffuser operating in the *worst-case combined regime* find that the 6-port radial diffuser dilutes the brine to within 2ppt of natural background at 98 m from the point of discharge, and is fully compliant with the new Ocean Plan brine discharge limits in all quadrants around the HBDF discharge site. The dilution factor at the edge of the BMZ at 98 m from the discharge is Dm = 13.9, and reaches a Dm = 14 at 100 m from the point of discharge. At 250 m from the point of discharge Dm = 60.6, but is still increasing rapidly with increasing distance, indicating that initial dilution is not yet complete.

When the HBDF is operated under quiescent ocean conditions in *stand-alone* configuration, with the 4 ea. 42 in. jet ports capped off, the Visual Plumes dilution model finds that dilution performance is excellent, achieving compliance with the new Ocean Plan discharge limit (2 ppt above natural background) within 29.4 m. from the point of discharge, where again the dilution factor Dm = 13.9. Dilution factor at 100 m from the point of discharge reaches Dm = 36.9 when operating in the 2-jet *stand-alone* configurations; but the Dm is still changing rapidly with increasing distance at 100 m from the point of discharge, indicating that initial dilution is not yet complete.

To establish when initial dilution is completed, the matched Visual Plumes - *COSMOS/ FLowWorks* models were run out to 1,024 computational iterations whence the salinity distribution between two adjacent computational steps became less than 1%. At this point, dilution was considered to have reached a steady state distribution. The brine plume becomes stationary at distance of 3,331 m seaward of the diffuser, marking the seaward limit of the ZID where the dilution factor reaches Dm = 236 for the 6-jet radial diffuser operating in the *worst-case combined regime* regime, and Dm = 257 for the radial diffuser operating in the *stand-alone regime* with only two 30 in. jets. None the less, the amended Ocean Plan defaults initial dilution to the smaller of Dm at the BMZ vs at the ZID. Therefore, initial dilution of HBDF brine when discharged from the Alden design 6-jet radial diffuser is merely Dm = 13.9.

Thermal effluent from HBGS is positively buoyant and disperses over a flat ocean surface which produces no slope along which the gravitational force field can accelerate the discharge stream. In contrast, the brine is heavier than sea water (negatively buoyant) and spreads across the sloping seabed. The Ocean Plan concept of when initial dilution is complete is associated with when the momentum induced velocity of the discharge ceases to produce significant mixing of the waste. The heavy brine effluent initially has two components of momentum: 1) momentum in the velocity field (products of mass and velocity); and 2) momentum in the force field (products of force acting over time, referred to as *impulsive momentum*); where the force field comes from gravity as a consequence of the negative buoyancy of the brine. As the brine begins to flow offshore and down the slopes of the nearshore bathymetry, momentum in the gravitational force field flows (*fluxes*) into the velocity field, and the brine accelerates under the force of gravity due to its negative buoyancy. Some of the gravitational acceleration is transferred to stresses of bottom friction, but the remaining momentum of the discharge stream is restructured as a system of transport streams and eddies, all of which derive their momentum and velocity from the initial discharge stream. The transport streams are *return flows* of receiving water that were displaced by the offshore-directed push (*momentum flux*) of the discharge stream, and transport receiving water into the ZID from offshore and along-shore sources which eventually merge with the discharge stream to produce dilution. Eddies are produced by shear stresses between the discharge stream and the receiving water which transfer momentum from the discharge stream into eddy momentum (*vorticity*), producing *irreversible turbulent mixing*. The dilution action of the transport streams and eddies dilutes the both the waste (brine) as well as the momentum contained in the discharge, until at some point offshore, the discharge becomes neutrally buoyant and the momentum of the residual velocity field is so diluted that turbulent mixing ceases. That point marks the edge of the ZID, and can be inferred from the velocity field as the zone beyond which organized eddy motion ceases. In the case of the down-slope gravity propelled brine plumes, large-scale transport flow patterns and eddies develop in the quiescent ocean simulation that would never exist in Nature, as these organized flow features would be sheared and broken up by shoaling waves and coastal boundary layer currents.

Initial Dilution in a Quiescent Ocean Due to Discharges of Concentrated Seawater from the Huntington Beach Desalination Facility (HBDF)

By: Scott A. Jenkins, Ph.D.

1) Introduction:

This is a supplement to the brine dilution analysis in Appendix- C (from Jenkins and Wasyl, 2004) of the Subsequent Environmental Impact Report Sea Water Desalination Facility at Huntington Beach," #2001051092, referred to herein as the SEIR (2010). The previous analysis was prepared before the newly amended *California Ocean Plan* as presented in Appendix-A of SWRCB (2105); and was evaluated under worst-case ocean mixing conditions derived from the historic record of waves, currents, tides, and winds. The amended California Ocean Plan defines a new water quality objective for salinity of dense brine discharges as follows: "*Discharges shall not exceed a daily maximum of 2.0 ppt above natural background salinity to be measured as total dissolved solids (mg/L) measured no further than 100 meters (328 feet) horizontally from the discharge*. *There is no vertical limit to this zone*" (SWRCB, 2015). The amended California Ocean Plan refers to the region within 100 m from the discharge as the *brine mixing zone* (BMZ) and allows for marine impacts inside this zone. The amended California Ocean Plan further requires: *"In addition, the owner or operator shall develop a dilution factor (Dm) based on the distance of 100 meters (328 feet) or initial dilution, whichever is smaller".* The present supplemental hydrodynamic analysis has been conducted in response to these new discharge requirements by performing an *initial dilution* analysis for a perfectly quiescent ocean, i.e., in the absence of any motion or mixing in the receiving waters due to waves, currents, tides, or winds. In particular, the present study is tasked with determining the relationship between the *Zone of Initial Dilution* (ZID) and the area within the *Brine Mixing Zone* (BMZ).

Under this new Ocean Plan amendment, *natural background salinity* is to be determined from 20 years of ocean salinity measurements representative of the at project site. This has already been established as 33.52 ppt in Appendix-C of the SEIR (2010). The relationship between the ZID and the BMZ is evaluated for the maximum possible hyper-salinity impact, arising when the HBDF discharges 56.7 mgd of concentrated seawater (brine) at a salinity of 63.1 ppt at the site of the present thermal outfall of the AES Huntington Beach Generating Station (HBGS), as noted in Figure 1.1. The initial dilution analysis will be performed for two different discharge structures; 1) The existing discharge tower at the outfall site (Figure 1.2); and 2) a multiport diffuser retrofitted to the top of the discharge tower after the upper section of the tower has been removed so that the diffuser does not extend above the elevation of the existing tower (Figure 1.3). The existing discharge tower is located at latitude 33° 38' 19" N, longitude 117° 58' 57" W, approximately 1,500 ft (457 m) offshore from the mean lower-low water tide line at a depth of 27.9 ft (8.5 m) below mean sea level .

2) Regulatory Definitions of Initial Dilution and the Zone of Initial Dilution:

Initial dilution is defined within Appendix I of the *California Ocean Plan* as follows:

Initial Dilution is the process which results in the rapid and irreversible turbulent

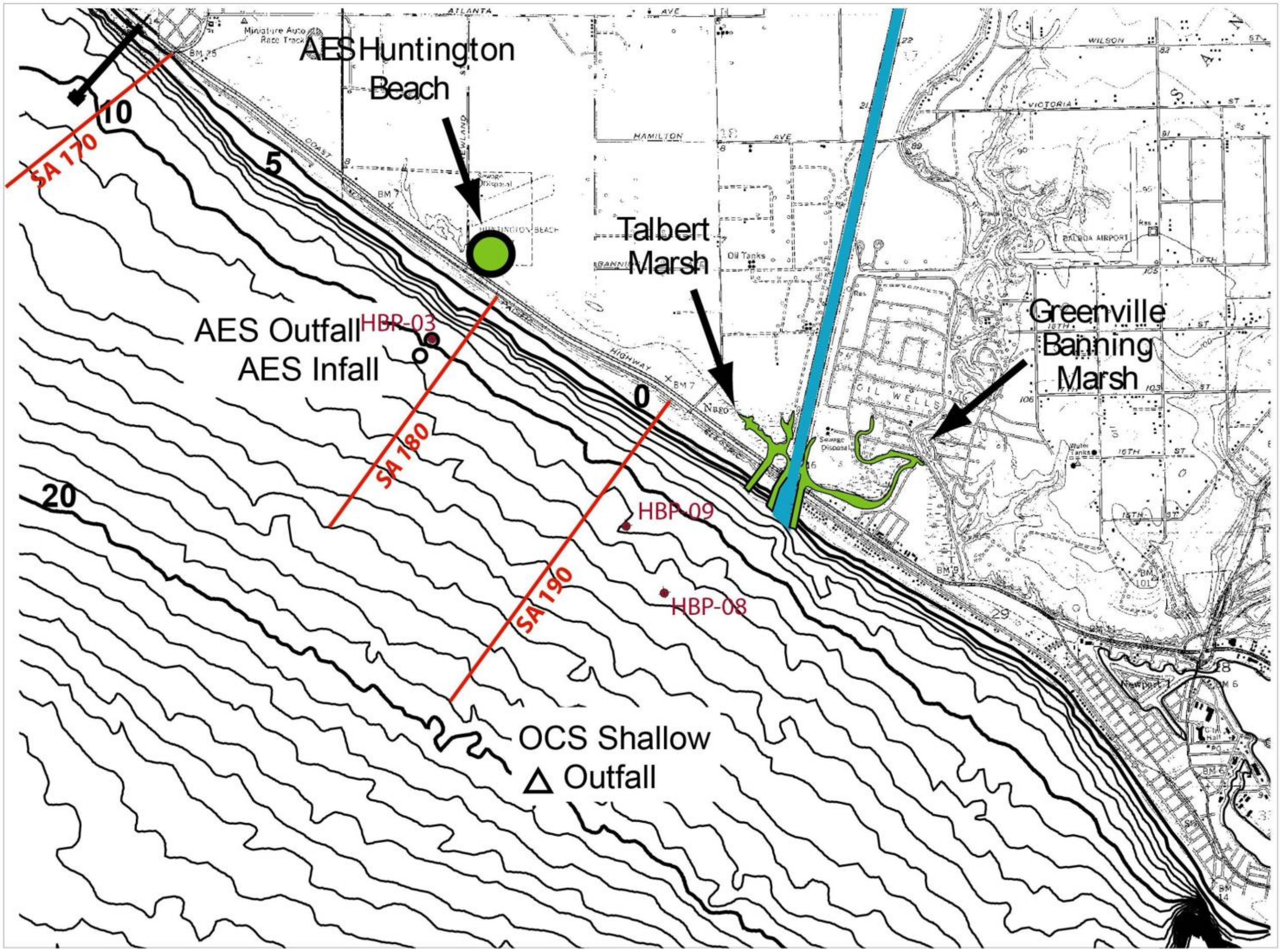


Figure 1.1: Physical setting of the HBDF co-located at the AES Huntington Beach Generating Station (HBGS), with bathymetry in meters MSL, historic beach profile range lines and sediment sample locations in red. Based on 80,000 grid points @ 0.1 x 0.1 arc-sec.

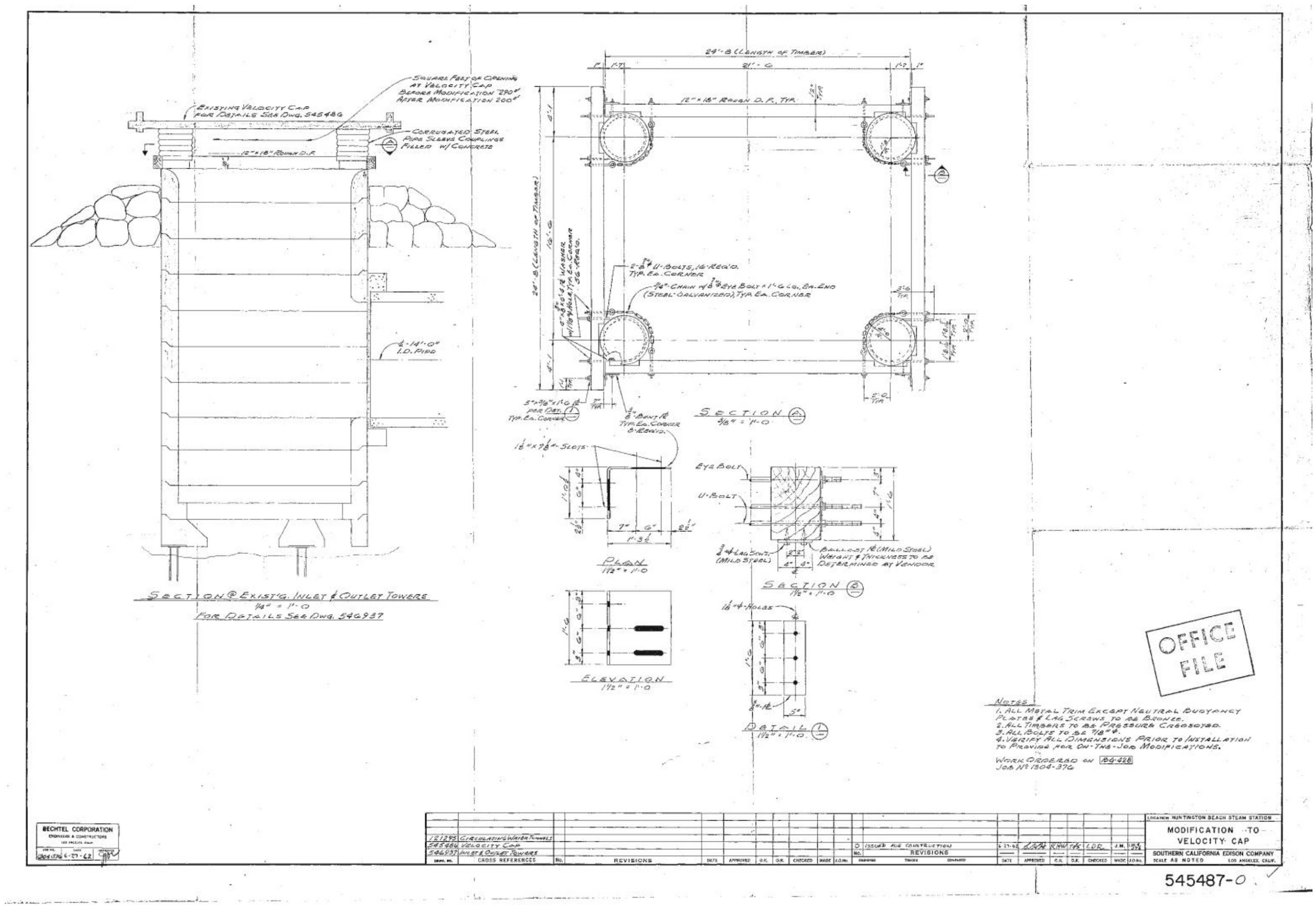
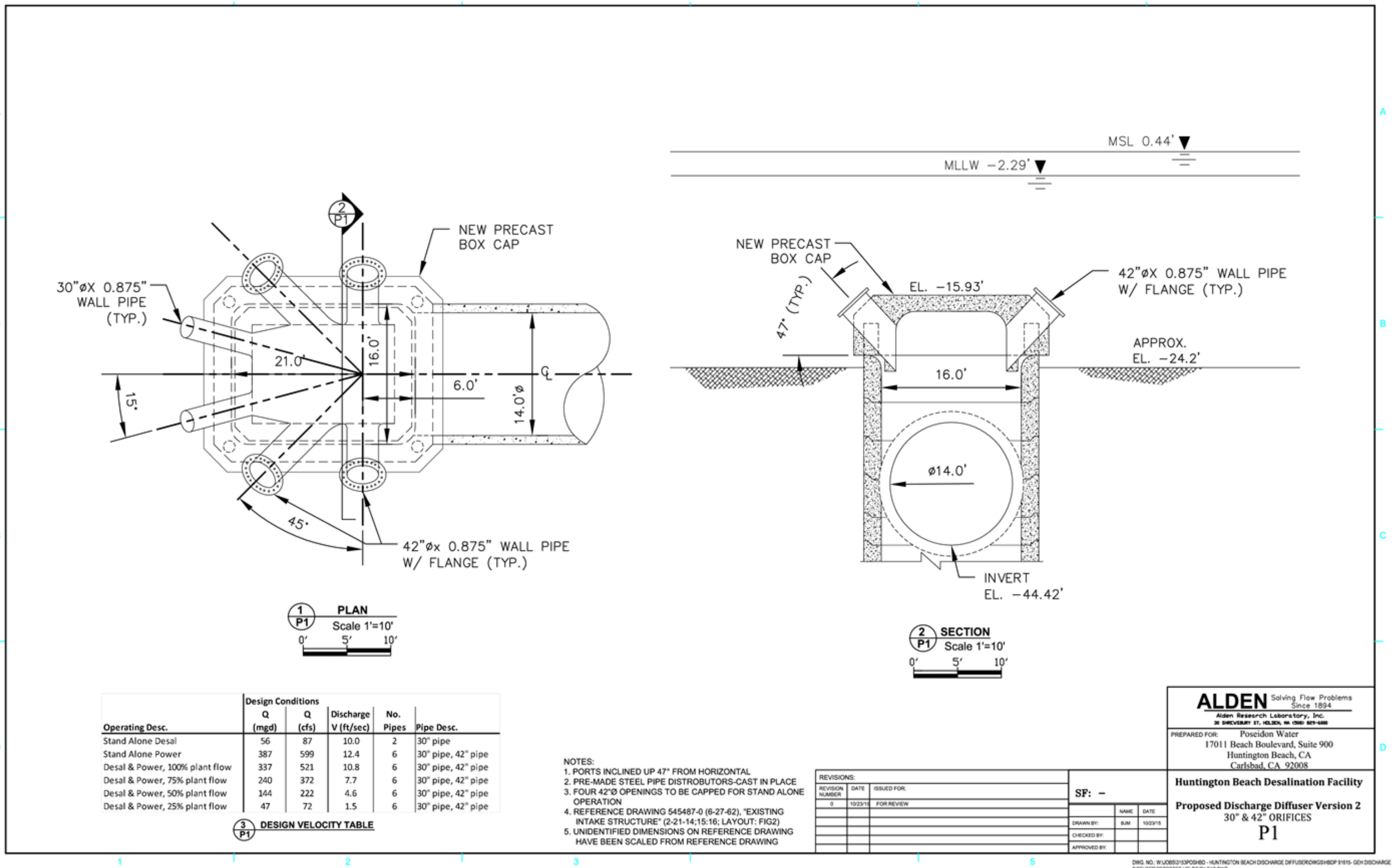


Figure 1.2 Mechanical drawing of infall and outfall tower, AES Huntington Beach Power Plant. Note, velocity cap on outfall tower replaced with 12" x 18" mesh screen constructed of 1" x 3" flatbar.



