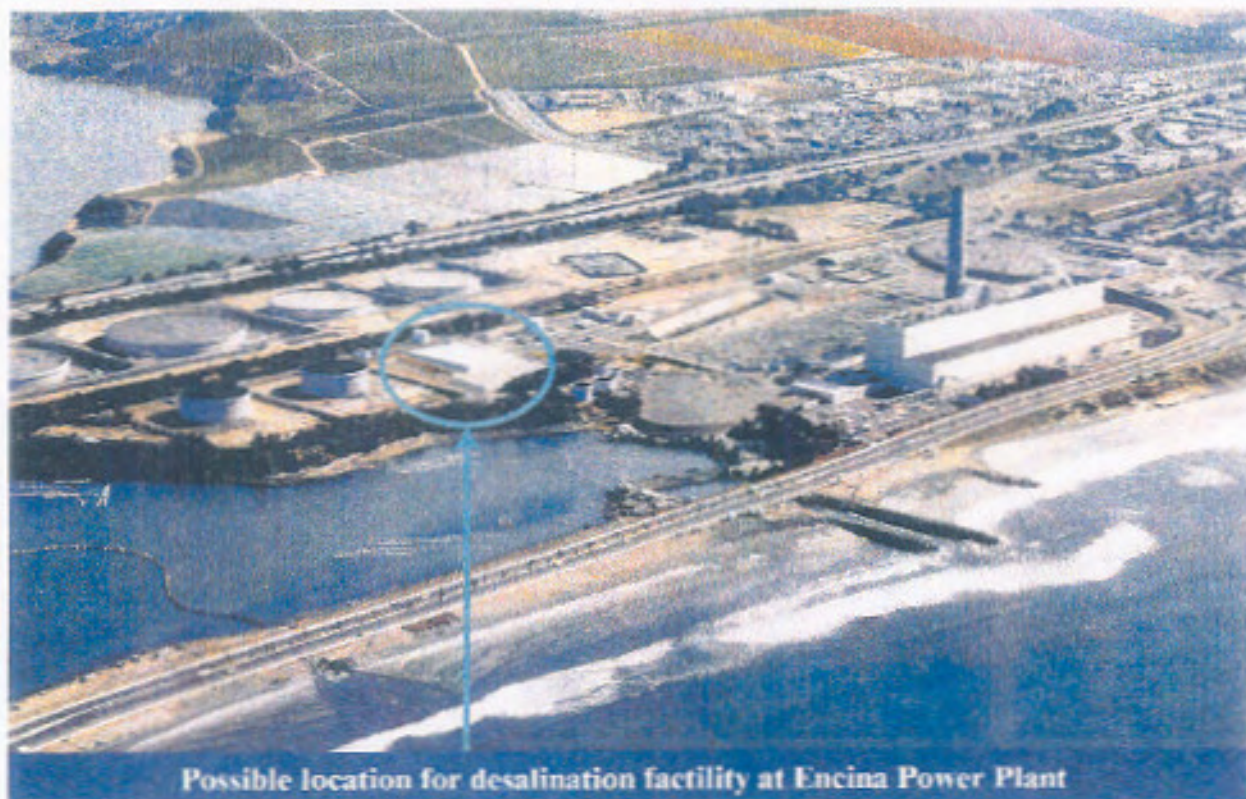


**HYDRODYNAMIC MODELING OF DISPERSION AND DILUTION OF
CONCENTRATED SEAWATER PRODUCED BY THE OCEAN
DESALINATION PROJECT AT THE ENCINA POWER PLANT,
CARLSBAD, CA**



Possible location for desalination facility at Encina Power Plant

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

501 West Broadway

San Diego, CA 92101

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Executive Summary

California experiences multi-decadal climate variability in rainfall leading to alternating periods of dry and wet climate, each lasting 20-30 years. A dry period extend from about 1945-1977, followed by an episodically wet period from 1978-1988 that included the occurrence of six strong El Niño events. Because of the previous durations of these climate cycles, we are likely at an end of a wet cycle and due to return to a period of dry climate similar to what prevailed in California from 1945-1977. Such a transition in climate would put increasing pressures on already limited supplies of fresh water, making the development of alternative sources in California a necessity.

Poseidon Resources plans to construct and operate a reverse osmosis (RO) desalination plant at the Encina Power Plant in Carlsbad, CA. This proposed project is referred to as the *Carlsbad Desalination Project*. Up to 100 million gallons per day (mgd) of treated water from this plant will be blended with other supplies to provide supplemental water to the City of Carlsbad, the San Diego County Water Authority, and the City of Oceanside. The source of water for the desalination plant will be seawater drawn from the Agua Hedionda Lagoon after passing through the power plant's cooling water condensers. The source water will

be pre-treated and filtered through reverse osmosis membranes to produce high quality drinking water. The plants product drinking water will be blended with other sources and distributed to consumers. The byproduct of the reverse osmosis process will be mixed with the cooling water and then conveyed to the existing outfall channel.

This hydrodynamic modeling study of the nearshore waters and the adjacent Agua Hedionda Lagoon was conducted to evaluate the mixing and dilution of the concentrated byproduct of the desalination process with its associated thermal plume after it is returned to the cooling water discharge channel from the power plant which discharges into the neighboring surfzone.

Hydrodynamic modeling of water mass dilution and dispersion was performed in a nearshore domain surrounding the Encina Power Plant including included the Agua Hedionda Lagoon. The model was initialized for four sets of average and extreme environmental conditions: 1) a worst case day, 2) an average day, 3) a worst case month, 4) an average month. For each of these worst case and average case conditions, the model analysis studied dispersion and dilution of concentrated seawater byproduct at two levels of RO production, 50 mgd and 100 mgd. Here the concepts of worst and average case apply to the simultaneous occurrence of 7 boundary condition and forcing function variables that in combination control acute and chronic toxicity tendencies for the combined RO and power plant discharge. These 7 variables include: ocean temperatures and salinities, ocean water levels, power plant flow rates, wind, waves, and currents. These variables control the dose levels and persistence of elevated salinities and temperatures associated with the combined discharge. Historical combinations of these variables that minimize mixing and ventilation in nearshore waters while

maximizing absolute salinity and temperature lead to worst case scenarios, while combinations having the highest historic occurrence lead to average case scenarios. Twenty and one half year long records of these 7 variables were reconstructed and subjected to computerized recurrence and probability analyses to find the historic surrogate for each scenario. This analysis determined that these historic surrogates were: 1) 17 August 1992 for worst case day, 2) 23 May 1994 for average day, 3) August 1992 for worst month, and a consecutive 30 day period in May and June for worst month. The probability of recurrence of the conditions of the worst day was 0.01% and 0.4% for the worst month.

Based on these representative historic data. The investigation provided a reasonable estimate of the likely worst case and average effects which the Carlsbad Desalination Project might have on the local and nearshore and lagoonal physical environment.

Salinity Effects:

The historic data indicates that nearshore ocean and lagoon salinities can vary by as much as 10% in response to El Niño events and climate cycles.

* The model analysis of concentrated seawater dispersion and dilution indicates that project effects are in all cases less than natural variability when the RO production rates are 50 mgd and less. Even for the worst case day, no benthic area experiences a 10% increase in bottom salinity, and the maximum salinity anomaly found anywhere in the lagoon (at the mouth) is only 0.4%. Benthic area in the nearshore experiencing a 1% increase in salinity varies from 465 acres for the worst case month to 111 acres for an average day. The minimum dilutions of concentrated seawater at 1000 feet

in any direction from the discharge channel range from 20 to 1 for worst case day and 35 to 1 for an average month. At the power plant infall (inside the lagoon) dilution factors vary between 170,000 to 1 for a worst case day and more than 600,000 to 1 for an average month. Consequently, recirculation of concentrated seawater into the RO unit is a negligible.

****** If RO production is raised to 100 mgd then small areas of seabed in the immediate neighborhood of the mouth of the discharge channel will be subjected to salinity increases of 10% or more (as large as 17.6%). Benthic area subject to 10% elevations in salinity range from 24.4 acres for a worst case day to 7.4 acres for an average day. The maximum salinity in any case reaches 39.4 ppt on 11.6 acres of seabed inside the surfzone directly offshore of the discharge channel. Benthic areas subjected to a 1% salinity increase ranges from 855 acres for a worst case month to 241 acres for an average day. The maximum salinity anomaly found anywhere in the lagoon is 1.2% for the worst case day and is confined to only 1.1 acres in the jettied inlet. The minimum dilution of concentrated seawater found 1000 feet from the discharge channel is between 10 to 1 for a worst case day and 22 to 1 for an average day. Dilutions of concentrated seawater at the power plant infall vary between 100,000 to 1 for a worst case day and more than 500,000 to 1 for an average month.

Thermal Effects:

California's thermal plan incorporates provisions of Section 316(A) of the Federal Water Pollution Control Act of 1972 and defines the relevant regulatory

requirements for power plant cooling water discharge at Encina. The applicable regulatory requirements are found in those sections of California's Thermal Plan dealing with Specific Water Quality Objectives, General Water Quality Provisions, as well as provisions within the Implementation Section. The most restrictive of these provisions with respect to the problem at hand is Water Quality Objective 3B(4) "The discharge of elevated temperature wastes should not result in increases in the natural water temperature exceeding 4 °F at the: (a) shoreline, (b) surface of any ocean substrate, or c) ocean surface beyond 305 m (1000 ft) from the discharge system. The surface temperature limitation shall be maintained at least 50% of the duration of any complete tidal cycle."

The model analysis finds that the addition of concentrated seawater to the thermal waste stream of the power plant renders the combined discharge heavier than ambient seawater at all levels of power plant and RO operating conditions. By causing the thermal plume to sink into the water column rather than float on the sea surface, we find that the addition of the RO byproduct provides for more efficient and rapid dissipation of heat into the receiving waters. The following findings were made specific to Water Quality Objective 3B(4).

* At an RO production level of 50 mgd during the worst case day, 0.8 acres of seabed within the surfzone directly offshore of the discharge channel experience a 4 °F (2.2 °C) temperature increase. However, due to active littoral sand transport in this effected area no hard bottom ocean substrate is effected by this thermal impingement. For all other environmental scenarios studied, there is no finding of impingement of the 4 °F temperature anomaly on the seabed. The maximum temperature increase found at any depth at a

distance of 1000 ft from the discharge channel range from 3.1 °F (1.7 °C) for the worst case day to 1.5 °F (0.8 °C) for an average month. The thermal footprint of the 2 °F temperature anomaly varied between 57 acres for a worst case day and 9 acres for an average day. This represents a reduction of between 50% and 86% in the thermal footprint relative to existing conditions.

****** At an RO production level of 100 mgd during the worst case day, 8 acres of seabed within the surfzone containing no hard bottom substrate will experience a 4 °F (2.2 °C) temperature increase. For all other environmental scenarios studied, there is no finding of impingement of the 4 °F temperature anomaly on the seabed. The maximum temperature increase found at any depth at a distance of 1000 ft from the discharge channel range from 3.5 °F (1.9 °C) for the worst case day to 2.0 °F (1.1 °C) for an average month. The thermal footprint of the 2 °F temperature anomaly varied between 73 acres for a worst case day and 14.7 acres for an average day. This represents a reduction of between 36% and 78% in the thermal footprint relative to existing conditions.

Conclusions:

Based on these findings we conclude that the proposed Carsbad Desalination Project when operated at a production level of 50 mgd would produce saline and thermal effects which are within the range of natural variability and compliant with Water Quality Objectives under California's Thermal Plan. When operated at 100 mgd production rates the project remains compliant with Water Quality Objectives,

but results in saline effects outside the range of natural variability in a limited area immediately offshore of the discharge channel. No significant effects were found on Agua Hedionda Lagoon water properties.

SECTION 1: INTRODUCTION

1) Introduction

1.1) Physical Setting and Domain of Study

This study investigates saline and thermal effects related to the proposed Carlsbad Desalination Project to be sited at the Encina Power Plant, (Figure 1.1). The proposed desalination project would be retrofitted to the existing Encina cooling water circulation system which draws its influent source water from the Agua Hedionda Lagoon (Figure 1.2) and discharges thermal effluent water into the adjacent surfzone through a jettied discharge channel (Figure 1.3). A *reverse osmosis* (RO) desalination system would be coupled to the existing Encina cooling water system and would remove total dissolved solids (TDS) from seawater derived from the Agua Hedionda Lagoon and discharge concentrated seawater into the heated waste water effluent of the power plant. This effluent would subsequently form a thermal plume in the nearshore waters seaward of the discharge channel.

The Agua Hedionda Lagoon is one of the healthiest lagoons in California and functions as a nursery for pelagic and benthic species as well as providing a home for an ongoing aqua culture business in white sea bass and abalone (Le Page and Ware 2001). Tidal circulation is insured for the lagoon by a combination of a jettied inlet and a maintenance dredging program that periodically removes sand fluxed into into the lagoon and returns it to the beaches on either side of the inlet. A project is presently in the EIR/EIS process to lengthen the north inlet jetty by an additional 200 ft to further reduce sand influx into the lagoon. An ephemeral creek (Agua Hedionda Creek) discharges into the east end of the east basin of the lagoon. Because of the combined action of the tidal flushing and the power plant consumption of lagoon water (as large as 808 mgd), the residence time of creek water in the lagoon is less than 1 day (Jenkins and Wasyl, 1997). Although

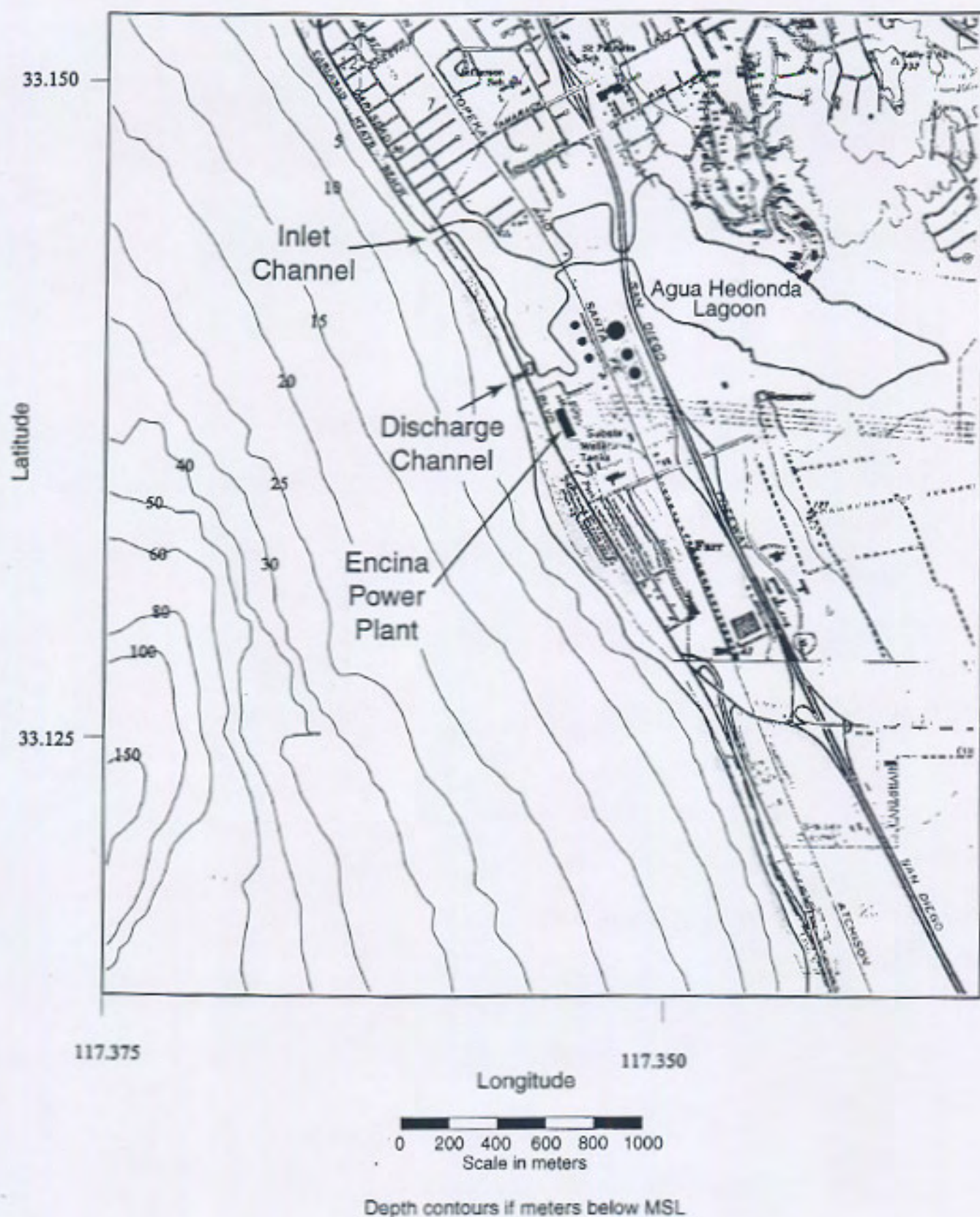
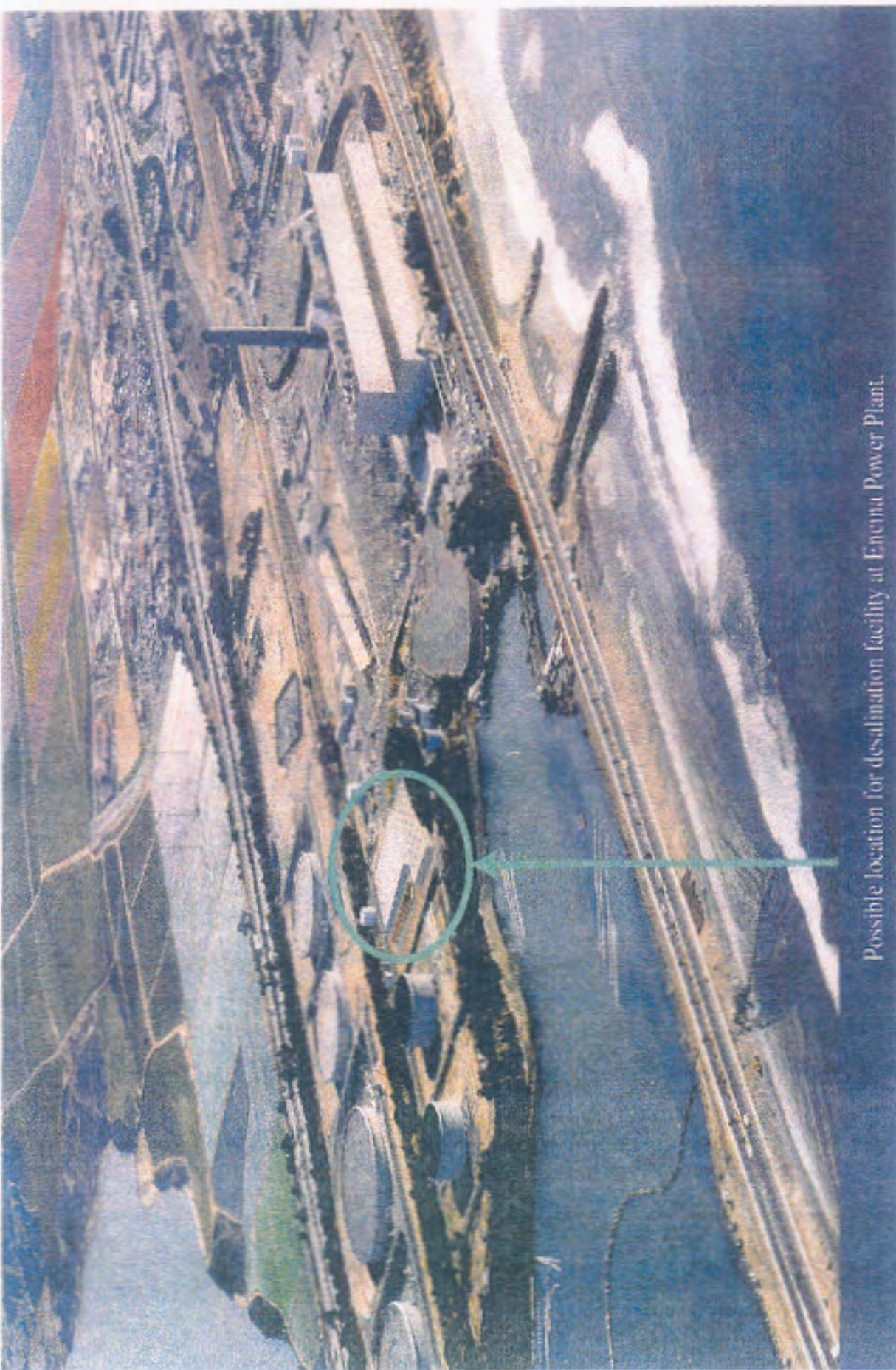