Operating Desc.	Design Conditions Q (mgd)	Q (cfs)	Discharge V (ft/sec)	No. Pipes	Pipe Desc.
Stand Alone Desal	56	87	10.0	2	30" pipe
Stand Alone Power	387	599	12.4	6	30" pipe, 42" pipe
Desal & Power, 100% plant flow	337	521	10.8	6	30" pipe, 42" pipe
Desal & Power, 75% plant flow	240	372	7.7	6	30" pipe, 42" pipe
Desal & Power, 50% plant flow	144	222	4.6	6	30" pipe, 42" pipe
Desal & Power, 25% plant flow	47	72	1.5	6	30" pipe, 42" pipe

Figure 1.3: Alden 6-Jet Radial Diffuser Retrofit at Huntington Beach Desalination Facility (HBDF). Elevations shown in ft. MSL

mixing of wastewater with ocean water around the point of discharge. For a submerged buoyant discharge, characteristic of most municipal and industrial wastes that are released from the submarine outfalls, the momentum of the discharge and its initial buoyancy act together to produce turbulent mixing. Initial dilution in this case is completed when the diluting wastewater ceases to rise in the water column and first begins to spread horizontally.

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

Here, non-buoyant discharges are those whose density matches that of the receiving water, and consequently have no net buoyancy. Brine is actually a buoyant discharge in which the buoyancy is negative. Brine dilution behaves like that from a municipal waste water outfall turned upside down; where instead of rising from the seabed toward the sea surface as treated wastewater effluent behaves, brine descends from near the sea surface and falls towards the seabed.

The California Ocean Plan only provides a notional definition the ZID as the zone in which the process of initial dilution is completed. The California Ocean Plan establishes receiving water concentration standards that are to be achieved upon completion of initial dilution. Provision III.C.4.d of the Ocean Plan states:

For the purpose of this Plan, minimum initial dilution is the lowest average initial dilution within any single month of the year. Dilution estimates shall be based on observed waste characteristics, observed receiving water density structure, and the assumption that no currents, of sufficient strength to influence the initial dilution process, flow across the discharge structure.

Provision III.M.3.b of the amended Ocean Plan (SWRCB, 2015) requires owners or operators of desalination facilities to develop a dilution factor (Dm) for application to the BMZ:

The dilution factor (Dm) shall be developed within the Brine Mixing Zone using applicable water quality models that have been approved by the regional water boards in consultation with State Water Board staff.

Under the terms within Appendix I of the *California Ocean Plan* the solution for the ZID boundary requires model input defined as, "*the trapping level when considering worst-case scenarios*". Trapping levels result from the vertical stratification of the receiving waters as a consequence of the temperature/salinity depth profile, and the worst case month results from the weakest degree of vertical stratification when temperature and salinity have the smallest gradient between the sea surface and the sea floor.

3) Technical Approach:

To convert the notional water quality definition of the ZID into a mathematical equation that the hydrodynamic model can solve, we pose the ZID definition as a *calculus of variations* problem, (Boas, 1966). Because the highest salinity in the discharge plume is found on the seabed, the ZID represents a closed contour curve ζ on the seabed surrounding the outfall along which the total momentum flux of the discharge plume reaches a *stationary minimum*. The curvilinear coordinate ζ that defines the ZID contour may be written in model coordinates as,

$$d\zeta = \sqrt{(dx)^2 + (dy)^2} = \sqrt{1 + x'^2}\; dy = \sqrt{1 + y'^2}\; dx \qquad (1)$$

$$x' = \frac{dx}{dy} \quad ; \quad y' = \frac{dy}{dx}$$

where *x* is the model grid coordinate in longitude, and *y* is the grid coordinate in latitude. Gridding for the ZID modeling herein is by latitude and longitude with a 0.1 x 0.1 arc second grid cell resolution yielding a computational domain of 2 km x 2 km.

The momentum flux of the discharge plume has two components: 1) momentum in the velocity field, and 2) momentum in the force field; where the force field comes from gravity as a consequence of the negative buoyancy of the brine. The momentum flux of the discharge plume $H(\zeta)$, is written (Batchelor, 1970) as:

$$H(\zeta) = \frac{1 - c_f}{2}\, \rho_s\, u_s^2(\zeta) \quad + \quad \left[\rho(\zeta) - \rho\right] g\, h(\zeta) \qquad (2)$$

where $\rho_s(\zeta)$ is the density of the brine plume; ρ is ambient sea water density; $u_s(\zeta)$ is the fluid velocity in the discharge plume along the ζ contour; $h(\zeta)$ is the local depth along the ζ contour, and c_f is the bottom friction coefficient related to seabed roughness. The first term on the right hand side of equation-2 is the momentum flux due to the discharge velocity, while the second term is the momentum flux associated with the net buoyancy (negative) of the discharge plume. The variational problem for the ZID requires minimization of the integral:

$$\oint H(\zeta)\, d\zeta \quad \rightarrow \quad \text{stationary minimum} \qquad (3)$$

Because the plume by definition must be a stationary spreading front at the ZID contour, the velocity field term in equation-2 vanishes as the plume velocity decays to stagnation along the stationary front, ($u_s \rightarrow 0$). The force field term in equation-2 reaches a minimum wherein the density structure of the plume is in hydrostatic balance with the ambient ocean density field, ($\rho_s \rightarrow \rho$). This reduces the contour integral in equation-3 to the more tractable indefinite integral:

$$\oint H(\zeta)\, d\zeta = \int F(y,x,x')\, dy \qquad (4)$$

where:

$$F(y,x,x') = (\rho_s - \rho)\, g\, h\,(x,y)\, \sqrt{1+x'^2}$$

The variational problem for the ZID can thus be posed in terms of finding the depth contour $h(x,y)$ that minimizes the integral on the right hand side of equation-4. This is accomplished by solving the *Euler-Lagrange equation* [*Boas*, 1966],

$$\frac{\mathrm{d}}{\mathrm{d}y}\frac{\partial F}{\partial x'} - \frac{\partial F}{\partial x} = 0 \qquad (5)$$

Equation-5 is solved by double integration using the hydrodynamic solutions for the discharge plume density field. The solution is based quiescent ocean receiving waters at mean sea level, with no waves, currents tides or wind mixing.

Analysis of brine dilution at the BMZ, initial dilution at the edge of the ZID and delineation of the ZID boundary itself is based on a combination of hydrodynamic models. It is standard practice to use a near-field dilution model for the initial dilution of the turbulent discharge, and a far-field dilution model for predicting the trajectory and dispersion of the discharge plume after initial dilution. The unique feature of the present problem is that the processes initial dilution and dispersion occur as a gravity flow on a sloping bottom. As the heavy brine effluent flows downslope from the discharge tower into the deeper receiving waters offshore, initial dilution is continually regenerated as this gravity flow converts potential energy of elevation into turbulent kinetic energy. Therefore initial dilution extends into the far-field and two separate types of models are required to fully resolve the initial dilution problem. For the near field mixing zone model, we employ Visual Plumes (UM3), certified by the U.S. Environmental Protection Agency and the California State Water Resources Control Board for use in ocean outfall design (Baumgartner, et al., 1994). For the far-field trajectory and dispersion solution we employ a class of models known as ***computational fluid dynamics*** (CFD). We used two different CFD models: 1) *COSMOS/ FLowWorks* was employed solve the far-field brine dispersion trajectories, and 2) the regeneration of turbulent kinetic energy from downslope flow was evaluated using a $\bar{v}^2 - f$ mode computational fluid dynamics model, *Star-CD ,* Version 3.1, with *QUICK* space discretization for the mean flow and first order up-winding of the turbulence equations, (Iaccarino, G, 2000, Star, 1998).

4) Model Initialization

The models were initialized for quiescent, tideless ocean receiving waters at mean sea level bounded by the existing beach and offshore bathymetry surrounding the discharge tower for the Huntington Beach Desalination Facility. The discharge tower was initialized in the model according to as-built drawings. The temperature and salinity profiles in the receiving water were initialized from NPDES permit monitoring for the

AES Huntington Beach outfall and the nearby Orange County Sanitation Department (OCSD) outfall supplemented by buoy and ship data collected under the CDIP (2012) and CalCOFI, (2014) programs as archived by SCCOOS, (2014).

4.1) Bathymetry: Because brine is negatively buoyant it will continue to flow downslope following bottom gradients once it falls to the sea floor after being discharged. Therefore, bathymetry provides a controlling influence on the initial dilution process vis a vis, the trajectory of the brine plume and the location of the ZID boundary once the brine plume becomes a stationary front and initial dilution is complete. Bathymetry is derived from the National Ocean Survey (NOS) digital database that are archived at the National Geophysical Data Center (NGDC, 2013) and available from the web site: http://www.ngdc.noaa.gov/mgg/gdas/gd_designagrid.html. Gridding is by latitude and longitude with a 3 x 3 arc second grid cell resolution yielding a computational domain of 15.4 km x 18.5 km centered around the HBDF site. Grid cell dimensions along the x-axis (longitude) are 77.2 meters and 92.6 meters along the y-axis (latitude). In the nearfield of the HBDF outfall (Figure 1.1) grid cell dimensions are interpolated to 1 x 1 arc second resolution. In either case this small amount of grid distortion is converted internally to Cartesian coordinates, using a Mercator projection of the latitude-longitude grid centered on Huntington Beach. The convention for Cartesian coordinates uses x-grid spacings for longitude and y-grid spacings for latitude. Total grid sizes are 400 x 200 points in the farfield (80,000 points), per Figure 1.1. Any depths below 305 meters are assigned default values of 305 m while any land masses or shoals about 0-MSL are assigned default values of -1.14 m. The resulting depth contours were input to ARCGIS kriging algorithms to create a 3-dimensional CAD model of the seafloor off the for the Huntington Beach Desalination Facility, (Figure 4.1), thereby creating a 3-d computational grid at 0.1 arc-second horizontal resolution and covering an area of receiving water 6 km x 6 km.

4.2) Salinity and Natural Background Definition: N*atural background salinity* according to the amended Ocean Plan is the mean of at least 20 years of ocean salinity measurements at a reference location that is representative of the discharge location. For the purposes of this evaluation, we have adopted reference locations in the coastal waters offshore of the Huntington Beach Desalination Facility derived from NPDES permit monitoring data at the co-located AES Huntington Beach outfall from (data reported in MBC, 1980-2004, and at the nearby the Orange County Sanitation Department (OCSD) outfall from OCSD 1993, 2000. This data is plotted in Figure 4.3a and includes the same period of record from the SEIR (2010) that is plotted in Figure 4.2a. The expanded period of record in Figure 4.3a, spanning 25.6 years of continuous NPDES monitoring during the period from 1980 through July 2004, also includes the extensive KOMEX (2003) monitoring of the AES Huntington Beach intake and outfall, performed for the California Energy Commission. Inspection of Figure 4.3a indicates that the ocean salinity varies naturally by 10% between summer maximums and winter minimums, with a long term (25-year) average value of 33.52 parts per thousand (ppt). Maximum salinity was 34.34 ppt during the 1998 summer El Nino when southerly winds transported high salinity water from southern Baja up into the Southern California Bight. Minimum salinity was about 31.02 ppt during the 1993 winter floods. The variation between maximum and minimum salinity is about 3.32 ppt, which is about 10 % of the average value of 33.5 ppt. From the probability density function in Figure 4.2b, it is found that the ocean salinity

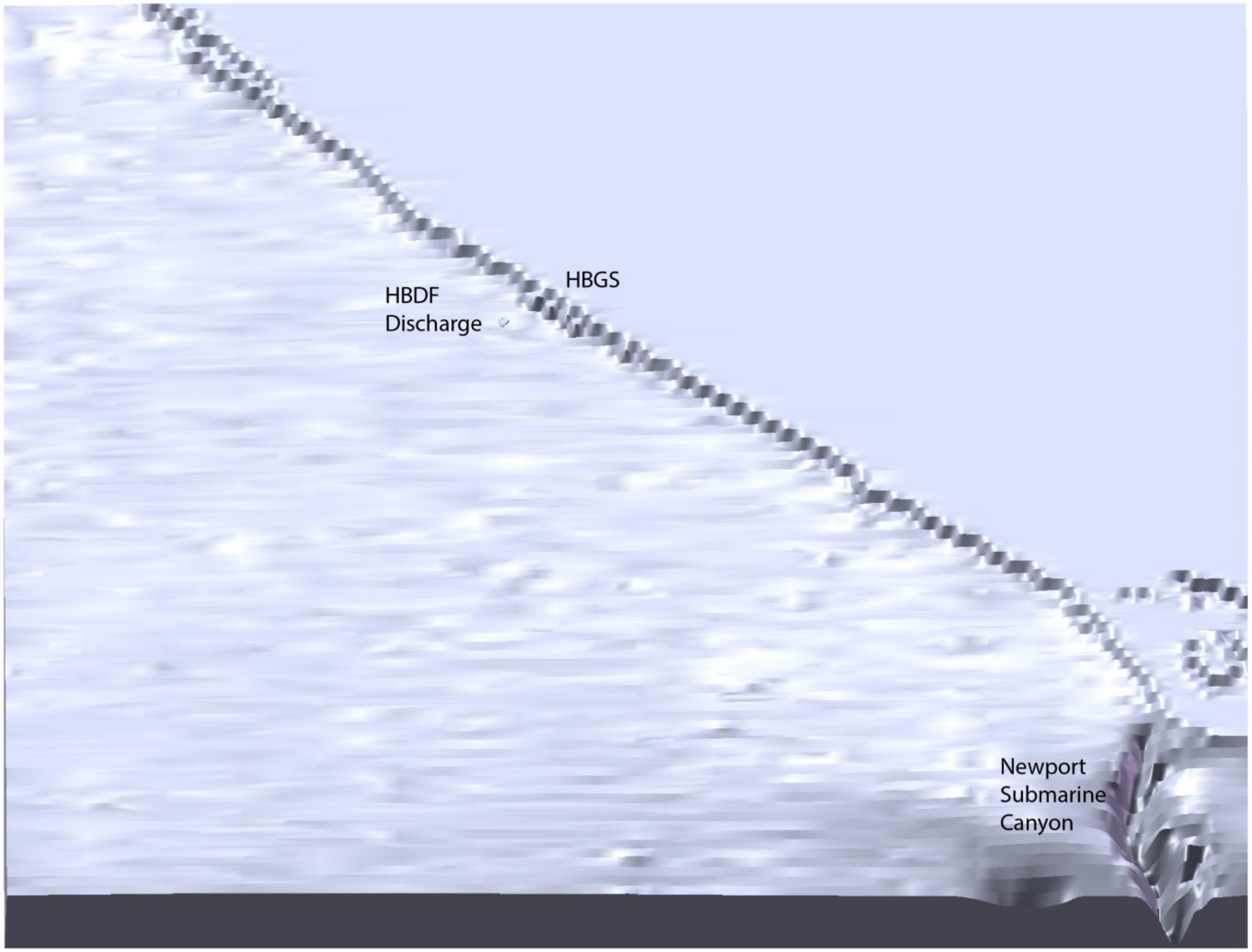


Figure 4.1: Three-dimensional CAD model of the seafloor off shore of the Huntington Beach Desalination Facility used for a 3-d hydrodynamic simulations of brine dilution and dispersion. Grid at 0.1 arc-second horizontal resolution and covering an area of receiving water 6 km x 6 km. Note Newport Submarine Canyon in the lower left corner of the image.