Figure 1.1. Bathymetry grid for nearfield dispersion analysis.



Possible location for desalination facility at Encina Power Plant.



CARLSBAD DESALINATION PROJECT
PROPOSED PLANT SITE

Figure 1.2



Figure 1.3. Discharge Channel at Agua Hedionda Lagoon, CA.

occasional episodes of high coliform counts have been recorded, these are generally thought to be associated with transient wetland and marine bird populations (LePage and Ware, 2001, MEC Analytic, 1997). For those reasons, source water issues are neglected in the present study.

The primary concerns of this study are issues related to receiving water. The marine waters offshore of the discharge channel contain areas of both low and high relief hard bottom habitat and portions are regarded as areas of special biological significance. The lagoon and its unique wetland ecology is a potential receiving water body if a portion of the RO byproduct is recirculated back into the lagoon. Therefore we focus our domain of study on resolving the fate and transport of a combined discharge of the power plant's waste heat and the concentrated seawater of the proposed desalination plant. We will solve for temperature and salinity anomalies which these combined activities cause in the marine and lagoonal environments.

The physical environment around the Encina Power Plant and Agua Hedionda Lagoon is quite dynamic due to an interplay between climatic variability and certain unique features of the physical setting. El Niño events cause significant warming and stratification of the coastal ocean around Encina over recurrence periods of 3 to 7 years. These warm El Niño events are superimposed on seasonal warming cycles. Tidal flow over the Carlsbad Canyon (Figure 1.4) excites large amplitude internal waves at the same frequency of the tides (internal tides). These internal waves propagate on the temperature interface between the warm surface water (mixed layer) and the colder bottom water. Internal waves shoal and break in the shallow near shore waters just like the surface waves forming a kind of "internal surf" that runs up into the surfzone creating alternating episodes and

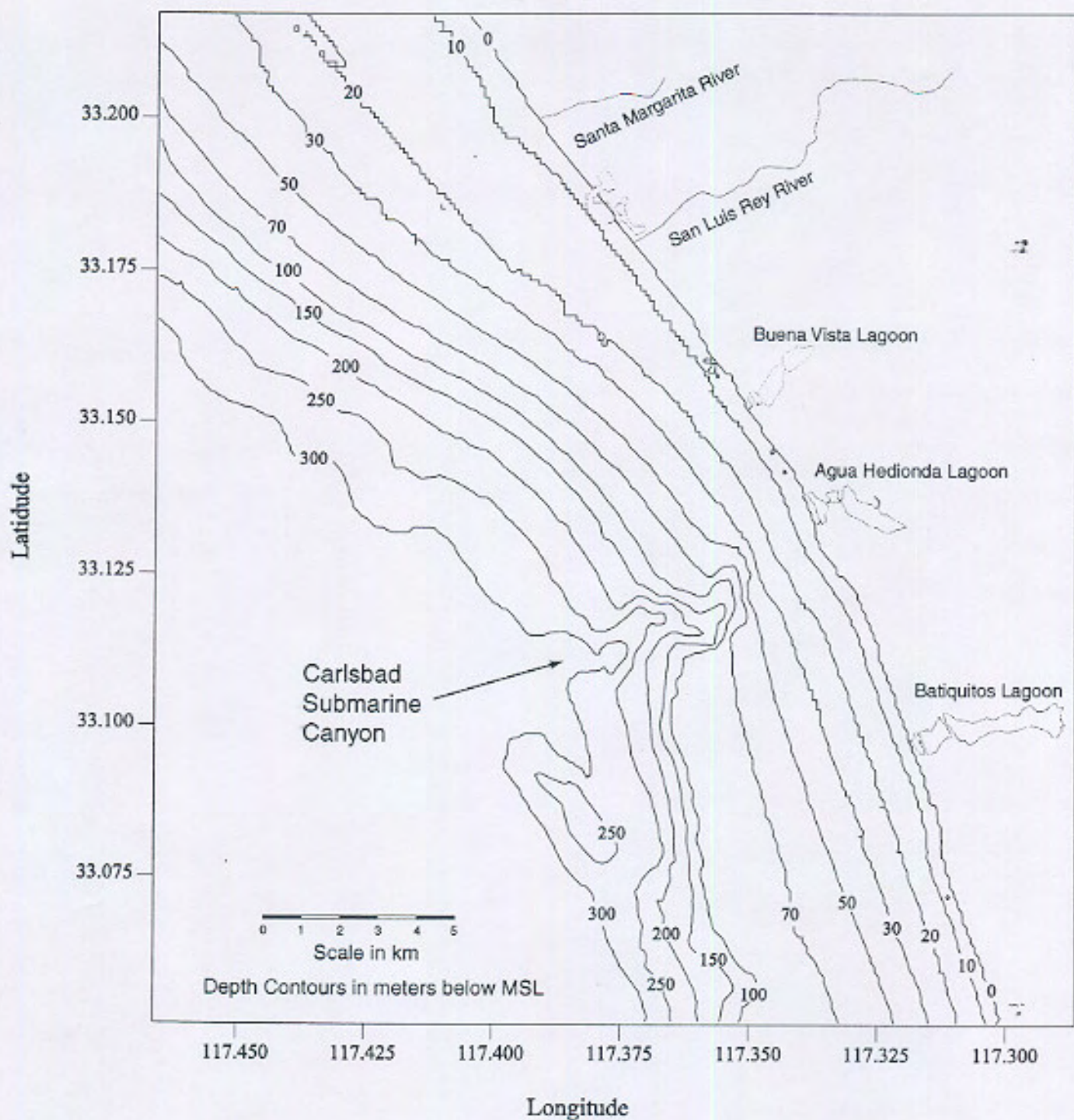


Figure 1.4. Bathymetry grid for dispersion analysis for the Carlsbad desalination plant at Agua Hedionda, CA

patches of cold water that co-mingle with the warm surface water (see Figure 1.5). Consequently, the baseline temperature fields of the receiving waters around Encina have large temperature variations over time scales that fluctuate at periods of several years, seasonally, or daily.

The salinity field shows similar variability due to the same sets of climatic, seasonal, and tidal mechanisms. 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. The shoaling internal waves (Figure 1.5) move higher salinity bottom water into the shallow nearshore and surfzone on hourly time scales. Therefore, the local environment already has a high degree of variability in temperature and salinity on which the activities of the power plant and desalination plants are superimposed. In addition the ocean forcing functions that will mix and carry away the heat and concentrated seawater resulting from these two activities are likewise modulated by El Niño events, seasonal changes in weather patterns and by diurnal and semi-diurnal changes in tidal stage. Even the power plant's production is effected by climatic, seasonal, and daily changes in user demand, with corresponding adjustments in the volume of lagoon water consumed by the plant and the amount of waste heat introduced into the coastal waters.