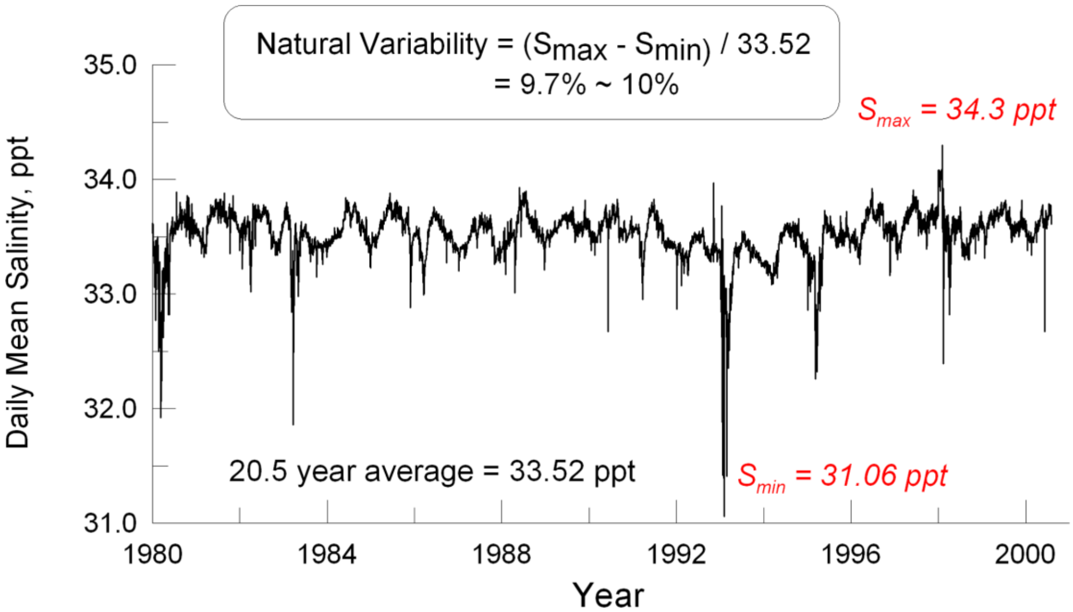


Figure 4.2a Period of record for ocean water daily mean salinity, Huntington Beach, 1980-2000. [data from NPDES monitoring reports for AES and OCSD outfalls, in MBC, 1980-2001; OCSD, 1993, 2000]

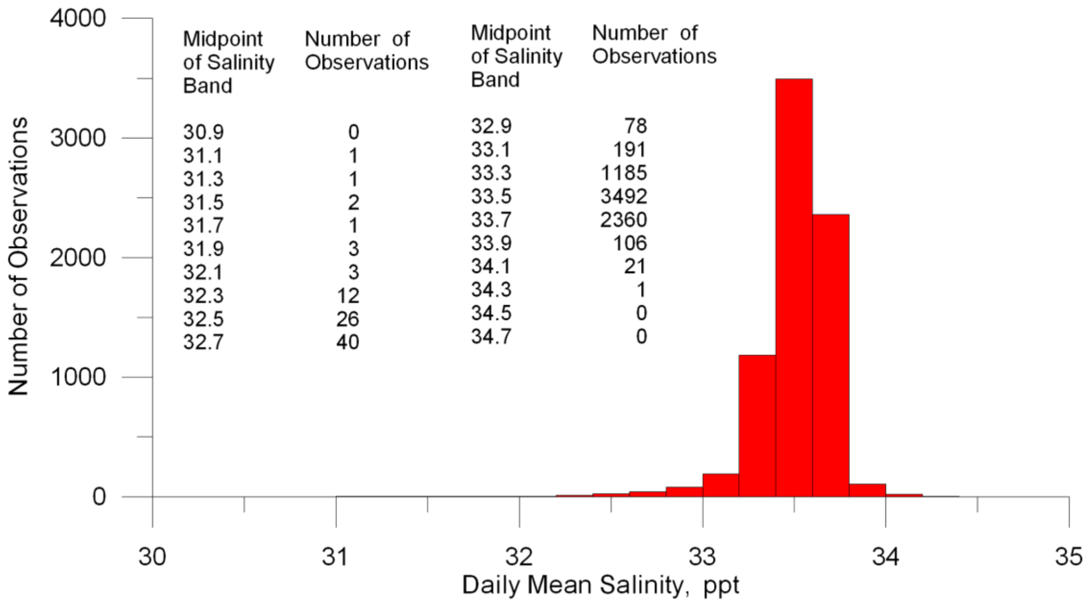


Figure 4.2b Histogram of ocean water daily mean salinity, Huntington Beach, 1980-2000. [from MBC, 1980-2001; OCSD, 1993,2000]

exceeded the 33.5 ppt average value during 2,488 days out of 7,523 days during the period of record, and was below average during 1,543 days. Therefore above average salinities are more common than below average salinities. Average salinities were observed a total of 3,492 days of the period of record, or about 46 % of the time. These data are also confirmed by long term salinity monitoring at Scripps Pier NOAA Station #941-0230, and by 55 CalCOFI cruises in the Southern California Bight between 1984 and 1997, see SIO, 2013; at
http://www-mlrg.ucsd.edu/shoresta/mnSIOMain/siomain.htm
and Roemmich, 1989, and Bograd, et al, 2001. These observations at more distant locations from the HBDF indicate that salinity has very little spatial variation throughout the Southern California Bight.

4.3) Ocean Temperature: The ocean temperature effects the buoyancy of the brine discharge through the absolute temperature of the discharge. This buoyancy effect is calculated by the specific volume change of the discharge relative to the ambient ocean water (see Appendix-1). The buoyancy of the brine plume exerts a strong effect on the mixing and rate of assimilation of the sea salts by the receiving waters. We use the average of temperature records from NPDES permit monitoring data at the co-located AES Huntington Beach outfall from (data reported in MBC, 1980-2004, and at the nearby the Orange County Sanitation Department (OCSD) outfall from OCSD 1993, 2000. The 25.6 year record of daily mean ocean water temperatures extracted from these data bases is plotted in Panel-b of Figure 4.3. This is includes the period of record for ocean temperature variation as that used in the SEIR (2010) as well as that of the KOMEX (2003) water quality study. A pronounced seasonal variation in these temperatures is quite evident with the maximum recorded daily mean temperature reaching 25.1 ^{o}C during the summer of the 1993 El Niño and the minimum falling to 9.9 ^{o}C during the winter of the 1999-2000 La Niña. The 20.5 year mean temperature was found to be 17.6 ^{o}C. On a percentage basis, the natural variability of the temperature of coastal waters in the vicinity of the HBDF is significantly greater than that of salinity (on the order of ΔT = 86% vs ΔS = 10%).

4.4) Temperature/Salinity Depth Profile. Under the terms within Appendix I of the *California Ocean Plan* the solution for the ZID boundary requires model input defined as, "*the trapping level when considering worst-case scenarios*". Trapping levels result from the vertical stratification of the receiving waters as a consequence of the temperature/salinity depth profile. A computer search of the temperature and salinity records in Figures 4.3 and the KOMEX (2003) water quality study, finds the worst-case scenario occurs in the historic record for the temperature/salinity profiles during August 2002. These profiles are plotted in Figures 4.4 and 4.5. The profiles show rather weak vertical stratification of the water column near the HBDF outfall site, with a very thin surface mixed layer extending down to about 2.5 m to 3 m depth. The surface mixed layer has an average temperature of about 23 ^{0}C and average salinity of about 33 ppt. Below the surface mixed layer the temperature is found to gradually decline with water depth, to about 21 ^{0}C resulting in a temperature gradient of only 0.3 ^{0}C per meter of depth. The salinity changes more abruptly below the surface mixed layer, but only increases by about 1 ppt to about 34 ppt on the seabed, resulting in a salinity gradient of

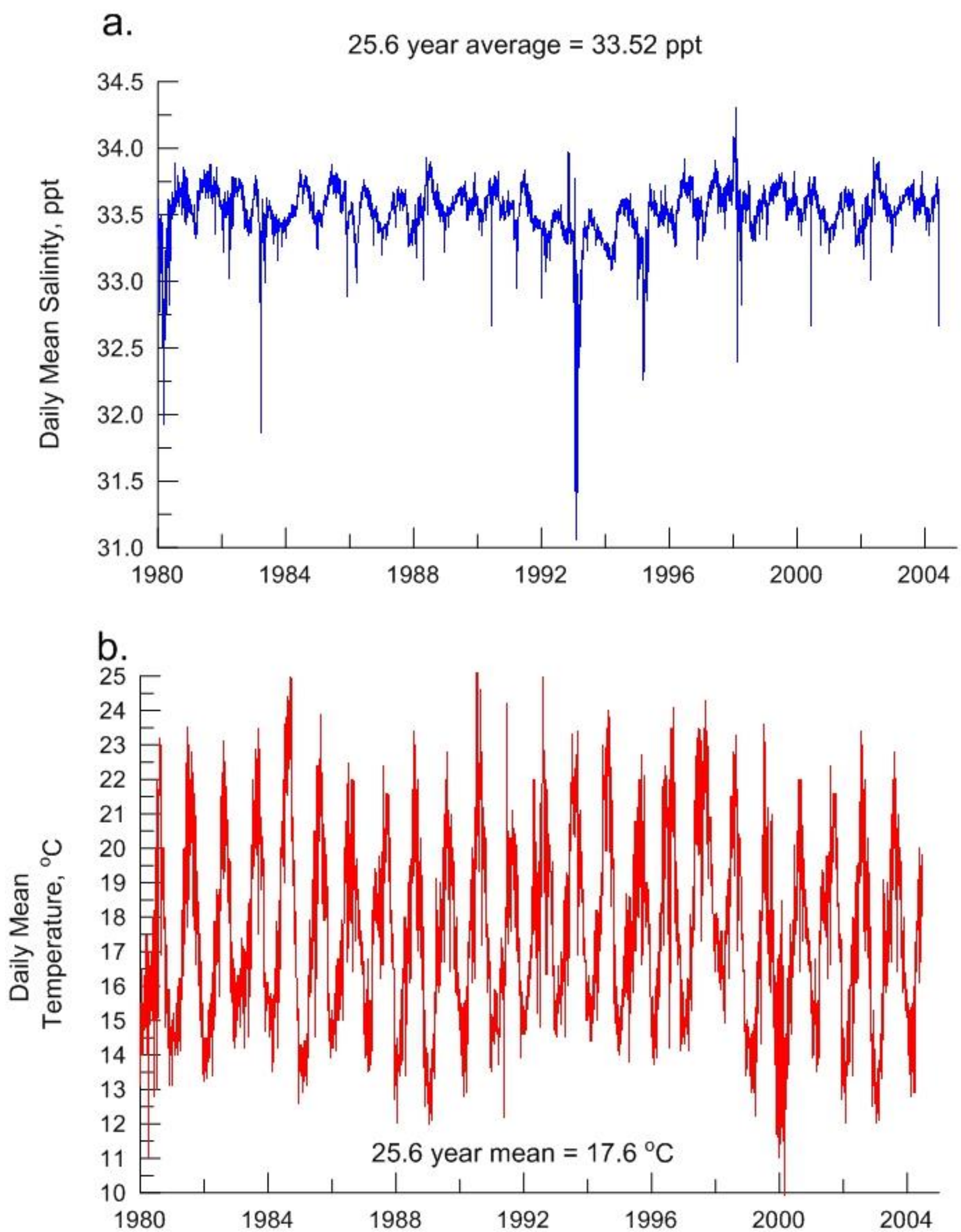
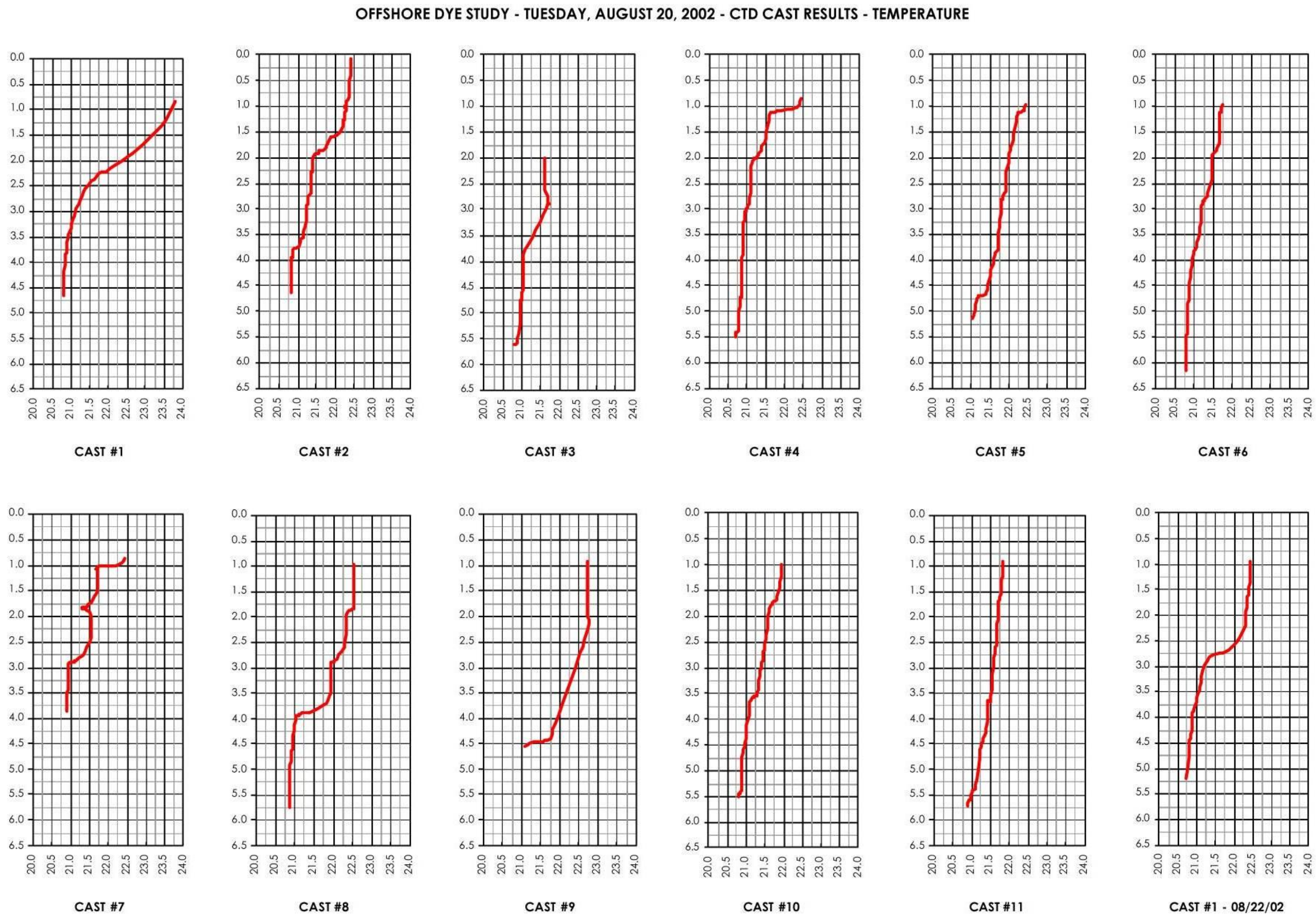


Figure 4.3. Controlling environmental variables for brine dilution: (a) daily mean salinity, b) daily mean temperature, [data from MBC, 1980-2004; OCSD, 1993, 2000; SIO, 2013]



Depths (shown along the vertical axis in each graph) are in meters.
Temperatures (shown along the horizontal axis in each graph) are in degrees Centigrade

Figure 4.4: Temperature – depth profiles around the HBDF discharge tower during worst-case month, August 2002. Data from KOMEX (2003).