Altogether there are seven primary variables that enter into a solution for resolving the dispersion and dilution of the waste heat and concentrated seawater by-product of the combination of the power plant and desalination plant working in conjunction. These seven variables may be organized into *boundary conditions*

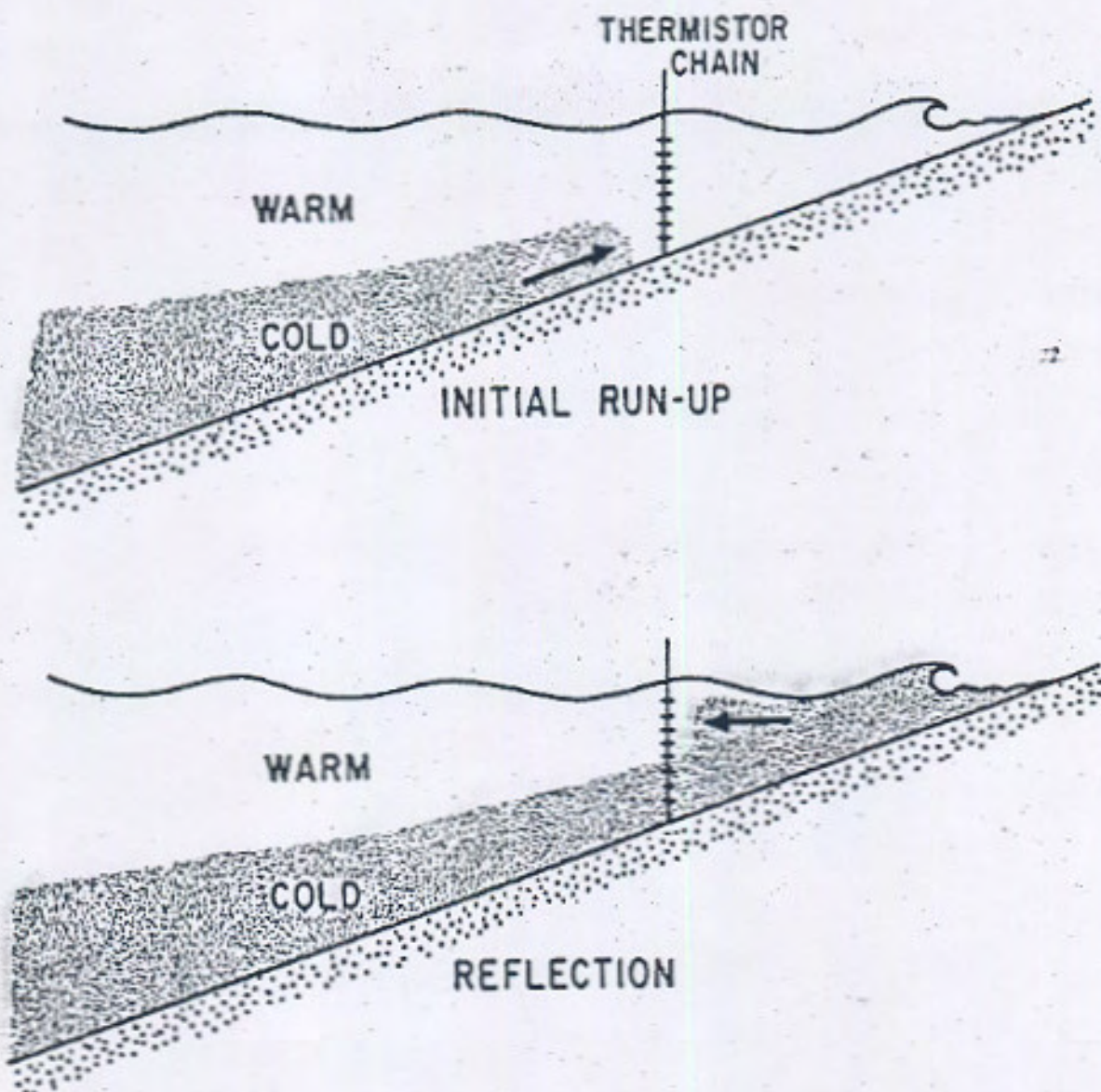


Figure 1.5. Schematic of run-up due to a broken internal wave in the nearshore, referred to as internal surges, from Winant (1974).

and *forcing functions*. The boundary conditions include: ocean salinity, ocean temperature, ocean water levels and power plant flow rates. There are two additional boundary conditions which we will treat as constants: local bathymetry and power plant "Delta-T" (the amount that the power plant raises the cooling water above the ambient ocean temperature, where ambient ocean temperature is already treated as a variable). These boundary condition variables are developed in Section 3.2. The forcing function variables include: waves, currents, and winds are developed in Section 3.3.

Overlapping 20.5 year long records containing 7,523 consecutive days between 1980 and 2000 are reconstructed in Sections 3.2 and 3.3 for each of the seven controlling variables. Our approach for bracketing the extreme amount of variability contained in this 20.5 year period and organizing this data into a manageable set of model problems involves focusing our analysis on the historically worst day, average day, worst month and average month conditions. The criteria for a worst day and worst month was based on the simultaneous occurrence of seven variables having the highest combination of absolute salinity and temperature during the periods of lowest mixing and advection in the local ocean environment. In the worst day and worst month scenarios low mixing and dilution periods coincide with periods of minimal wave, wind, currents, and ocean water level. The average day and average month scenarios were found by a statistical search of these records for the average 24 hour and 30 day combinations of the 7 variables occurring over the 20.5 year period of record. This procedure produced the model scenarios presented in Section 3.4.

The technical approach used to evaluate these scenarios for worst case and average case conditions involved the use of hydrodynamic transport models

described in Section 2 and calibrated in Section 3.5. The dispersion and dilution of concentrated seawater produced by the proposed desalination plant was evaluated at production rates of 50 mgd and 100 mgd and the results are presented in Section 4.1. Effects of the concentrated seawater on the thermal plume of the power plant are modeled in Section 4.2. Analysis of potential recirculation of the concentrated seawater by-product into the lagoon is presented in Section 4.3. Summary tables of the results are presented in Section 4.4, and conclusions are detailed in Section 5.

1.2) Climate Variations and Fresh Water Supplies

The California coast is subject to climate cycles of about 20-30 years duration known as the Pacific/ North American pattern (for atmospheric pressure) or the Pacific Decadal Oscillation (for sea surface temperature). A dry period extended from about 1945-1977, followed by an episodically wet period from 1978-1998 that included the occurrence of 6 strong El Niño events (Inman and Jenkins 1997; and Goddard and Graham 1997). Based on the historic duration of these cycles, 1998 was likely the end of the wet cycle of climate in California with a return to the dry climate that prevailed from 1945-1977 (White and Cayan 1998).

To illustrate the historical evidence for these dry and wet climate cycles in Southern California, we evaluate the rain gage records for Santa Ana, Laguna Beach and San Diego (panel-a of Figures 1.6-1.8). The records were analyzed for climate trends using the Hurst (1951, 1957) procedure that was first used for determining decadal climate effects on the storage capacity of reservoirs (Inman and Jenkins, 1999). Climate trends become apparent when the data are expressed in terms of cumulative residuals Q_n taken as the continued cumulative sum of departures of annual values of a time series Q_i from their long term mean value Q .