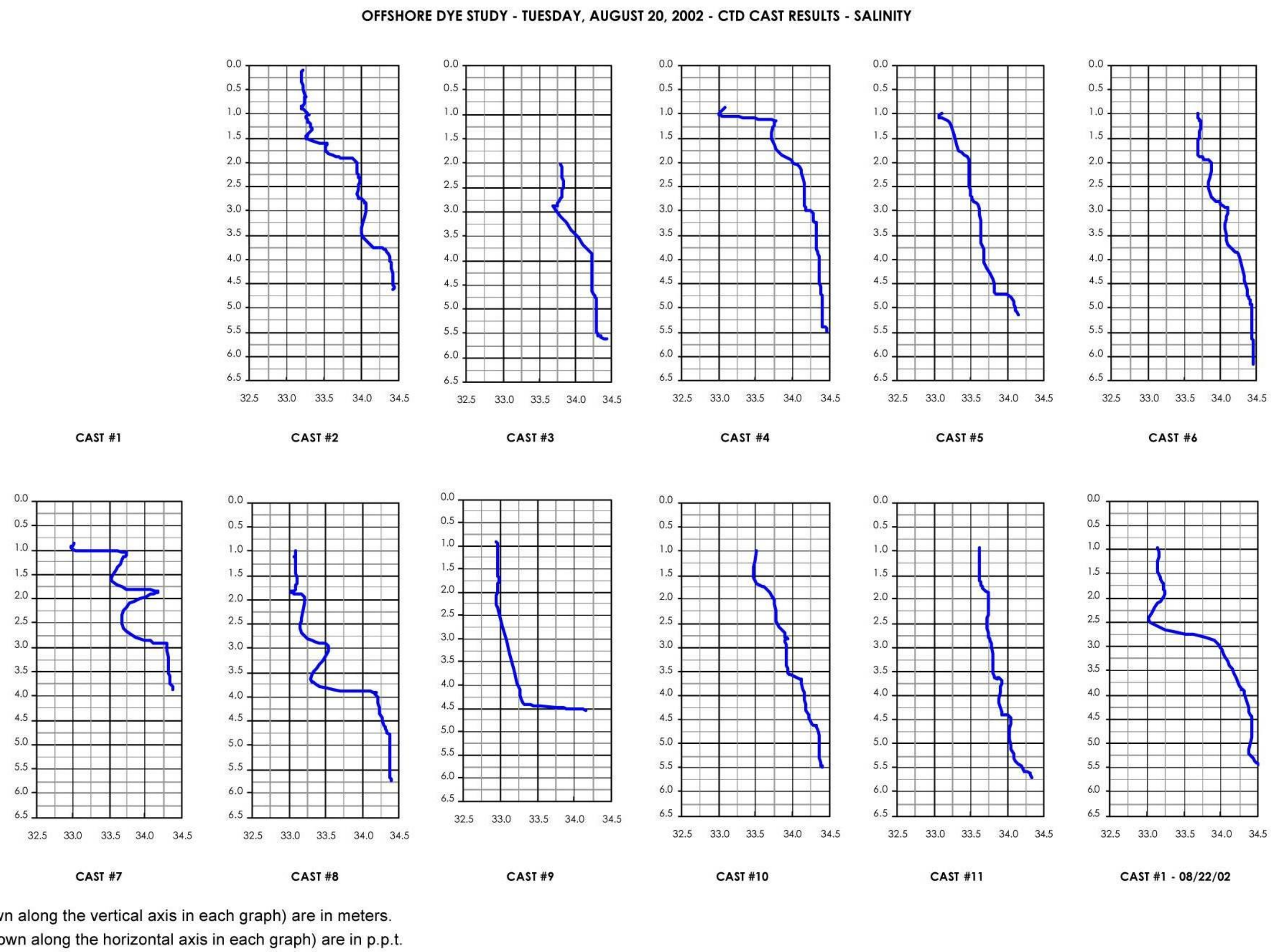


Figure 4.5. Temperature – depth profiles around the HBDF discharge tower during worst-case month, August 2002. Data from KOMEX (2003).

only about 0.16 ppt per meter of depth. Normally there is a very abrupt change in water temperature between the warm surface mixed layer and the cold bottom water; and this abrupt change is referred to as the thermocline. The thermocline interface produces the trapping layer, where the partially diluted discharge plume no longer has sufficient momentum or buoyancy to penetrate the thermocline, and instead spreads out horizontally along the thermocline interface, resulting in a trapping level beneath the sea surface. Because the surface mixed layer is so thin in Figures 4.4 and 4.5, and because the depth gradients of temperature and salinity are small, the trapping layer at the bottom of the surface mixed layer is very weak. Therefore, even if the brine discharge from the HBDF broaches the sea surface, it will not be greatly retarding in subsiding through the thermocline interface and reaching the sea floor in receiving waters greater than -6 m depth.

4.7) Brine Effluent Discharge Temperature: Because of similarities in design of pre-treatment and reverse osmosis facilities we shall use present discharge temperatures at the Carlsbad Desalination Project (CDP) as a proxy for The Huntington Beach Desalination Facility (HBDF). The CDP begin discharging brine effluent on 1 November 2015. Discharge monitoring results show an average temperature difference between intake and discharge temperatures during the first 3 operating months of $\triangle T = -0.7\ ^0F = -0.39\ ^0C$; increasing slightly to $\triangle T = +2.74\ ^0F = +1.96\ ^0C$ during the following two operating months. Therefore the Visual Plumes (UM3) and *COSMOS/ FLowWorks* models were initialized in two separate runs for effluent discharge streams having $\triangle T = 0\ ^0C$; and $\triangle T = +2\ ^0C$. The model runs using $\triangle T = 0\ ^0C$ give a slightly lower initial dilution because the mass diffusivity of NaCl in water (a proxy for sea salts) increases moderately with increasing temperature. Therefore we shall use $\triangle T = 0\ ^0C$ as a worst case simulation for the HBDF.

4.8) Waves, Currents, Tides and Winds: Following Provision III.C.4.d of the Ocean Plan, initial dilution shall be modeled with no excitation of receiving water motion from waves, currents, tides or winds were input to either the Visual Plumes (UM3) and *COSMOS/ FLowWorks* models. Ocean water levels were set at a constant elevation of 0 m MSL. We refer to this set of boundary conditions as the Quiescent Ocean Dilution condition.

5) Results for Quiescent Ocean Dilution of HBDF discharge

The modeled HBDF desalination operating scenario was based on 56.7 mgd of concentrated seawater (brine) at a salinity of 63.1 ppt being discharged into quiescent ocean receiving waters having a natural background salinity of 33.52 ppt and a worst-case month temperature salinity profile as shown in figures 4.4 and 4.5. No power generation is assumed to occur within the AES Huntington Beach Generating Station and the Delta-T of the undiluted brine relative to ocean water temperature is assumed to be $\triangle T = 0\ ^0C$. Two different discharge structures were studied: 1) The existing outfall tower (Figure 1.2) presently used by the AES Huntington Beach Generating Station at latitude 33^o 38' 19" N, longitude 117^o 58' 57" W, approximately 1,500 ft (457 m) offshore from the mean lower-low water tide line at a depth of 27.9 ft (8.5 m) below mean sea level; and 2) the Alden 6-Jet Radial Diffuser retrofitted to the existing outfall tower at the same location per Figure 1.3. The Visual Plumes (UM3) and *COSMOS/ FLowWorks* models were run out until the salinity distribution between two adjacent computational steps was less than 1%. At this point dilution was considered to have reached a steady state distribution. Initial dilution was considered to be complete along the loci of points in the receiving water where the dilution factor ceases to change with increasing distance from the point of discharge (gradient of Dm is less than 1%), thereby defining the outer limit of the ZID.

5.1 Initial Dilution Results Using the Existing Discharge Tower. Figure 5.1 shows a shoreline-normal cross section through the modeled salinity field after 1,024 computational time steps for 63.1 ppt brine discharging at 56.7 mgd from the existing AES Huntington Beach outfall tower. Salinity is contoured according to the color bar scale beneath the image, where red contours represent salinity 54 ppt and greater. The discharge plume consists of two primary features: 1) a high-salinity core that forms a narrow column around the outfall tower, and 2) a broad-scale salt wedge spreading outward from the core in which the salinities are weakly hyper-saline. The core is formed by the initial discharge jet momentum fluxing upward from the top of the outfall tower. The core has two distinct dynamical zones: an inner core comprised of an axi-symmetric turbulent jet whose momentum is directed vertically upward, and an outer core comprised of a collapsing subsidence zone around the inner core. The maximum salinity in the center of jet is 62 ppt immediately above the outfall tower, but the turbulence of the jet quickly dilutes salinities in the inner core to about 50 ppt, with sufficient residual momentum to pierce the trapping layer at 3 m depth and subsequently broach the sea surface, creating a "surface boil" of hyper-saline water. In the outer core that surrounds the ascending inner core, there is insufficient upward jet momentum to support the weight of the partially diluted brine, and the outer core collapses and subsides to the seabed, forming a salt wedge that spreads outward across the seabed. Subsidence of the heavy brine in the outer core induces transport of the surrounding water mass, causing dilution to about 40 ppt before reaching the seafloor; where the subsiding brine forms a bottom spreading layer that flows outward and downslope as a gravity driven salt wedge that follows the bottom gradients. The momentum flux of the velocity field in the inner core also has a shoreward directed component, causing some dispersion of the discharge plume shoreward. However, the shoreward directed momentum flux is quickly balanced by the downslope component of gravity once the outer core subsides to the seabed, and further shoreward dispersion ceases, (cf. left hand side of Figure 5.1). The radius of the inner core varies between 40 and 50 meters (measured from the center of the outfall), while the outer core extends outward to a maximum distance of 100 meters before morphing into a bottom spreading layer. Salinities in the spreading layer and salt wedge nominally range from about 2 ppt above ambient to only 0.1 ppt above ambient. The salt wedge spreading layer is highly asymmetric, extending at least 700 meters offshore of the outfall, but only about 150 m upslope in the shoreward direction.

Figure 5.2 gives the bottom salinity distribution for the 56.7 mgd of brine discharge at 63.1 ppt after 1,024 computational time steps using the existing AES HBGS discharge tower for the Huntington Beach Desalination Facility. The brine discharge is modeled assuming brine discharges with a $\triangle T = 0\ ^0C$ into quiescent ocean receiving waters with worst-case month temperature/salinity depth profiles per Figures 4.4 and 4.5. The $\triangle T = 0\ ^0C$ assumption represents worst-case initial dilution because the mass diffusivity of NaCl in water (a proxy for sea salts) increases moderately with increasing

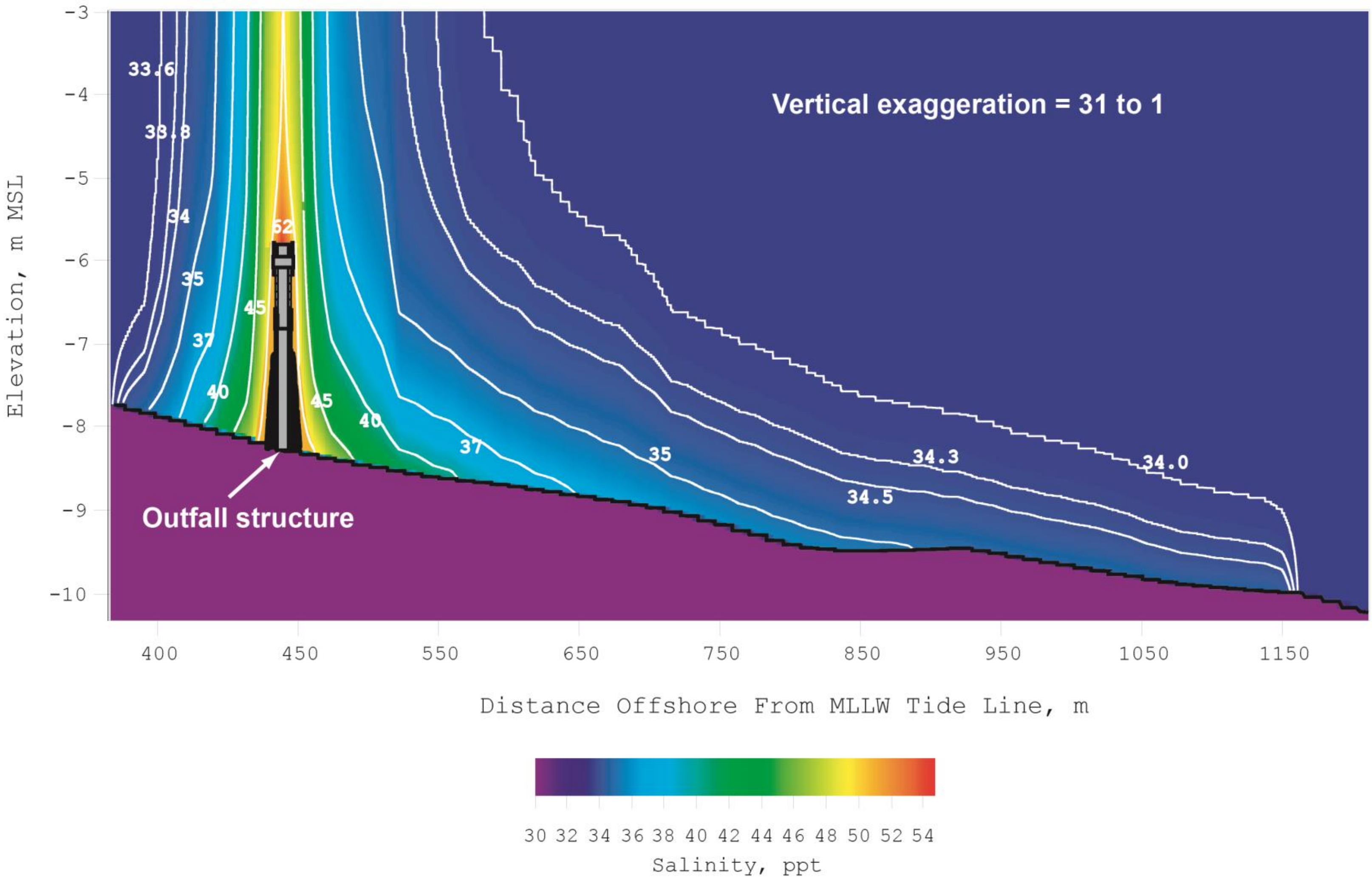


Figure 5.1 Cross section of salinity field due to brine discharges from the existing discharge tower. Brine discharge = 56.7 mgd at 63.1 ppt salinity end-of-pipe with delta-T = 0° C at the AES Huntington Beach outfall.

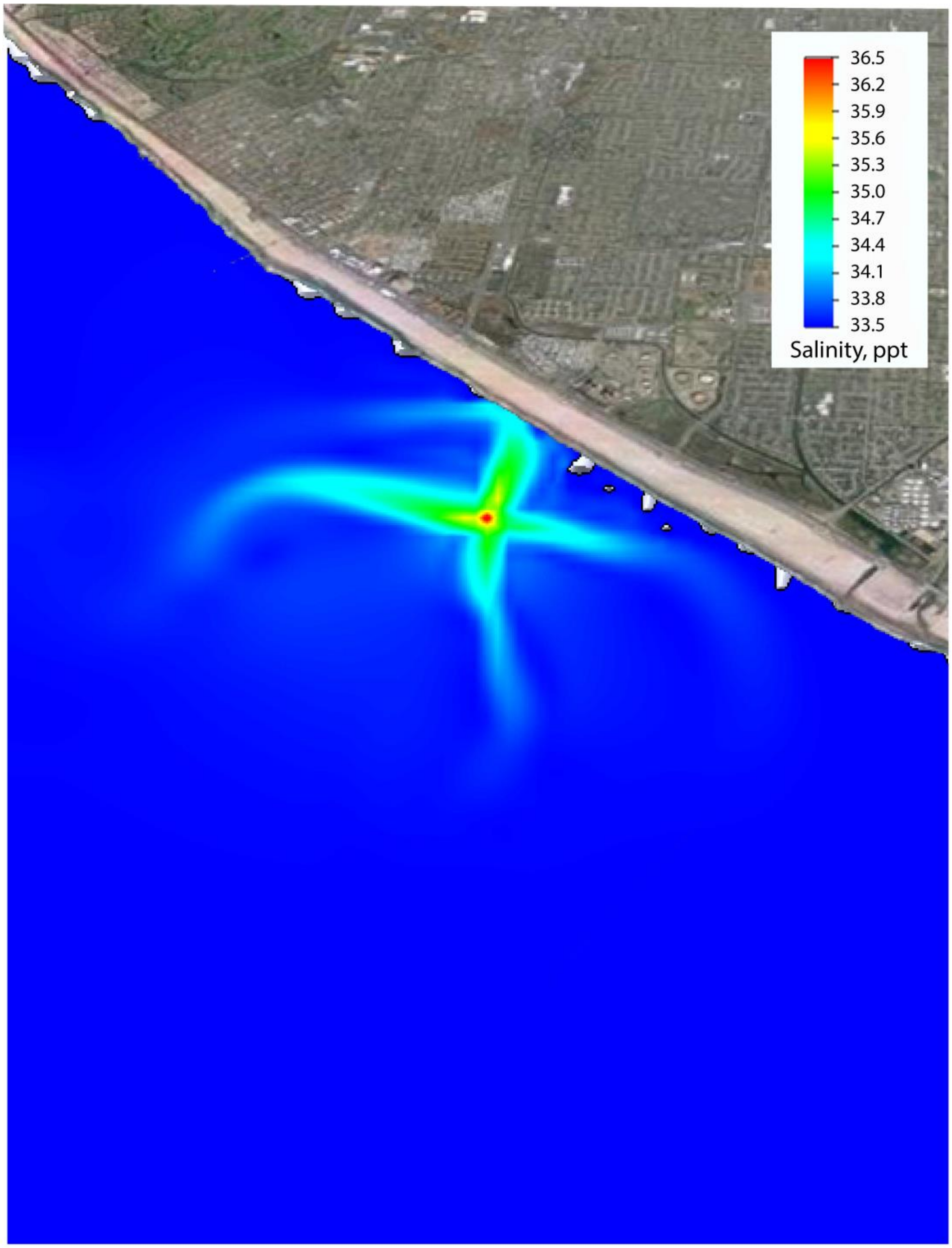


Figure 5.2: Bottom salinity distribution after 1,024 computational steps for the steady state discharge solution of 56.7 mgd of brine at 63.1 ppt from the Huntington Beach Desalination Facility discharging from the existing HBGS discharge tower into a quiescent ocean with a $\Delta T = 0\ ^0C$. Salinity contoured in ppt with ambient ocean salinity = 33.52 ppt.

temperature, and higher ΔT causes higher mixing rates. Because the brine is negatively buoyant (heavier than ambient receiving water), the salinity field has been mapped over the seabed surface to represent worst-case spatial distribution, as contoured in parts per thousand (ppt) according to the color bar scale in the figure. Red contours represent salinity equal to or greater than 36.5 ppt. The ZID radius defined by the maximum dispersion distance of initial dilution of brine (from equations 1 – 5). The unusual feature about Figure 5.2 is that the bottom dispersion of the brine plume from the existing HBGS discharge tower consists of four predominant bottom spreading layers that appear to be roughly in quadrature; but none of them occurring exactly shore parallel or shore normal. This was a persistent feature in all of the time steps as the *COSMOS/ FLowWorks* farfield simulations were run out to the final steady state salinity distribution, i.e., when the salinity distribution between two adjacent computational steps was less than 1% and initial dilution was considered complete. These four distinct bottom spreading layers appear to have resulted from how the ascending inner core rebounded off the sea surface and then broke apart into four discrete subsiding flow streams in the outer core as it descended through the trapping layer at 3 m depth. The residual momentum flux of these subsiding flow streams then spread across the seabed in four different directions, with the predominant spreading layers flowing downslope and offshore as found in Figure 5.1. The light blue hues of the salinity contours in four separate bottom spreading layers of figure 5.2 appear to fade into the dark blue background salinity gradation (corresponding to 33.52 ppt) at variable distances from the point of discharge, Figure 5.2. Where these vanishing points in the spreading layers occur, it is an indication that initial dilution is complete at distances of between 1500 m and 1900 m offshore of the discharge tower and at distances of about 450 m shoreward of the distance tower. At these distances, the change in dilution factor D_m with distance offshore becomes less than 1%.

The outflow of the four bottom spreading layers in Figure 5.2 create a system of transport streams and eddies as shown in Figure 5.3. The transport streams are *return flows* of receiving water that were displaced by the push (*momentum flux*) of the four spreading layers, and transport receiving water into the ZID from offshore and along-shore sources which eventually merge with the discharge stream to produce dilution. Eddies are produced by shear stresses between the discharge stream and the receiving water which transfer momentum of the discharge stream into eddy momentum (*vorticity*), producing *irreversible turbulent mixing*. The dilution action of the transport streams and eddies dilutes the both the waste (brine) as well as the momentum contained in the discharge, until at some point offshore, the discharge becomes neutrally buoyant and the momentum of the residual velocity field is so diluted that turbulent mixing ceases. That point marks the edge of the ZID, and can be inferred from the velocity field as the zone beyond which organized eddy motion ceases. Accordingly, the black dashed ZID contour calculated from equations 1 – 5 circumscribes the large scale eddy systems in Figure 5.3. (It should also be noted that this is the same ZID contour that circumscribes the vanishing points of the spreading layers in Figure 5.2). The large-scale transport flow patterns and eddies shown in the quiescent ocean simulation in Figures 5.3 would never exist in Nature, as these organized flow

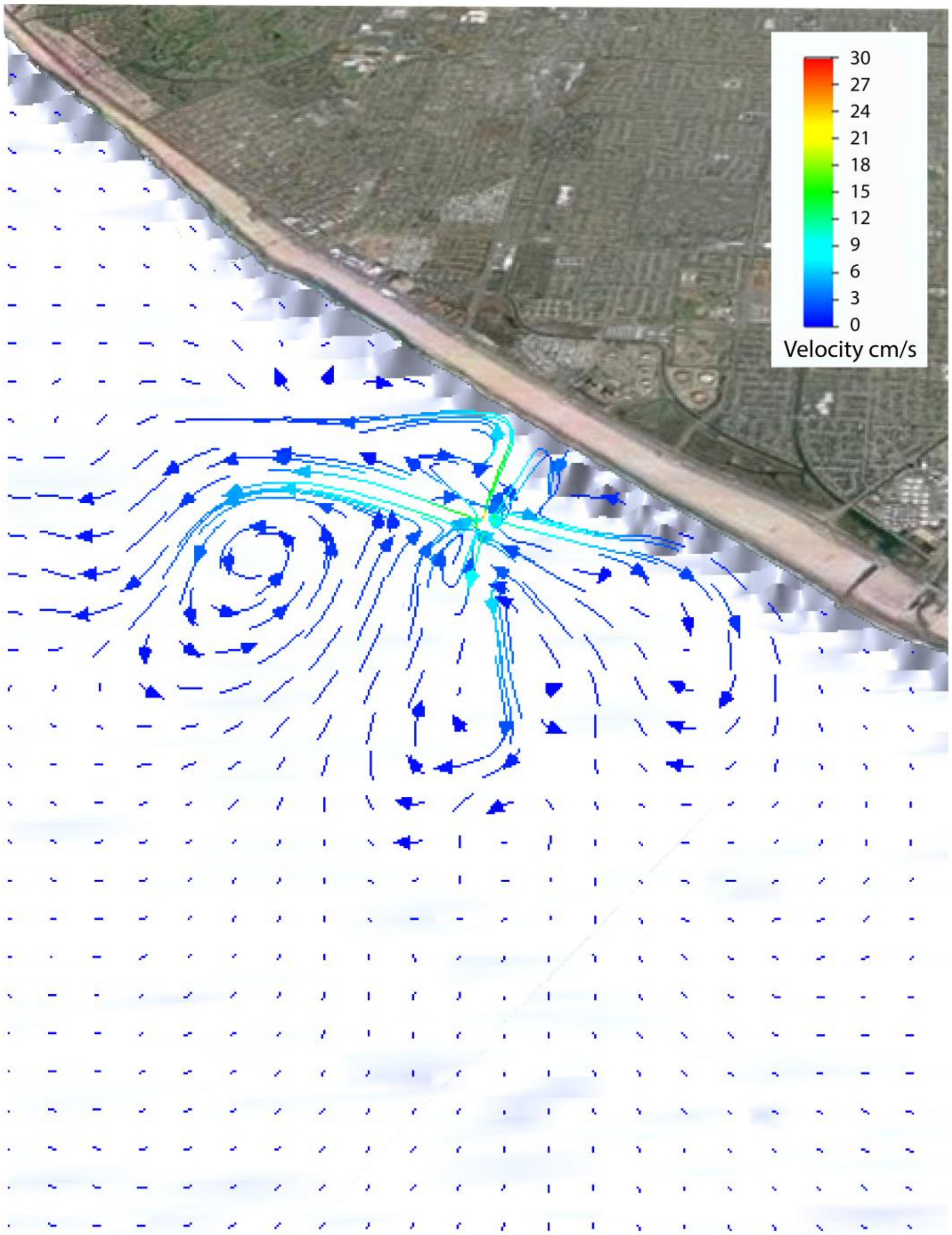


Figure 5.3: Streamline pattern of brine discharge and transport flow after 1,024 computational steps for the steady state discharge solution of 56.7 mgd of brine at 63.1 ppt from the Huntington Beach Desalination Facility discharging from the existing HBGS discharge tower into a quiescent ocean with a $\Delta T = 0\ {}^{0}C$. Velocity scaled in cm/s with quiescent ocean receiving water.

features would be sheared and broken up by shoaling waves and coastal boundary layer currents.

Because the brine discharge from the existing HBGS discharge tower breaks up into four discrete meandering spreading layers that do not follow a particular shoreline normal plane, the Visual Plumes (UM3) and *COSMOS/ FLowWorks* matched solutions of still water dilution were evaluated along a series of radials projected at 1^0 increments outward from the end of the discharge jetties, to find the worst case relationship between dilution and distance. The results are plotted in Figure 5.4 for $\Delta T = 0\ ^0C$; where the discharge salinity maximum is plotted in red according to the right hand axis as a function of distance along worst case radial; and dilution factor, D_m, is plotted in blue against the left hand axis. At the 100 m BMZ boundary, the maxima in discharge salinity is 42.0 ppt, thereby failing to satisfying the brine amendment of the California Ocean Plan, (Appendix-A of SWRCB 2015). The corresponding dilution factor is $D_m = 2.48$ at the 100 m BMZ boundary, where Dm is calculated based on 63.1 parts per thousand (ppt) effluent concentration at end-of-pipe. At the HBDF brine ZID, where brine dilution achieves a steady end state, initial dilution reaches a robust $D_m = 210$ to 1; but the amended Ocean Plan defaults initial dilution to the smaller of Dm at the BMZ vs at the ZID. Therefore, initial dilution of HBDF brine when discharged from the existing HBGS discharge tower is merely Dm = 2.48.

5.2 Initial Dilution Results Using the 6-Jet Radial Diffuser Retrofit. The initial dilution analysis of the Alden designed *6-Jet Radial Diffuser Retrofit* at Huntington Beach Desalination Facility (Figure 1.3) was conducted using *COSMOS/ FLowWorks* and the EPA certified Visual Plumes models. The Alden design employs 6 diffuser ports in a radial arrangement at an elevation of 10.33 ft above the seabed, 4 ports ea. 42 in. diameter, and 2 ea. 30 in. diameter ports.

The 6-jet radial diffuser was designed to be adaptable to two potential future operating regimes. The initial operations of the diffuser retrofit are expected to occur during what will be referred to as the *combined regime,* when the diffuser must provide excess conveyance capacity to accept once-through cooling water discharges from the Huntington Beach Generating Station (HBGS). During this operating regime, all six discharge ports of the radial diffuser will be open. Worst-case dilution during the *combined regime* occurs when the diffuser is receiving only brine effluent from the Huntington Beach Desalination Facility (HBDF) because the HBGS is operating in *stand-by mode* with no thermal discharges conveyed to the diffuser. In this case the 56.7 mgd of a brine at salinity of 63.1 ppt from the HBDF will be divided among the 6 discharge ports, producing densimetric Froude numbers ranging from $F_r = u/\sqrt{\Delta\rho g D/\rho}$ =1.1 to 1.3, while the jet velocities will average only u =1.79 ft/s (0.54 m/s), Figure 5.6. Once the HBGS has abandoned its once-through cooling operations, the 4 ports that are 42 in. diameter will be capped and the diffuser will operate in a *stand-alone* regime using only the two seaward facing 30 in. diameter ports. In the stand-alone regime the diffuser will produce maximum jet velocities of 10.0 ft/sec (3 m/s), Figure 5.7, with a densimetric Froude number $F_r = u/\sqrt{\Delta\rho g D/\rho}$ = 7.26.

The height of the diffuser will not exceed the height of the existing outfall tower. To remain within the height parameters of the existing outfall tower, the height of the

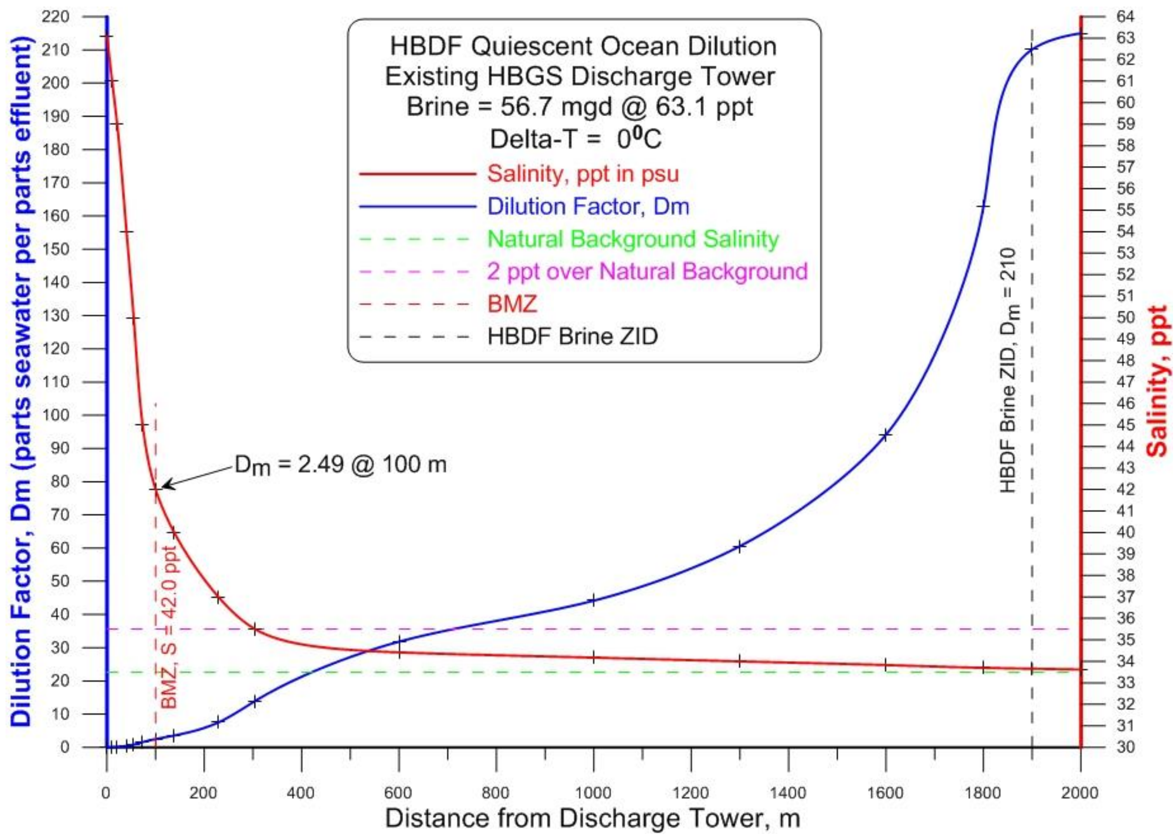


Figure 5.4: Visual Plumes (UM3) and *COSMOS/ FLowWorks* matched solution of still water dilution of HBDF brine discharge = 56.7 mgd at 63.1 ppt, with $\triangle T = 0\ ^0C$. Discharge salinity maximum (red, right hand axis) as a function of distance along worst case radial from end of discharge jetties. Dilution factor, Dm, (blue, left hand axis) as a function of distance along worst case radial from HBGS discharge tower. Dm based on 63.1 parts per thousand (ppt) effluent concentration at end-of-pipe.