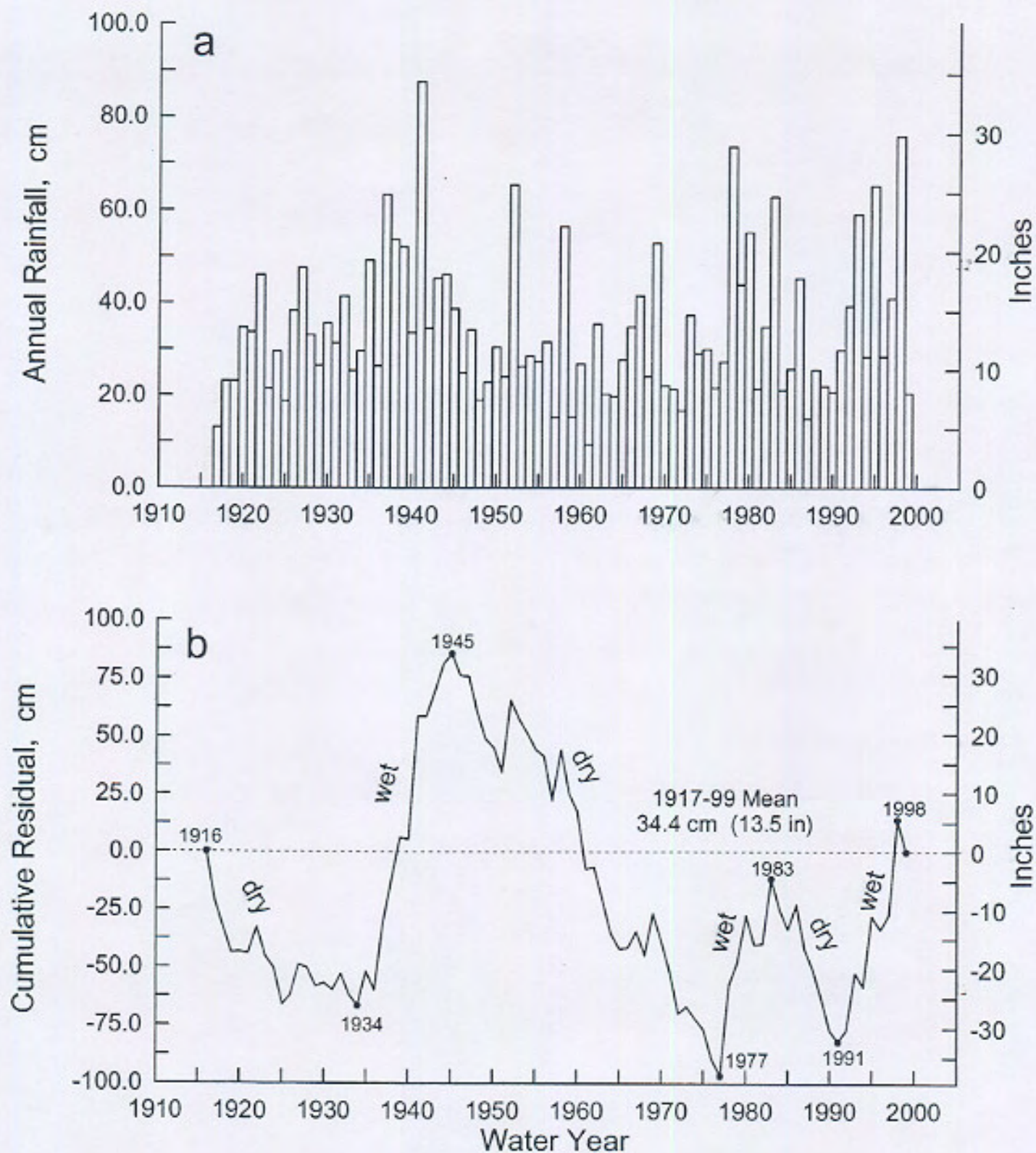


Figure 1.6. a) Total record of annual rainfall, Santa Ana, CA (National Weather Service) and b) Cumulative residual of the annual rainfall for the the period 1917-1999.

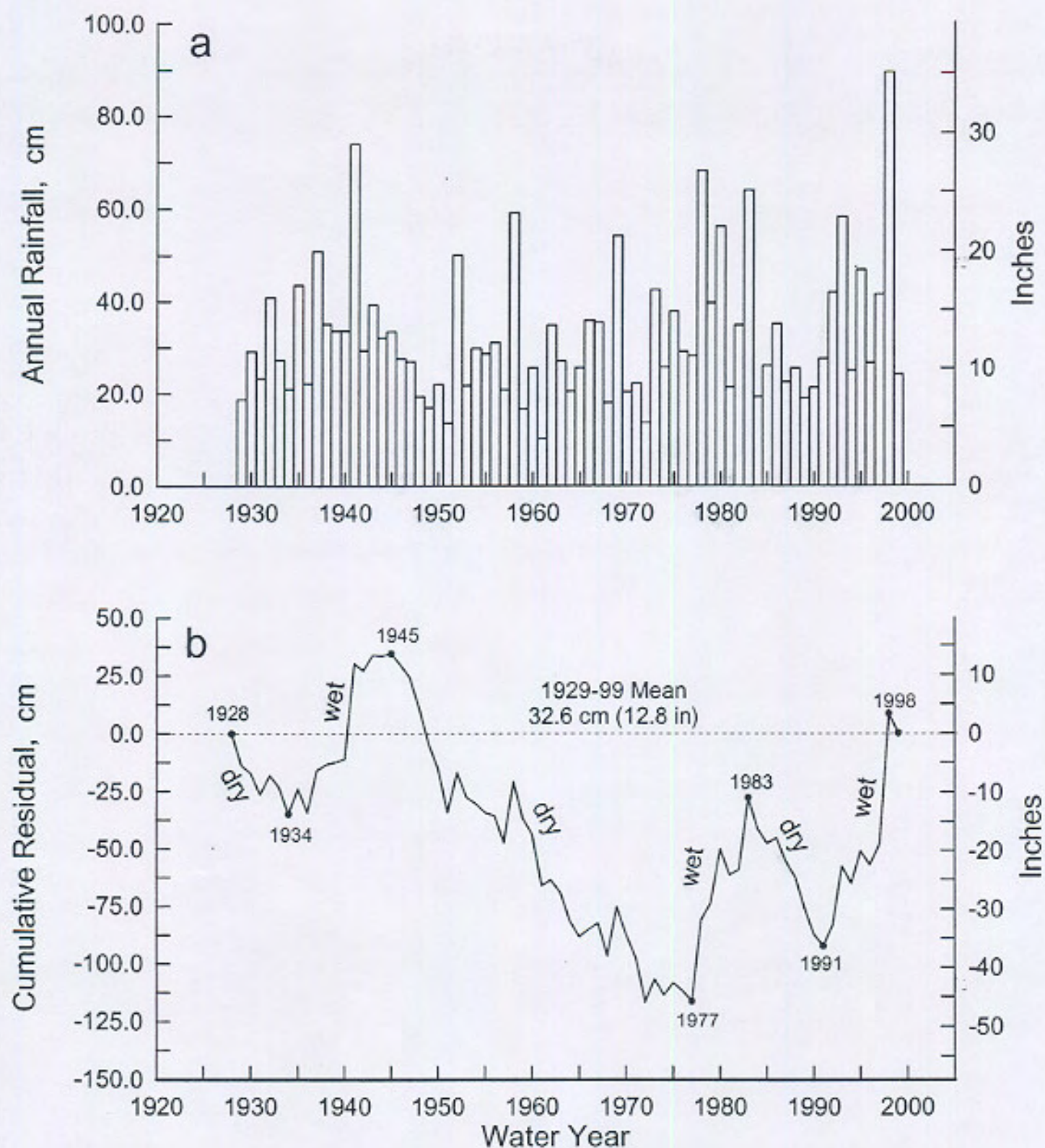


Figure 1.7. a) Total record of annual rainfall, Laguna Beach, CA (National Weather Service) and b) Cumulative residual of the annual rainfall for the the period 1929-1999.

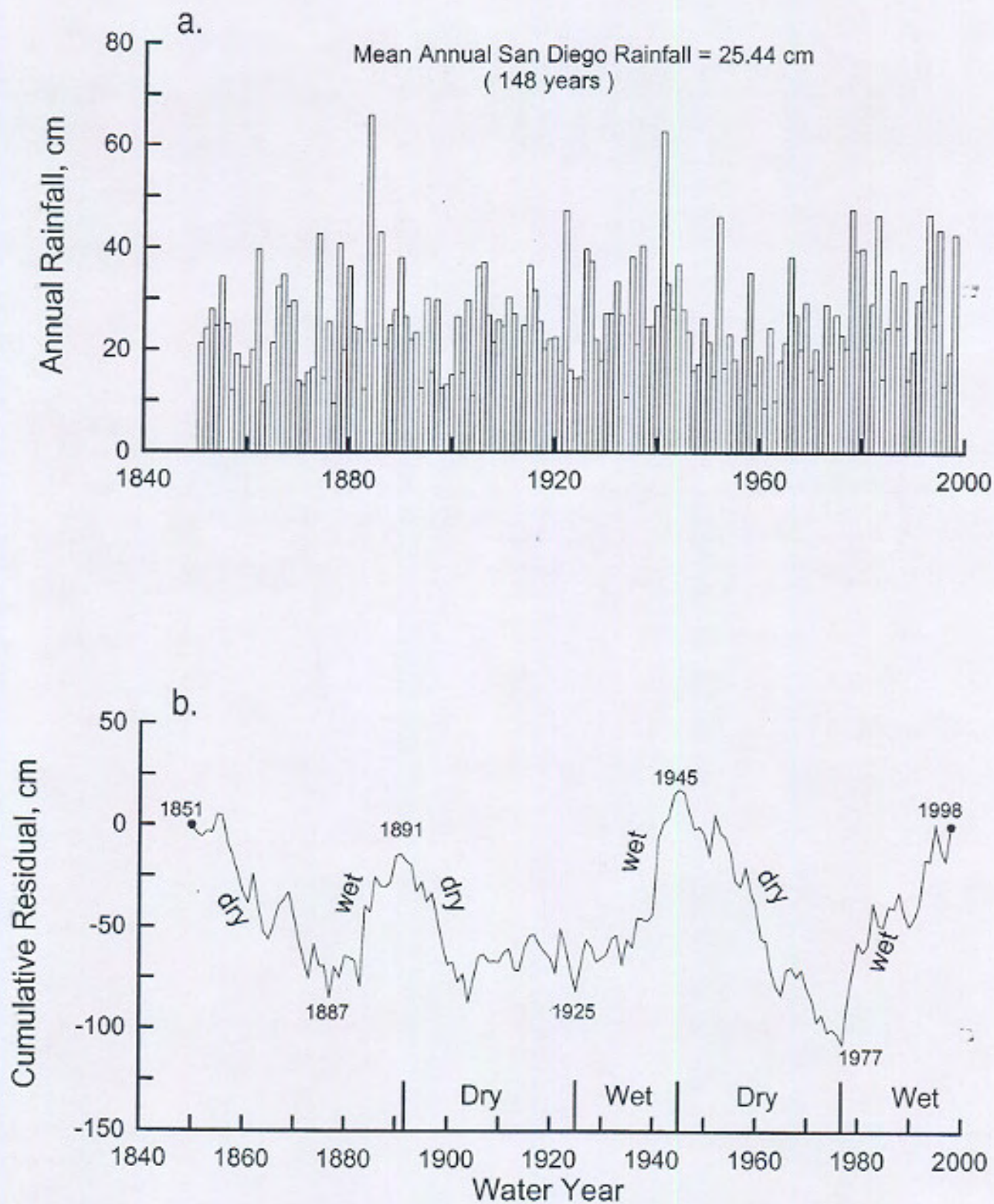


Figure 1.8 Annual rainfall histogram (a) and cumulative residual (b) for the city of San Diego, California.

such that $Q_n = \sum_0^n (Q_i - Q_i)$ where n is the sequential value of the time series.