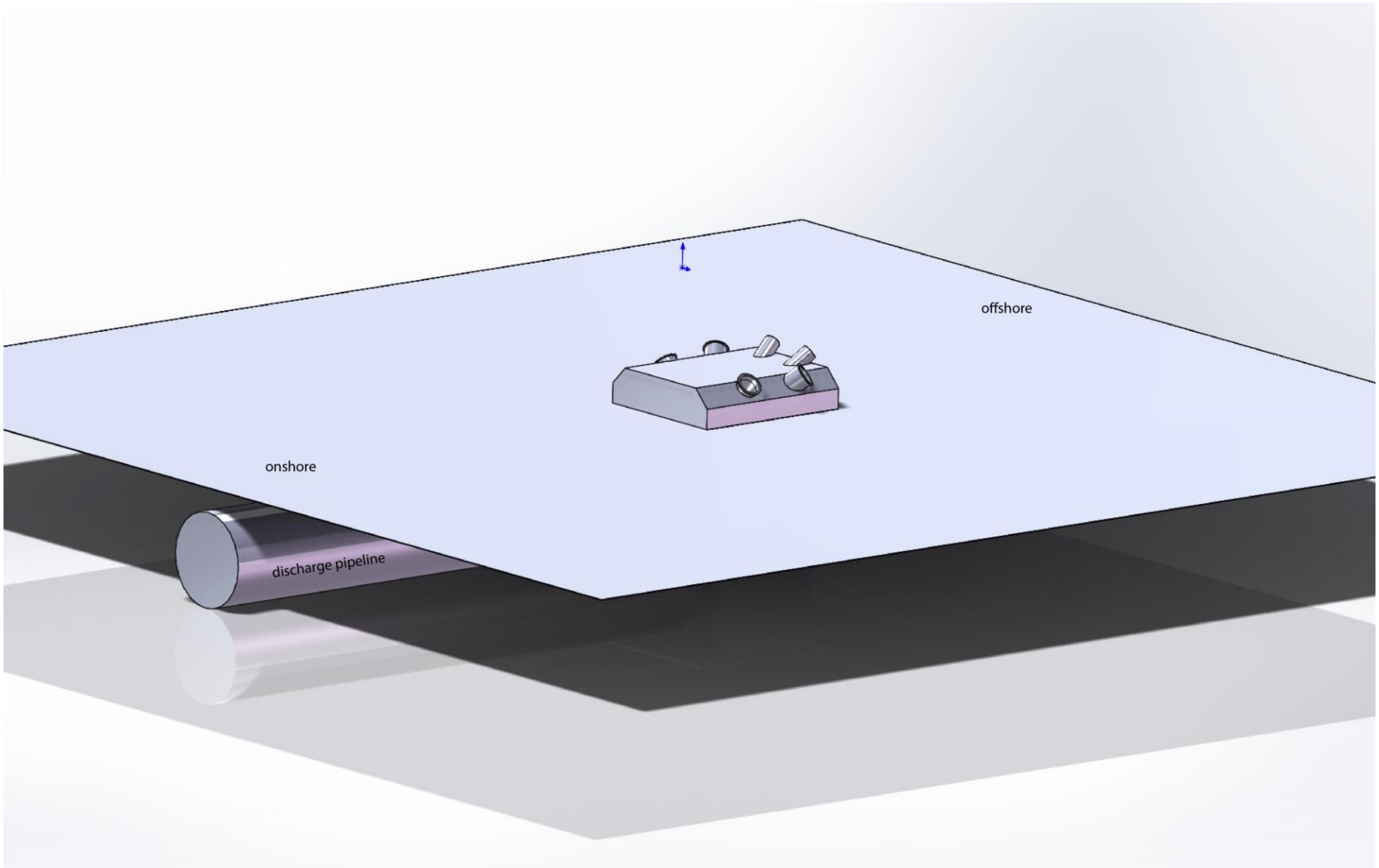


Figure 5.5: Three-dimensional CAD of the Alden designed *6-Jet Radial Diffuser Retrofit* at the discharge tower site located at latitude 33° 38' 19" N, longitude 117° 58' 57" W, approximately 1,500 ft (457 m) offshore from the mean lower-low water tide line at a depth of 27.9 ft (8.5 m) below mean sea level.

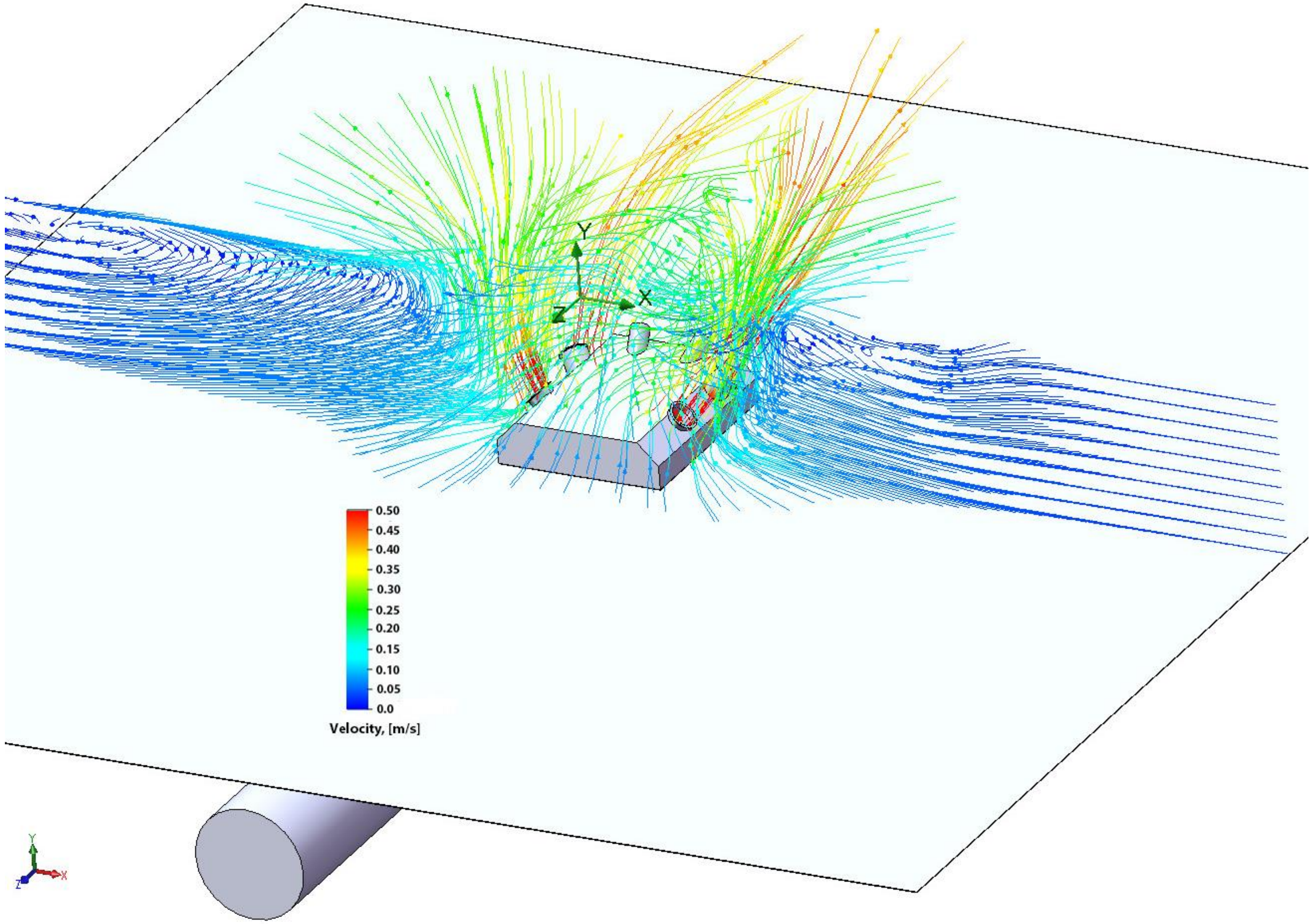


Figure 5.6: Matched Visual Plumes (UM3) and *COSMOS/ FLowWorks* solutions of the nearfield discharge and transport streams from the HBDF radial diffuser operating in the *worst-case combined regime* using 4 ports ea. 42 in. diameter, and 2 ea. 30 in. diameter ports. Brine discharge = 56.7 mgd at 63.1 ppt, with ΔT = 0 ^{0}C. Densimetric Froude number $F_r = u/\sqrt{\Delta\rho g D/\rho}$ =1.1 for the four 42 in. diameter jets and $F_r = u/\sqrt{\Delta\rho g D/\rho}$ = 1.3 for the two 30 in. diameter jets

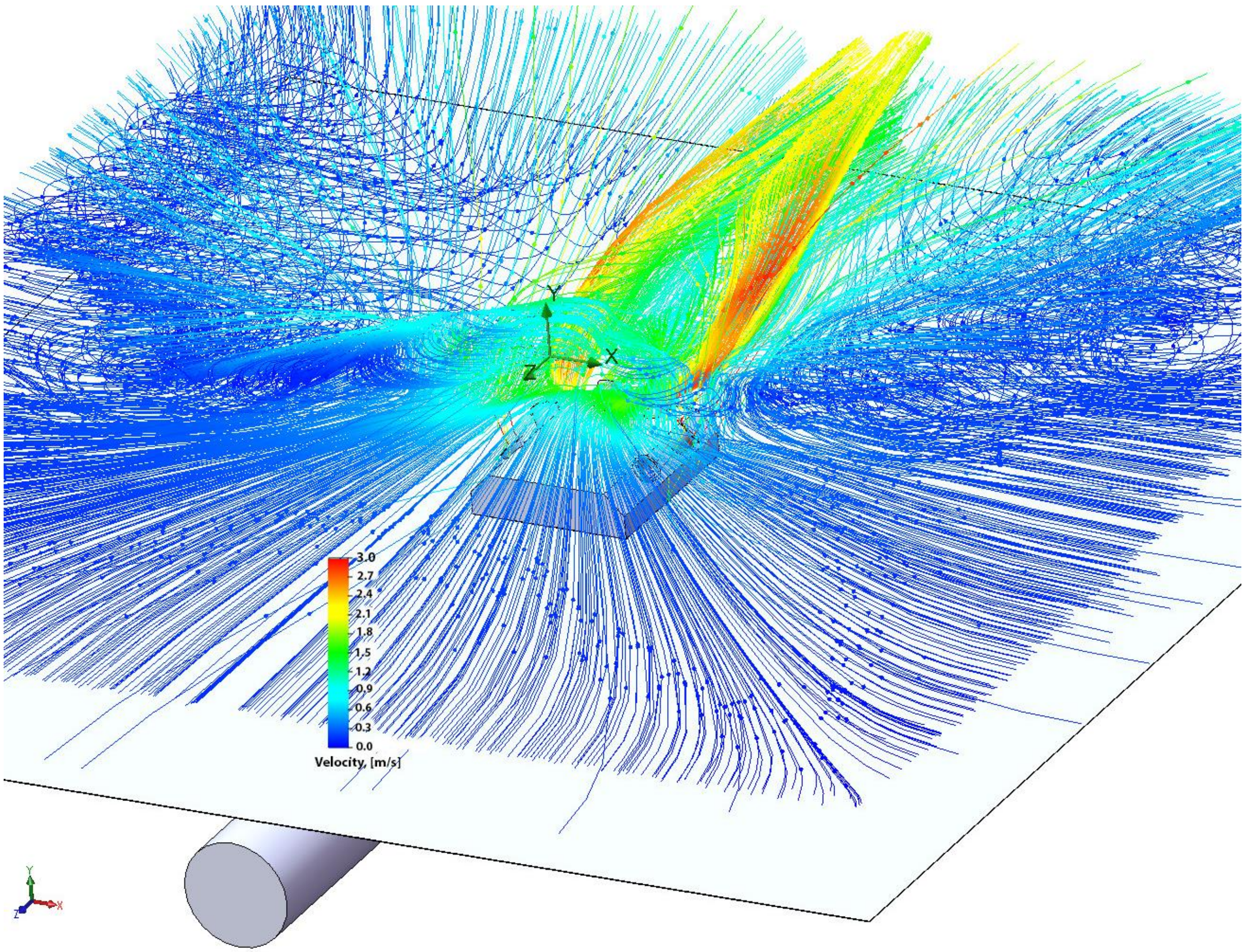


Figure 5.7: Matched Visual Plumes (UM3) and *COSMOS/ FLowWorks* solutions of the discharge and transport streams from the HBDF radial diffuser operating in the *stand-alone* regime using only the two seaward facing 30 in. diameter ports. Brine discharge = 56.7 mgd at 63.1 ppt, with $\Delta T = 0\ ^0C$. Densimetric Froude number $F_r = u \big/ \sqrt{\Delta \rho g D / \rho} = 7.26$.

diffuser will be 10.33 ft above seabed, requiring that 6.85 ft. of the existing tower will be removed. The diffuser will be placed on top of the shortened outfall tower and is oriented with the four 42 in. ports oriented along shore and the two 30 in. ports facing off shore (Figure 5.5). This orientation minimizes transport of the brine plume by the shoaling wave-induced longshore current which otherwise might cause excessive plume spreading into the down-current south side of the inshore quadrant. In addition, all diffuser jets are inclined to 47 degrees to allow for maximum apex in brine trajectory but is just sufficient to prevent a surface boil effect on the surface (Figures 5.6 & 5.7).

The EPA certified Visual Plumes (UM3) model was used to determine compliance with discharge limits set under the newly amended California Ocean Plan which requires that brine discharge salinity declines to within 2 ppt over natural background salinity within a brine mixing zone (BMZ) measuring 100 m from the point of discharge, (SWRCB, 2015). Natural background at Huntington Beach is 33.52 ppt. The Visual Plumes dilution results are shown in Figure 5.8 for the Alden radial diffuser operating in the *worst-case combined regime* using 4 ports ea. 42 in. diameter, and 2 ea. 30 in. diameter ports per Figure 5.7. The solutions in Figure 5.8 are based on quiescent ocean conditions with worst month temperature/salinity profiles in the water column per Figures 4.4 and 4.5. In Figure 5.8, the red salinity distribution curve intersects 2ppt over natural background (35.52 ppt) at 98 m from the point of discharge (intersection of the two black dashed lines). The new Ocean Plan brine discharge limits require this condition is met within 100 m from the point of discharge. Thus, we conclude that the 6-port radial diffuser is fully compliant with the new Ocean Plan brine discharge limits in all quadrants around the HBDF discharge site. The dilution factor at the edge of the BMZ at 98 m from the discharge is Dm = 13.9, and reaches a Dm = 14 at 100 m from the point of discharge. At 250 m from the point of discharge Dm = 60.6, but is still increasing rapidly with increasing distance at 250 m from the point of discharge indicating that initial dilution is not yet complete.

When the HBDF is operated under quiescent ocean conditions in *stand-alone* configuration, with the 4 ea. 42 in. jet ports capped off, the Visual Plumes dilution model shows in Figure 5.9 that dilution performance is excellent, achieving compliance with the new Ocean Plan discharge limit (achieving 2 ppt above natural background) within 29.4 m. from the point of discharge, where the two black dashed lines intersect and the dilution factor Dm = 13.9. Dilution factor at 100 m from the point of discharge reaches Dm = 36.9 when operating in the 2-jet *stand-alone* configurations; but the Dm curve in Figure 5.9 is still changing rapidly with increasing distance at 100 m from the point of discharge, indicating that initial dilution is not yet complete.