The records for the total period of rainfall and their cumulative residual graphs are shown in Figures 1.6-1.8. All records show decadal scale climate changes (panel-b of Figures 1.6-1.8). Dry periods are shown by segments of the cumulative residuals having negative (downward) slopes while the wet periods have positive (upward) slopes. A dry period is found in all three records from 1945-1997, (negative slopes) while a wet period (positive slope) is shown from 1978-1998. The wet period of the climate cycle is more irregular caused by 6 strong El Niño events (water years 1978, 80, 83, 93, 95, and 98) and one 4 year period (1987-1990) of low rainfall.

The analysis shows that the average annual rainfall increased by about 38% from the dry to the wet portions of the cycle. Furthermore, both the minimum and maximum ranges in rainfall are higher in the wet period, while the averages of the 6 major rainfall events in 21 year periods before and after the climate change (1977/78) are about 8 to 9 inches greater during the wet period. Therefore, the expected transition back into the dry period for the next 20-30 years is likely to cause severe reductions in terminal storage levels of Southern California reservoirs. The development of alternative fresh water sources such as the proposed Carlsbad Desalination Project is likely to prove extremely timely while addressing a significant societal need.

SECTION 2: MODEL DESCRIPTION AND CAPABILITIES

2) Model Description and Capabilities

This study addresses concerns over combined power plant and desalination plant discharge, dispersion, and dilution issues by utilizing a coupled set of numerical tidal and wave transport models to evaluate dilution and dispersion when the proposed desalination plant is functioning at its maximum production capacity of 100 mgd. The numerical model used to simulate tidal currents in the nearshore and shelf region of Encina as well as within Agua Hedionda Lagoon is the finite element model **TIDE_FEM**. Wave-driven currents are computed from the shoaling wave field by a separate model, **OCEANRDS**. The dispersion and transport of concentrated seawater and storm water discharge by the wave and tidal currents is calculated by the finite element model known as **SEDXPORT**. The “wiring-diagram” showing the architecture for how these models were coupled together is shown in Figure 2.1.

The finite element research model, **TIDE_FEM**, (Jenkins and Wasyl, 1990; Inman and Jenkins, 1996) was employed to evaluate the tidal currents inside Agua Hedionda Lagoon and along a nearshore region extending between Oceanside and Encinitas, CA (Figure 1.4). **TIDE_FEM** was built from some well-studied and proven computational methods and numerical architecture that have done well in predicting shallow water tidal propagation in Massachusetts Bay (Connor and Wang, 1974) and along the coast of Rhode Island, (Wang, 1975), and have been reviewed in basic text books (Weiyan, 1992) and symposia on the subject, e.g., Gallagher (1981). The governing equations and a copy of the core portion of the **TIDE_FEM** FORTRAN code are found in Appendix B. **TIDE_FEM** employs a variant of the vertically integrated equations for shallow water tidal propagation after Connor and Wang (1975). These are based upon the Boussinesq

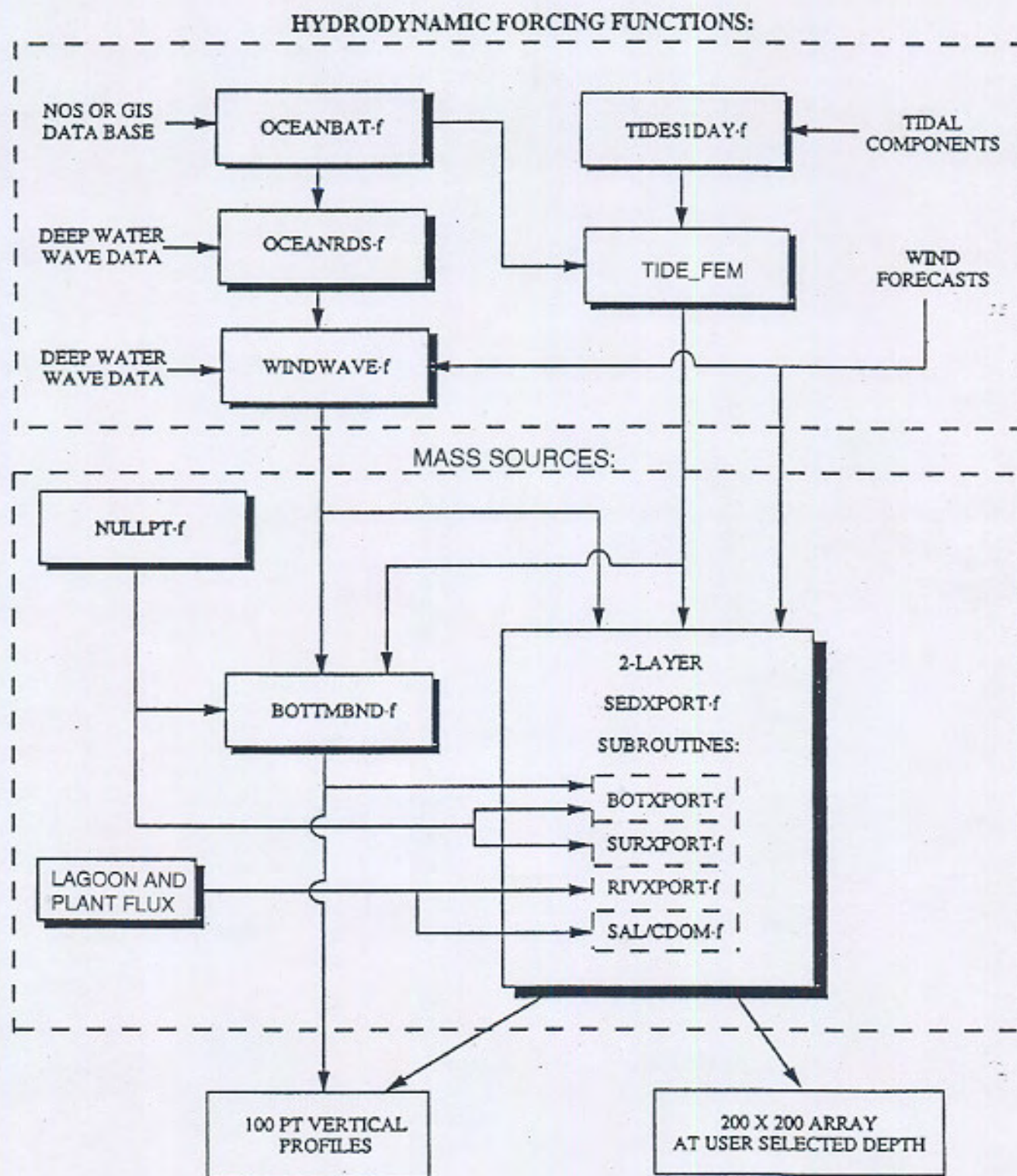


Figure 2.1. SEDXPORT architecture and computational sequence.

approximations with Chezy friction and Manning's roughness. The finite element discretization is based upon the commonly used **Galerkin weighted residual method** to specify integral functionals that are minimized in each finite element domain using a variational scheme, see Gallagher (1981). Time integration is based upon the simple **trapezoidal rule** (Gallagher, 1981). The computational architecture of **TIDE_FEM** is adapted from Wang (1975), whereby a transformation from a **global** coordinate system to a **natural** coordinate system based on the unit triangle is used to reduce the weighted residuals to a set of order-one ordinary differential equations with constant coefficients. These coefficients (**influence coefficients**) are posed in terms of a **shape function** derived from the natural coordinates of each nodal point in the computational grid. The resulting systems of equations are assembled and coded as banded matrices and subsequently solved by **Cholesky's method**, see Oden and Oliveira (1973) and Boas (1966). The hydrodynamic forcing used by **TIDE_FEM** is based upon inputs of the tidal constituents derived from Fourier decomposition of tide gage records. Tidal constituents are input into the module **TID_DAYS**, which resides in the hydrodynamic forcing function cluster (see Appendix C for a listing of **TID_DAYS** code). **TID_DAYS** computes the distribution of sea surface elevation variations in the ocean off Encina and adjacent nearshore after compensating for phase shifts associated with travel time between the Scripps Pier tide gage station (NOAA #941-0230) and Encina. Forcing for **TIDE_FEM** is applied by the distribution in sea surface elevation across the deep water boundary of the computational domain in Figure 1.4. Here the tidal currents reduce to the deep water solutions to

Laplace's tidal equations (Lamb, 1932). The x-component (longitudinal) of the deep water tidal current is given by:

$$u_{x,\infty} = \frac{ig}{a} \left[\frac{2\Omega s \cot\theta (\xi - \bar{\xi}) + \varpi \left(\frac{d\xi}{d\theta} - \frac{d\bar{\xi}}{d\theta} \right)}{\varpi^2 - (2\Omega \cos\theta)^2} \right] \quad (1)$$

while the y-component (latitudinal) is:

$$u_{y,\infty} = \frac{g}{a} \left[\frac{s\varpi \csc\theta (\xi - \bar{\xi}) \Omega \cos\theta \left(\frac{d\xi}{d\theta} - \frac{d\bar{\xi}}{d\theta} \right)}{\varpi^2 - (2\Omega \cos\theta)^2} \right] \quad (2)$$

where θ is the co-latitude; $\bar{\xi}$ is the equilibrium tide; g is the acceleration of gravity; Ω is the angular speed of rotation of the earth, a is the mean radius of the earth; s is an integer; ϖ is the radian frequency of the potential tide as determined from the tidal constituents.

Wave driven currents were calculated from wave measurements by Scripps SAS station at Torrey Pines (Pauka, 1982) and by the CDIP arrays at Huntington Beach, San Clemente, and Oceanside, CA, see CDIP (2000). These measurements were back refracted out to deep water to correct for island sheltering effects between the monitoring sites and the Encina/Carlsbad region. The waves were then forward refracted onshore to give the variation in wave heights, wave lengths and directions throughout the nearshore around Encina. The numerical refraction-diffraction code used for both the back refraction from these wave monitoring sites

out to deep water, and the forward refraction to the Encina Power Plant site is **OCEANRDS** and may be found in Appendix D. This code calculates the simultaneous refraction and diffraction patterns of the swell and wind wave components propagating over bathymetry replicated by the **OCEANBAT-f** code, (Figures 1.1 and 1.4). **OCEANBAT-f** generates the associated depth fields for the computational grid networks of both **TID_FEM** and **OCEANRDS** using packed bathymetry data files derived from the National Ocean Survey (NOS) depth soundings. The structured depth files written by **OCEANBAT-f** are then throughput to the module **OCEANRDS-f**, which performs a refraction-diffraction analysis from deep water wave statistics. **OCEANRDS-f** computes local wave heights, wave numbers, and directions for the swell component of a two-component, rectangular spectrum. These values are then throughput to **WINDWAVE-f**, which completes the refraction-diffraction analysis of the two-component spectrum including wind wave effects up to Nyquist frequencies.

The wave data computed throughout the domain of Figures 1.1 and 1.4 are throughput to a wave current algorithm in **SEDXPORT** which calculates the wave-driven longshore currents, $v(r)$. These currents were linearly superimposed on the tidal current. The wave-driven longshore velocity, $v(r)$, is determined from the longshore current theories of Longuet-Higgins (1970), according to:

$$\begin{aligned}
\bar{v}(r) &= v_o \left(\frac{10}{49} \frac{r}{X_b} - \frac{5}{7} \ln \frac{r}{X_b} \right) \text{ if } 0 \leq r \leq X_b \\
&= v_o \frac{10}{49} \left(\frac{r}{X_b} \right)^{5/2} \text{ if } r > X_b \\
v_o &= \frac{5\pi}{8} \frac{0.41}{C_D} (gh_b)^{1/2} \beta \sin \alpha_b
\end{aligned} \tag{3}$$

where r is the shoreline-normal coordinate, X_b is the width of the surf zone, taken as $X_b = 5/4 H_b \tan \beta$, H_b is the breaker height from the refraction solution, $\tan \beta$ is the beach slope, α_b is the breaker angle, h_b is the breaker depth, taken as $h_b = 5/4 H_b$. C_D is the drag coefficient, and g is the acceleration of gravity. Inspection of (3) reveals that the longshore transport is strongest in the neighborhood of the breakpoint, $r = X_b$, where the longshore currents approach a maximum value of $v(r) = v_o$.

Once the tidal and wave driven currents are resolved by **TIDE_FEM** and **OCEANRDS** and **WINDWAVE**, the dilution and dispersion of flood water runoff and concentrated seawater discharge in those flows is computed by the stratified transport model **SEDXPORT** (Figure 2.1). The **SEDXPORT** code is a time stepped finite element model which solves the advection-diffusion equations over a fully configurable 3-dimensional grid. The vertical dimension is treated as a two-layer ocean, with a surface mixed layer and a bottom layer separated by a pycnocline interface. The code accepts any arbitrary density and velocity contrast

between the mixed layer and bottom layer that satisfies the Richardson number stability criteria and composite Froude number condition of hydraulic state.

The combined discharge of the power plant and desalination plant is represented as sources in the surface mixed layer. The Encina infall is similarly treated as a sink. The source initializations for the plant infall and outfall are handled by a companion code called **MULTINODE** that couples the computational nodes of **TIDE_FEM** and **OCEANRDS** with **SEDXPORT**. The codes do not time split advection and diffusion calculations, and will compute additional advective field effects arising from spatial gradients in eddy diffusivity, i.e., the so-called "gradient eddy diffusivity velocities" after Armi (1979). Eddy mass diffusivities are calculated from momentum diffusivities by means of a series of Peclet number corrections based upon TSS and TDS mass and upon the mixing source. Peclet number corrections for the surface and bottom boundary layers are derived from the work of Stommel (1949) with modifications after Nielsen (1979), Jensen and Carlson (1976), and Jenkins and Wasyl (1990). Peclet number correction for the wind-induced mixed layer diffusivities are calculated from algorithms developed by Martin and Meiburg (1994), while Peclet number corrections to the interfacial shear at the pycnocline are derived from Lazara and Lasheras (1992a;1992b). The momentum diffusivities to which these Peclet number corrections are applied are due to Thorade (1914), Schmidt (1917), Durst (1924), and Newman (1952) for the wind-induced mixed layer turbulence and to Stommel (1949) and List, et al. (1990) for the current-induced turbulence. The primitive equations for the **SEDXPORT** code may be found in Appendix E and in Appendix F for **MULTINODE**.

In its most recent version, **SEDXPORT** has been integrated into the Navy's Coastal Water Clarity Model and the Littoral Remote Sensing Simulator (LRSS) (see Hammond, et al., 1995). The **SEDXPORT** code has been validated in mid-to-inner shelf waters (see Hammond, et al., 1995; Schoonmaker, et al., 1994). Validation of the **SEDXPORT** code was shown by three independent methods: 1) direct measurement of suspended particle transport and particle size distributions by means of a laser particle sizer; 2) measurements of water column optical properties; and, 3) comparison of computed stratified plume dispersion patterns with LANDSAT imagery. An example of the resolution of plumes by the **SEDXPORT** model is shown in Figure 2.2 for the nearby Santa Margarita River. In this figure the isocontours of suspended sediment concentrations computed by **SEDXPORT** (red lines) are overlaid on the LANDSAT image. The colored patchwork on the land delineate the primary and secondary drainage basins of streams discharging into the nearshore following the storm of 23 January 1993.

SEDXPORT has been built in a modular computational architecture (Figure 2.1). The modules are divided into two major clusters: 1) those which prescribe hydrodynamic forcing functions; and, 2) those which prescribe the mass sources acted upon by the hydrodynamic forcing to produce dispersion and transport. The cluster of modules for hydrodynamic forcing ultimately prescribes the velocities and diffusivities induced by wind, waves, and tidal flow for each depth increment at each node in the grid network.

The lower set of modules in Figure 2.1 compute the mixing and transport induced by the forcing functions acting on mass sources and sinks, including the lagoon and the concentrated seawater discharged from the R. O. process. The

Comparison

Suspended Particulate--LANDSAT RGB Image

Modeled Concentration Contours (Log10)