To establish when initial dilution is completed the matched Visual Plumes -*COSMOS/ FLowWorks* models were run out 1024 time steps whence the salinity distribution between two adjacent computational steps became less than 1%. At this point dilution was considered to have reached a steady state distribution. Initial dilution was considered to be complete along the loci of points in the receiving water where the dilution factor ceases to change with increasing distance from the point of discharge (gradient of Dm is less than 1%), thereby defining the outer limit of the ZID. Figure 5.10 gives the bottom salinity distribution for brine discharge from the Huntington Beach Desalination Facility after 1,024 computational time steps using the Alden designed 6-jet radial diffuser in the *worst-case combined regime* operating regime, (with 56.7 mgd of brine discharging at 63.1 ppt through the four 42 in. diameter ports and two 30 in. diameter ports). The brine discharge is modeled assuming brine discharges with a $\Delta T = 0\ ^0C$ into quiescent ocean receiving waters with worst-case month temperature/salinity depth profiles per Figures 4.4 and 4.5. (The $\Delta T = 0\ ^0C$ assumption represents worst-case initial dilution because the

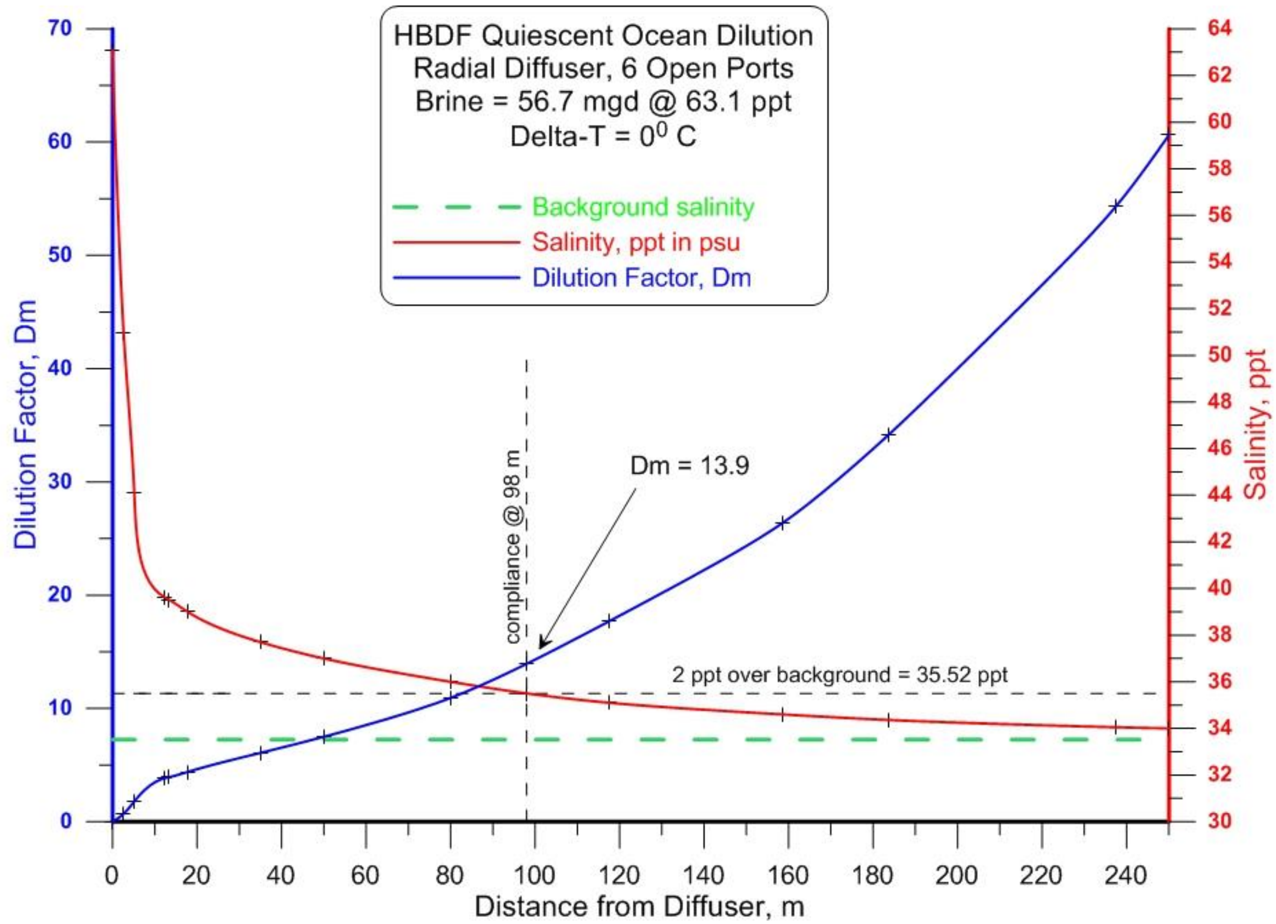


Figure 5.8: Visual Plumes (UM3) simulation of dilution of brine discharged from the Alden 6-jet radial diffuser with 47^0 jet inclination angles. Discharge salinity on the seabed (red per right hand axis) as a function of radial distance averaged over 6 jets. Dilution factor on the seabed (blue per left hand axis) as a function of radial distance averaged over 6 jets. Total discharge = 56.7 mgd of brine at 63.1 ppt end-of-pipe. Densimetric Froude number, Fr =1.10 for 4 ea. 42 in. diameter jets; Fr =1.30 for 2 ea. 30 in. diameter jets.

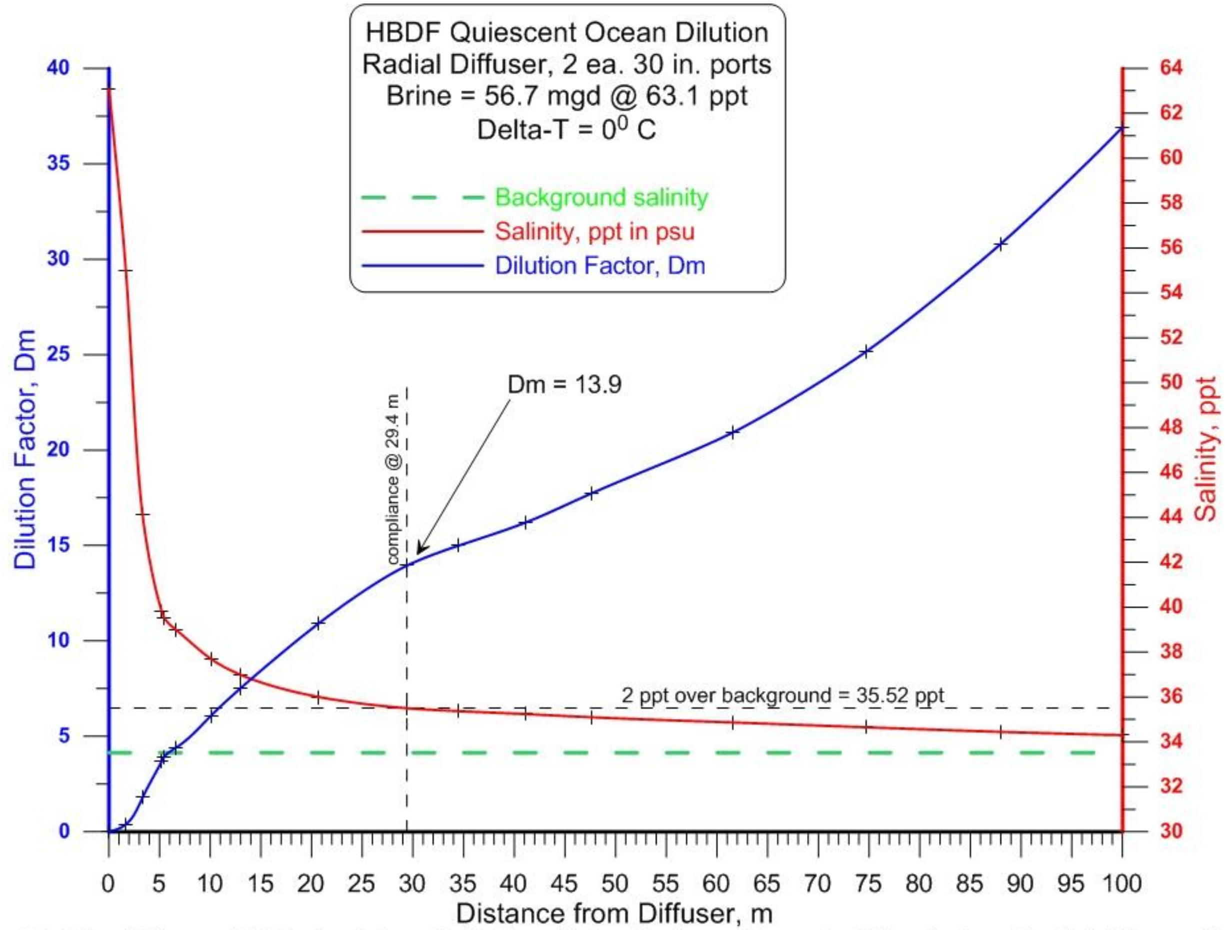


Figure 5.9: Visual Plumes (UM3) simulation of dilution of brine discharged from the Alden designed radial diffuser with 47^0 jet inclination angles. Discharge salinity on the seabed (red per right hand axis) as a function of radial distance averaged over 2 jets. Dilution factor on the seabed (blue per left hand axis) as a function of radial distance averaged over 6 jets. Total discharge = 56.7 mgd of brine at 63.1 ppt end-of-pipe. Densimetric Froude Number Fr =7.26 for 2 ea. 30 in. diameter jets. (Note 4 ea. 42 in. jet ports are capped.)

Figure 5.10: Bottom salinity distribution after 1,024 computational steps for the steady state discharge solution of brine from the Huntington Beach Desalination Facility, discharging from the Alden designed 6-jet radial diffuser. The diffuser is configured for the *worst-case combined* operating regime, with 56.7 mgd of brine discharging at 63.1 ppt through the four 42 in. diameter ports and two 30 in. diameter ports into a quiescent ocean with a $\Delta T = 0\ ^0C$. Salinity contoured in ppt with ambient ocean salinity = 33.52 ppt

mass diffusivity of NaCl in water (a proxy for sea salts) increases moderately with increasing temperature, and higher ΔT causes higher mixing rates. Because the brine is negatively buoyant (heavier than ambient receiving water), the salinity field has been mapped over the seabed surface to represent worst-case spatial distribution, as contoured in parts per thousand (ppt) according to the color bar scale in the figure. Red contours represent salinity equal to or greater than 38.5 ppt. Because the brine is negatively buoyant (heavier than ambient receiving water), the salinity field has been mapped over the seabed surface to represent worst-case distribution, as contoured in parts per thousand (ppt) according to the color bar scale at the figure. There is an apparent offshore bias to the spreading of the salinity plume due to the unrestricted tendency for the denser brine to move down-slope as a gravity flow in these still water simulations following the offshore sloping bottom gradients (see Figures 1.1 & 4.1). The brine is free to move down-slope in still water, propelling itself as a gravity flow by exchanging potential energy in elevation for kinetic energy. As the brine continues down-slope it entrains a portion of the surrounding water mass, diluting itself until its density is reduced to that of the surrounding water mass, when $\rho_s \rightarrow \rho$ (cf. equation 2). This occurs when the brine plume travels far enough down-slope to run into colder bottom water (Figure 4.4).

Comparing the offshore plume meanders in Figure 5.10 with the digital bathymetry contours in Figure 1.1, it appears as though the dense brine plume is following bottom depressions in the micro-bathymetry. These bottom depressions are approximately in shoreline-normal alignment, slightly skewed towards the west-northwest, causing the brine plume to bend in that general direction as it follows the local bottom gradients. This is in direct contrast to the general behavior of the brine plumes modeled in the antecedent study (Appendix-K of SEIR, 2010), where the brine plumes consistently exhibit a southerly displacement due a prevailing southerly drift from tidal currents and wave-induced longshore currents. (It should be remembered that the bathymetric depressions and troughs in Figure 1.1 that control the brine plume trajectory under quiescent ocean conditions are themselves ephemeral, dynamic features that could change seasonally or over longer time periods). The large-scale transport flow patterns and eddies shown in the quiescent ocean simulation would never exist in Nature, as these organized flow features would be sheared and broken up by shoaling waves and coastal boundary layer currents.

In Figure 5.10, the brine plume becomes stationary at distance of 3,331 m seaward of the diffuser. Here, the light blue contours of the remnants of the brine plume fade into the dark blue background salinity of the receiving water. At this *vanishing point*, the change in dilution factor D_m with distance offshore becomes less than 1%. The Ocean Plan defines the ZID as the zone in which the process of initial dilution is completed; and since dilution ceases to increase beyond 3,331 m from the point of discharge, this distance marks the seaward limit of the ZID where the dilution factor reaches Dm = 236 for the 6-jet radial diffuser operating in the *worst-case combined regime* operating regime, and Dm = 257 for the radial diffuser operating in the *stand-alone regime* with only two 30 in. jets.

In the Ocean Plan the concept of when initial dilution is complete is also associated with when the momentum induced velocity of the discharge ceases to produce significant mixing of the waste. The heavy brine effluent initially has two components of momentum: 1) momentum in the velocity field (as expressed by the first term on the right hand side of equation-2); and 2) momentum in the force field (*impulsive momentum* as expressed by the second term on the right hand side of equation-2); where the force field comes from gravity as a consequence of the negative buoyancy of the brine. As the brine begins to flow offshore and down the slopes of the nearshore bathymetry, momentum in the gravitational force field flows (*fluxes*) into the velocity field, and the brine accelerates under the force of gravity due to its negative buoyancy. Some of the gravitational acceleration is transferred to stresses of bottom friction, (the friction coefficient in equation-2), but the remaining momentum of the discharge stream is restructured as a system of transport streams and eddies, all of which derive their momentum and velocity from the initial discharge stream. The transport streams are *return flows* of receiving water that were displaced by the offshore-directed push (*momentum flux*) of the discharge stream, and transport receiving water into the ZID from offshore and along-shore sources which eventually merge with the discharge stream to produce dilution. Eddies are produced by shear stresses between the discharge stream and the receiving water which transfer momentum of the discharge stream into eddy momentum (*vorticity*), producing *irreversible turbulent mixing*. The dilution action of the transport streams and eddies dilutes the both the waste (brine) as well as the momentum contained in the discharge, until at some point offshore, the discharge becomes neutrally buoyant and the momentum of the residual velocity field is so diluted that turbulent mixing ceases. That point marks the edge of the ZID, and can be inferred from the velocity field as the zone beyond which organized eddy motion ceases.

Obviously the ZID for brine discharge is considerably larger than the historic 1000 ft radius ZID that the AES Huntington Beach Generating Station (HBGS) has operated under with prior NPDES permits. However, first it must be noted that thermal effluent from HBGS is buoyant and disperses over a flat ocean surface which produces no slope along which the gravitational force field can accelerate the discharge stream. Second, the HBGS is discharging heat not sea salts, and the thermal diffusivity (ε_T = 0.196 cm^2/sec) is 4 orders of magnitude greater than that of salt (NaCl) in water, (ε_S = 1.11 X 10^{-5} cm^2/sec). Hence the salts in the brine diffuse 10,000 times slower than the heat content of the heated, contributing to a larger ZID for brine than for heat effluent. For the same reason, there is little difference in the brine plumes between the *worst-case combined regime* and the *stand-alone regime*; and only minor differences in the eddy structures near the ZID boundary; although Dm = 236 when the diffuser is operating in the *worst-case combined regime* operating regime, and Dm = 257 when operating in the *stand-alone regime* with only two 30 in. jets. None the less, the amended Ocean Plan defaults initial dilution to the smaller of Dm at the BMZ vs at the ZID. Therefore, initial dilution of HBDF brine when discharged from the Alden design 6-jet radial diffuser is merely Dm = 13.9.

6) Conclusions:

The amended California Ocean Plan defines a new water quality objective for salinity of dense brine discharges as follows: "*Discharges shall not exceed a daily maximum of 2.0 ppt above natural background salinity to be measured as total dissolved solids (mg/L) measured no further than 100 meters (328 feet) horizontally from the discharge. There is no vertical limit to this zone*" (SWRCB, 2015).

A set of coupled high resolution dilution models were constructed and run to determine compliance with this new water quality objective and to establish initial dilution values for discharges of concentrated seawater and trace pollutants at the boundaries of the zone of initial dilution (ZID) under stand-alone operations of the Huntington Beach Desalination Facility (HBDF). Peer reviewed, published and USEPA certified hydrodynamic models were employed to resolve initial dilution and discharge plume trajectories under standard NPDES dilution modeling protocols (as defined in the California Ocean Plan); according to which "*Initial Dilution will be considered the process which results in the rapid and irreversible turbulent mixing of wastewater with ocean water around the point of discharge".* As such the models do not consider any additional mixing due to the action of ocean currents, waves, tides or wind. The models were initialized for quiescent ocean receiving waters at mean sea level bounded by the existing bathymetry surrounding the offshore discharge site for the Huntington Beach Desalination Facility.

The modeled HBDF desalination operating scenario was based on 56.7 mgd of concentrated seawater (brine) at a salinity of 63.1 ppt being discharged into quiescent ocean receiving waters having a natural background salinity of 33.52 ppt and worst-case month temperature salinity profiles obtained from the extensive KOMEX (2003) monitoring of the AES Huntington Beach intake and outfall, performed for the California Energy Commission. No power generation is assumed to occur within the AES Huntington Beach Generating Station and the delta-T of the undiluted brine relative to ocean water temperature is assumed to be $\Delta T = 0\ ^{0}C$. Two different discharge structures were studied: 1) The existing outfall tower presently used by the AES Huntington Beach Generating Station (HBGS) at latitude 33º 38' 19" N, longitude 117º 58' 57" W, approximately 1,500 ft (457 m) offshore from the mean lower-low water tide line at a depth of 27.9 ft (8.5 m) below mean sea level; and 2) the Alden designed 6-Jet Radial Diffuser retrofitted to the existing outfall tower at the same location. The 6-jet radial diffuser was designed to be adaptable to two potential future operating regimes, both of which were evaluated by the initial dilution models. The operations of the diffuser retrofit are expected to initially occur during what will be referred to as the *combined regime*, when the diffuser must provide excess conveyance capacity to accept once-through cooling water discharges from the Huntington Beach Generating Station (HBGS). During this operating regime, all six discharge ports of the radial diffuser will be open. Worst-case dilution during the *combined regime* occurs when the diffuser is receiving only brine effluent from the Huntington Beach Desalination Facility (HBDF) because the HBGS is operating in *stand-by mode* with no thermal discharges conveyed to the diffuser. Once the HBGS has abandoned its once-through cooling operations, the four diffuser ports that are 42 in. diameter will be capped and the diffuser will operate in a *stand-alone* regime using only the two seaward facing 30 in. diameter ports.

The Visual Plumes (UM3) and *COSMOS/ FLowWorks* matched solutions of brine discharge from the existing HBGS discharge tower find that the brine discharge plume breaks up into four discrete meandering spreading layers that do not follow a particular shoreline normal or shore-parallel plane. At the 100 m BMZ boundary, the maxima in discharge salinity was found to be 42.0 ppt, thereby failing to satisfying the brine amendment of the California Ocean Plan, (Appendix-A of SWRCB 2015). The corresponding dilution factor is $D_m = 2.48$ at the 100 m BMZ boundary, where Dm is calculated based on 63.1 parts per thousand (ppt) effluent concentration at end-of-pipe. At the HBDF brine ZID, 1,900 m from the point where brine dilution achieves a steady end state, initial dilution reaches a robust D_m = 210; but the amended Ocean Plan defaults initial dilution to the smaller of Dm at the BMZ vs at the ZID. Therefore, initial dilution of HBDF brine when discharged from the existing HBGS discharge tower is merely Dm = 2.48.

The Visual Plumes nearfield dilution results for the Alden radial diffuser operating in the *worst-case combined regime* find that the 6-port radial diffuser dilutes the brine to within 2ppt of natural background at 98 m from the point of discharge, and is fully compliant with the new Ocean Plan brine discharge limits in all quadrants around the HBDF discharge site. The dilution factor at the edge of the BMZ at 98 m from the discharge is Dm = 13.9, and reaches a Dm = 14 at 100 m from the point of discharge. At 250 m from the point of discharge Dm = 60.6, but is still increasing rapidly with increasing distance, indicating that initial dilution is not yet complete.

When the HBDF is operated under quiescent ocean conditions in *stand-alone* configuration, with the 4 ea. 42 in. jet ports capped off, the Visual Plumes dilution model finds that dilution performance is excellent, achieving compliance with the new Ocean Plan discharge limit (2 ppt above natural background) within 29.4 m. from the point of discharge, where again the dilution factor Dm = 13.9. Dilution factor at 100 m from the point of discharge reaches Dm = 36.9 when operating in the 2-jet *stand-alone* configurations; but the Dm is still changing rapidly with increasing distance at 100 m from the point of discharge, indicating that initial dilution is not yet complete.

To establish when initial dilution is completed, the matched Visual Plumes - *COSMOS/ FLowWorks* models were run out to 1,024 computational iterations whence the salinity distribution between two adjacent computational steps became less than 1%. At this point, dilution was considered to have reached a steady state distribution. The brine plume becomes stationary at distance of 3,331 m seaward of the diffuser, marking the seaward limit of the ZID where the dilution factor reaches Dm = 236 for the 6-jet radial diffuser operating in the *worst-case combined regime* regime, and Dm = 257 for the radial diffuser operating in the *stand-alone regime* with only two 30 in. jets. None the less, the amended Ocean Plan defaults initial dilution to the smaller of Dm at the BMZ vs at the ZID. Therefore, initial dilution of HBDF brine when discharged from the Alden design 6-jet radial diffuser is merely Dm = 13.9.

Thermal effluent from HBGS is positively buoyant and disperses over a flat ocean surface which produces no slope along which the gravitational force field can accelerate the discharge stream. In contrast, the brine is heavier than sea water (negatively buoyant) and spreads across the sloping seabed. The Ocean Plan concept of when initial dilution is complete is associated with when the momentum induced velocity of the discharge ceases to produce significant mixing of the waste. The heavy brine effluent initially has two components of momentum: 1) momentum in the velocity field (products of mass and velocity); and 2) momentum in the force field (products of force acting over time, referred to as *impulsive momentum*); where the force field comes from gravity as a consequence of the negative buoyancy of the brine. As the brine begins to flow offshore and down the slopes of the nearshore bathymetry, momentum in the gravitational force field flows (*fluxes*) into the velocity field, and the brine accelerates under the force of gravity due to its negative buoyancy. Some of the gravitational acceleration is transferred to stresses of bottom friction, but the remaining momentum of the discharge stream is restructured as a system of transport streams and eddies, all of which derive their momentum and velocity from the initial discharge stream. The transport streams are *return flows* of receiving water that were displaced by the offshore-directed push (*momentum flux*) of the discharge stream, and transport receiving water into the ZID from offshore and along-shore sources which eventually merge with the discharge stream to produce dilution. Eddies are produced by shear stresses between the discharge stream and the receiving water which transfer momentum from the discharge stream into eddy momentum (*vorticity*), producing *irreversible turbulent mixing*. The dilution action of the transport streams and eddies dilutes the both the waste (brine) as well as the momentum contained in the discharge, until at some point offshore, the discharge becomes neutrally buoyant and the momentum of the residual velocity field is so diluted that turbulent mixing ceases. That point marks the edge of the ZID, and can be inferred from the velocity field as the zone beyond which organized eddy motion ceases. In the case of the down-slope gravity propelled brine plumes, large-scale transport flow patterns and eddies develop in the quiescent ocean simulation that would never exist in Nature, as these organized flow features would be sheared and broken up by shoaling waves and coastal boundary layer currents.

7) References:

Batchelor, G. K., 1970, *An Introduction to Fluid Mechanics,* Cambridge Univ. Press, New York., 615 pp.

Baumgartner, D. J.,, W.E. Frick, and P.J.W. Roberts, 1994, “EPA Dilution Models for Effluent Discharges”, Third Addition, U.S. Environmental Protection Agency, Standards and Applied Science Division Office of Science and Technology, 199 pp.58.

Bograd, S. , Chereskin, T., and D. Roemmich, 2001, “Transport of mass, heat, salt and nutrients in the southern California current system”, *Journal of Geophysical Research,* vol 106, no C5, pp

CalCOFI, 2014, “California Cooperative Oceanic Fisheries Investigation”, Southern California Coastal Ocean Observation System, SCOOS Data: http://www.calcofi.org/data/sccoos/sccoos-data.html

CDIP (2012), "Coastal data information program," *SIO Reference Series*, 01-20 and http://cdip.ucsd.edu.

Inman, D. L., M. H. S. Elwany & S. A. Jenkins, 1993, “Shoreline and bar-berm profiles on ocean beaches,” *Jour. Geophys. Res.,* v. 98, n. C10, p. 18,181–18,199.

Jenkins, S. A. , Aijaz, S., and J. Wasyl, 1992, “Transport of fine sediments by hydrostatic jets”,*Nearshore and Estuarine Cohesive Sediment Transport,* American Geophysical Union, v. 42, 1992, p. 331–347.

Jenkins, S. A. and J. Wasyl, 2005, “Hydrodynamic Modeling of Dispersion and Dilution of Concentrated Seawater Produced by the Ocean Desalination Project at the Encina Power Plant, Carlsbad, CA, Part II: Saline Anomalies due to Theoretical Extreme Case Hydraulic Scenarios*,”* submitted to Poseidon Resources, 97pp.

Jenkins, S. A. and J. Wasyl, 2005, “Coastal evolution model,” Scripps Institution of Oceanography Tech Report No. 58, 179 pp + appendices. http://repositories.cdlib.org/sio/techreport/58/

Jenkins, S. A. and D. L. Inman, 2006, “Thermodynamic solutions for equilibrium beach profiles”, *Jour. Geophys. Res.,* v.3, C02003, doi:10.1029/2005JC002899, 2006. 21pp

Jenkins, S. A., J. Paduan, P. Roberts, D. Schlenk, and J. Weis, 2012, “Management of Brine Discharges to Coastal Waters; Recommendations of a Science Advisory Panel”, submitted at the request of the California Water Resources Control Board, 56 pp. + App.

KOMEX, 2003, "AES Huntington Beach Generating Station surf zone water quality study", draft report submitted to California Energy Commission, August 4, 2003, 268 pp + app

MBC Applied Environmental Sciences. 1982. National Pollutant Discharge Elimination System receiving water monitoring program, Huntington Beach Generating Station. Prepared for Southern California Edison Company, Rosemead, CA. 82-RD-130. 34 p. plus appendices.

MBC Applied Environmental Sciences. 1983. National Pollutant Discharge Elimination System receiving water monitoring program, Huntington Beach Generating Station. Prepared for Southern California Edison Company, Rosemead, CA. 83-RD-145. 37 p. plus appendices.

MBC Applied Environmental Sciences. 1984. National Pollutant Discharge Elimination System receiving water monitoring program, Huntington Beach Generating Station. Summer 1984 survey. Prepared for Southern California Edison Company, Rosemead, CA. 84-RD-135. 50 p. plus appendices.

MBC Applied Environmental Sciences. 1985. National Pollutant Discharge Elimination System receiving water monitoring program, Huntington Beach Generating Station. Summer 1985 survey. Prepared for Southern California Edison Company, Rosemead, CA. 85-RD-99. 33 p. plus appendices.

MBC Applied Environmental Sciences. 1986. National Pollutant Discharge Elimination System, 1986 receiving water monitoring report, Huntington Beach Generating Station, Orange County, California. Prepared for Southern California Edison Company, Rosemead, CA. 86-RD-54. 35 p. plus appendices.

MBC Applied Environmental Sciences. 1987. National Pollutant Discharge Elimination System, 1986 receiving water monitoring report, Huntington Beach Generating Station, Orange County, California. Prepared for Southern California Edison Company, Rosemead, CA. 87-RD-83. 48 p. plus appendices.

MBC Applied Environmental Sciences. 1988. National Pollutant Discharge Elimination System, 1988 receiving water monitoring report, Huntington Beach Generating Station, Orange County, California. Prepared for Southern California Edison Company, Rosemead, CA. 88-RD-57. 46 p. plus appendices.

MBC Applied Environmental Sciences. 1989. National Pollutant Discharge Elimination System, 1989 receiving water monitoring report, Huntington Beach Generating Station, Orange County, California. Prepared for Southern California Edison Company, Rosemead, CA. 90-RD-01. 45 p. plus appendices.

MBC Applied Environmental Sciences. 1990. National Pollutant Discharge Elimination System, 1990 receiving water monitoring report, Huntington Beach Generating Station, Orange County, California. 1990 survey. Prepared for Southern California Edison Company, Rosemead, CA. 90-RD-85. 46 p. plus appendices.

MBC Applied Environmental Sciences. 1991. National Pollutant Discharge Elimination System, 1991 receiving water monitoring report, Huntington Beach Generating Station, Orange County, California. 1991 survey. Prepared for Southern California Edison Company, Rosemead, CA. 91-RD-25. 48 p. plus appendices.

MBC Applied Environmental Sciences. 1992. National Pollutant Discharge Elimination System, 1992 receiving water monitoring report, Huntington Beach Generating Station, Orange County, California. 1992 survey. Prepared for Southern California Edison Company, Rosemead, CA. 92-RD-009. 50 p. plus appendices.

MBC Applied Environmental Sciences. 1993. National Pollutant Discharge Elimination System, 1993 receiving water monitoring report, Huntington Beach Generating Station, Orange County, California. 1993 survey. Prepared for Southern California Edison Company, Rosemead, CA. 93-RD-009. 49 p. plus appendices

MBC Applied Environmental Sciences. 1994. National Pollutant Discharge Elimination System, 1994 receiving water monitoring report, Huntington Beach Generating Station, Orange County, California. 1994 survey. Prepared for Southern California Edison Company, Rosemead, CA. 94-RD-008. 53 p. plus appendices.

MBC Applied Environmental Sciences. 1995. National Pollutant Discharge Elimination System, 1995 receiving water monitoring report, Huntington Beach Generating Station, Orange County, California. 1995 survey. Prepared for Southern California Edison Company, Rosemead, CA. 96-RD-002. 59 p. plus appendices.

MBC Applied Environmental Sciences. 1996. National Pollutant Discharge Elimination System, 1996 receiving water monitoring report, Huntington Beach Generating Station, Orange County, California. 1996 survey. Prepared for Southern California Edison Company, Rosemead, CA. 97-RD-001. 56 p. plus appendices.

MBC Applied Environmental Sciences. 1997. National Pollutant Discharge Elimination System, 1997 receiving water monitoring report, Huntington Beach Generating Station, Orange County, California. 1997 survey. Prepared for Southern California Edison Company, Rosemead, CA. 97-EA-07. 58 p. plus appendices.

MBC Applied Environmental Sciences. 1998. National Pollutant Discharge Elimination System, 1998 receiving water monitoring report, AES Huntington Beach L.L.C. Generating Station, Orange County, California. 1998 survey. Prepared for Southern California Edison Company, Rosemead, CA. and AES Huntington Beach L.L.C. 98-EA-04. 59 p. plus appendices.

MBC Applied Environmental Sciences. 1999. National Pollutant Discharge Elimination System, 1999 receiving water monitoring report, AES Huntington Beach L.L.C. Generating Station, Orange County, California. 1999 survey. Prepared for Southern California Edison Company, Rosemead, CA. and AES Huntington Beach L.L.C. 99-EA-03. 47 p. plus appendices.

MBC Applied Environmental Sciences. 2000. National Pollutant Discharge Elimination System, 2000 receiving water monitoring report, AES Huntington Beach L.L.C. Generating Station, Orange County, California. Prepared for AES Huntington Beach L.L.C. 52 p. plus appendices.

MBC Applied Environmental Sciences. 2001. National Pollutant Discharge Elimination System, 2001 receiving water monitoring report, AES Huntington Beach L.L.C. Generating Station, Orange County, California. Prepared for AES Huntington Beach L.L.C. 54 p. plus appendices.

MBC Applied Environmental Sciences. 2002. National Pollutant Discharge Elimination System, 2002 fish impingement monitoring report, AES Huntington Beach L.L.C. Generating Station, Orange County, California. Prepared for AES Huntington Beach L.L.C. 15 p. plus appendices.

Morgan, R. P., R. E. Ulanowicz, V. J. Rasin, L.A. Noe, and G. B. Gray. 1974. Effects of shear on eggs and larvae of the striped bass, Norene saxatilis, and the white perch, M.americana. *Trans. Am. Fish. Soc*., 1974

OCSD, 1993, Orange County Sanitation District, Marine Monitoring Annual Report.

OCSD, 1999, Orange County Sanitation District 1999 Strategic Plan, Program Environmental Impact Report, prepared by EA Engineering Science Associates, MEC Analytical Systems Inc., and KP Lindstrom, Inc., 461 pp + Appendices.

OCSD, 2000, Orange County Sanitation District, Marine Monitoring Annual Report.

OCSD, 2001, Orange County Sanitation District Surfzone Bacteriology Monitoring at URL address: http://www.ocsd.com/Environment/BeachMon.

Roemmich, D. 1989, “Mean transport of mass, heat, salt and nutrients in southern California coastal waters”, *Deep-Sea Research,* vol 36, no 9, pp 1359-1378.

RWQCB, 2014, “ORDER NO. R9-2012-0012, NPDES NO. CA0107417 WASTE DISCHARGE REQUIREMENT FOR THE SOUTH ORANGE COUNTY WASTEWATER AUTHORITY, DISCHARGE TO THE PACIFIC OCEAN THROUGH THE SAN JUAN CREEK OCEAN OUTFALL, APPENDIX-H DILUTION MODEL INFORMATION” CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD SAN DIEGO REGION, 8 pp.

RWQCB, 2015, “Regional Water Quality Control Board (Regional Water Board) Order No. R9-2006-0065 (NPDES CA0109223)” 54 pp

SCCWRP, 2012, Southern California Coastal Water Research Project: “Management of Brine Discharges to Coastal Waters - Recommendations of a Science Advisory Panel. Technical Report 694 to the State Water Resources Control Board, Southern California Coastal Water Research Project, Costa Mesa, CA.

SCCOOS, 2014, “Southern California Coastal Ocean Observation System”, Current Data, SJCOO: http://www.sccoos.org/data/hfrnet/

SEIR, 2010, “Subsequent Environmental Impact Report Sea Water Desalination Project at Huntington Beach,” #2001051092, City of Huntington Beach, prepared by Dudek Consulting, May, 2010, 9 sections + append.

SIO, 2013, “SIO shore station, Scripps Pier”, http://www-mlrg.ucsd.edu/shoresta/mnSIOMain/siomain.htm

SWRCB, 2015, Amendment to the Water Quality Control Plan For Ocean Waters of California Addressing: “DESALINATION FACILITY INTAKES, BRINE DISCHARGES, AND THE INCORPORATION OF OTHER NON-SUBSTANTIVE CHANGES”, cf. Appendix-A: “Ocean Plan with the May 6, 2015 Final Desalination Amendment”, 1303 pp.

Star-CD, 1998 Manuals Version 3.1, *Computational Dynamics*. 1999.

Wygnanski, I. and H. E. Fiedler (1969). "Some Measurements in the Self-Preserving Jet". *Journal of Fluid Mechanics* 38(3): 577-612.