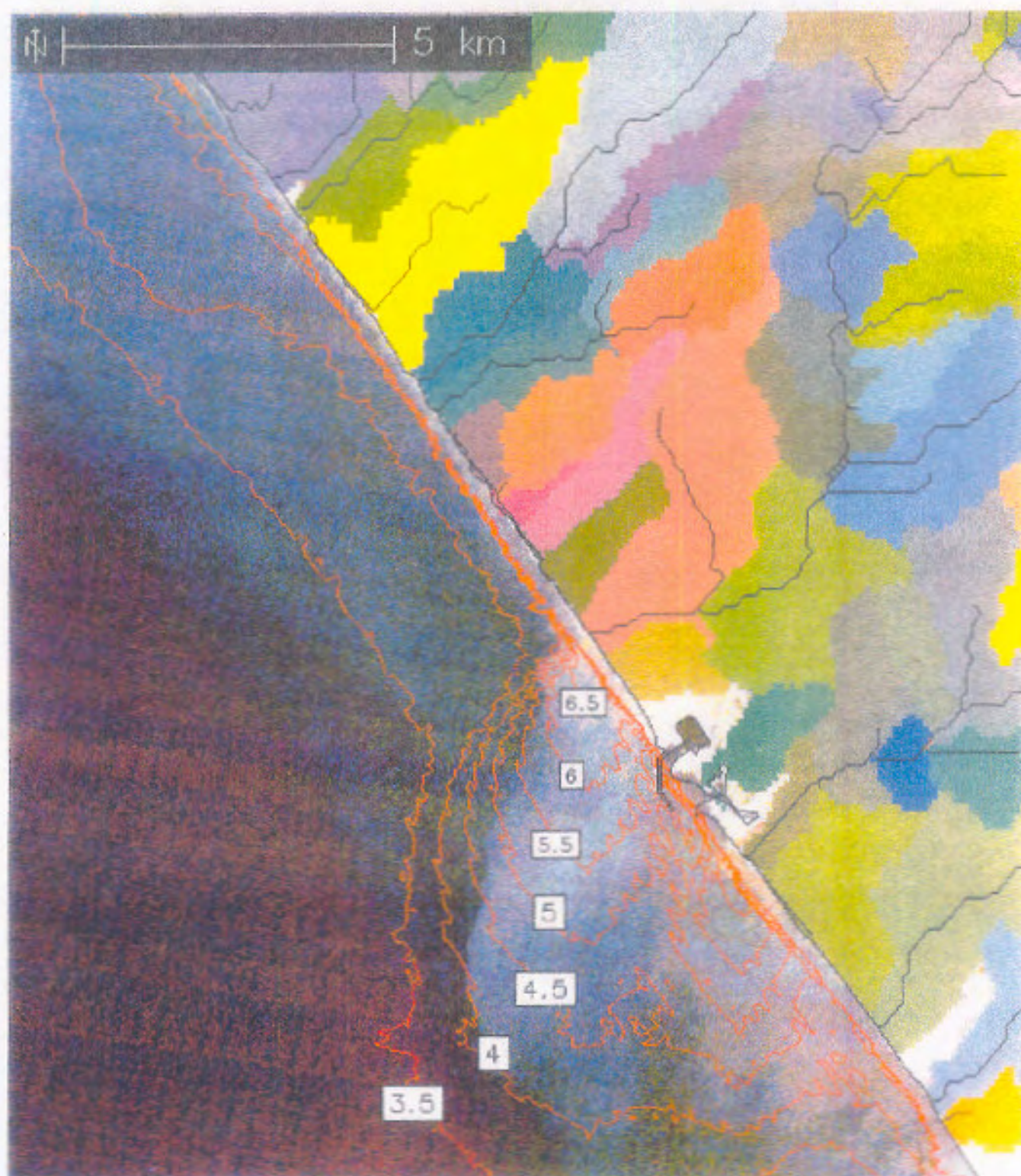


Figure 2.2. Comparisons of the SEDXPORT plume model with a LANDSAT image of the Santa Margarita River discharge on January 23, 1993. Modeled sediment concentration contours are expressed in base-10 log scale of particle number per ml. The color patchwork on the land denotes drainage basins of local streams.

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subroutines **RIVXPORT** and **BOTXPORT-f** in **SEDXPORT-f** solve for the mixing and advection of the negatively buoyant concentrated seawater in response to the wave and tidal flow using an rms vorticity-based time splitting scheme. Both **BOTXPORT** and **RIVXPORT** solve the eddy gradient form of the advection diffusion equation for the water column density field

$$\frac{\partial \rho}{\partial t} = (u - \nabla \epsilon) \cdot \nabla \rho - \epsilon \nabla^2 \rho \quad (4)$$

where u is the vector velocity from a linear combination of the wave and tidal currents, ϵ is the mass diffusivity and ρ is the water mass density. The primitive equations for the heat transport in **SEDXPORT** have the form:

$$\begin{aligned} \frac{\partial Q}{\partial t} &= (u - \nabla \epsilon_H) \cdot \nabla Q - \epsilon_H \nabla^2 Q + Q_o V(t) \\ dQ &= C_p dT \end{aligned} \quad (5)$$

where dQ is the increment of heat per unit mass due to a temperature differential, dT ; Q_o is the heat per unit mass initially imparted to the cooling water as it leaves the plant due to a temperature differential ΔT between the plant intake and outfall temperatures; $V_o(t)$ is the non-dimensional plant flow rate normalized by the tidal prism; C_p is the heat capacity of seawater at constant pressure, ϵ_H is the diffusivity of heat, u is the vector resultant of the longshore velocity, $\bar{v}(x)$, the

tidal current, u_n , and the discharge velocity $u_0(t)$; and ∇ is the vector gradient operator. In Equations (4 and 5) the last term is the heat source term and the term $-\nabla\epsilon_H$ acts much like an additional advective field in the direction of high to low eddy diffusivity. This additional "gradient eddy diffusivity velocity" is the result of local variations in wave intensity associated with the refraction/diffraction pattern, and is strongest in the wave shoaling region nearshore. For further details see Appendix E.

The water mass density is a function of temperature, T , and salinity, S , according to the equation of state expressed in terms of the specific volume, $\alpha = 1/\rho$, or:

$$\frac{d\alpha}{\alpha} = \frac{1}{\alpha} \frac{\partial\alpha}{\partial T} dT + \frac{1}{\alpha} \frac{\partial\alpha}{\partial S} dS \quad (6)$$

The factor $\partial\alpha/\partial T$, which multiplies the differential temperature changes, is known as the coefficient of thermal expansion and is typically 2×10^{-4} per $^{\circ}\text{C}$ for seawater; the factor $\partial\alpha/\partial S$ multiplying the differential salinity changes, is the coefficient of saline contraction and is typically 8×10^{-4} per part per thousand (ppt) where 1.0 ppt = 1.0 g/L of total dissolved solids (TDS). For a standard seawater, the specific volume has a value $\alpha = 0.97264 \text{ cm}^3/\text{g}$. If the percent change in specific volume by equation (6) is less than zero, then the new water mass is heavier than standard seawater, and lighter if the percent change is greater than zero. Solutions to the density field calculated from equation (4) by **SEDXPORT** are used to calculate the field salinity, $S_{(x,y,z)}$, from equation (6) for temperature inputs T for the ambient

ocean water and ΔT for plant thermal effluent. The salinity field in turn can be used to solve for the spacial varying dilution factor, $D_{(x,y,z)}$ according to:

$$D_{(x,y,z)} = \frac{S_b - S_o}{S_{(x,y,z)} - S_o} \quad (7)$$

where S_o is the ambient seawater salinity in ppt, S_b is the end-of-the-pipe salinity of concentrated seawater and $S_{(x,y,z)}$ is the local salinity from the model solution in ppt. Model solutions will find a significant variation in the salinity with water depth, z . Therefore we introduced a depth averaged dilution factor,

$$\bar{D}_{(x,y,z)} = \frac{1}{H_{(x,y)}} \int_0^H D_{(x,y,z)} dZ \quad (8)$$

where $H = H_{(x,y)} = h + \eta$ is the local water depth, h is the local water depth below mean sea level and η is the tidal amplitude.

The diffusivity, ϵ , in equations (4 and 5) controls the strength of mixing and dilution of the concentrated seawater and flood water constituents, and varies with position in the water column relative to the pycnocline interface. Vertical mixing includes two mixing mechanisms at depths above and below the pycnocline: 1) fossil turbulence from the bottom boundary layer, and 2) wind mixing in the surface mixed layer. The pycnocline depth is treated as a zone of hindered mixing and varies in response to the wind speed and duration. Below the pycnocline, only turbulence from the bottom wave/current boundary layer contributes to the local diffusivity. Nearshore, breaking wave activity also contributes to mixing. The surf

zone is treated as a line source of turbulent kinetic energy by the subroutine **SURXPORT-f**. This subroutine calculates seaward mixing from fossil surf zone turbulence, and seaward advection from rip currents embedded in the line source. Both the eddy diffusivity of the line source and the strength and position of the embedded rip currents are computed from the shoaling wave parameters evaluated at the breakpoint, as throughput of **OCEANRDS-f**.

SECTION 3: MODEL INITIALIZATION

3.1) Ocean Monitoring Data and Variability

Uninterrupted, long-term monitoring of ocean properties has not been maintained at Encina, but has been at the nearby Scripps Pier. The Scripps Pier site has many physical features in common with the nearshore area around Encina. Both sites have a narrow shelf and a submarine canyon nearby. Consequently internal waves are an active mechanism at both sites in causing daily (diurnal) variations in salinity, temperature, and other ocean properties. The longer period variations at seasonal and multiple year time scales are the same at both sites due to their proximity. Consequently the Scripps Pier Shore Station data (SIO, 2001) and the Coastal Data Information Program monitoring at Scripps Pier (CDIP, 2001) are used as surrogates for long term records of physical ocean properties at Encina. These properties will be shown to exhibit considerable natural variability over the period of record from 1980 to mid 2000 due to daily and seasonal changes, but most especially due to climate changes.

The seasonal variations in the exposure of the hemispheres to the sun produce inter-annual changes in the duration of daylight and the angle of the sun's irradiance. These effects modulate solar heating, resulting in the inter-annual variation of the earth's atmospheric pressure field which in turn introduces seasonal climatic effects. Inter-annual variations are enhanced by the higher convective effects of land and the greater concentration of land mass relative to water in the temperate latitudes of the northern hemisphere.

Upon occasion the typical seasonal weather cycles are abruptly and severely modified on a global scale. These intense global modifications are signaled by anomalies in the pressure fields between the tropical eastern Pacific and Malaysia

known as the *El Niño/Southern Oscillation* (ENSO) (e.g., Diaz & Markgraf, eds., 1992). The intensity of the oscillation is often measured in terms of the *Southern Oscillation Index* (SOI), defined as the monthly mean sea level pressure anomaly in mb normalized by the standard deviation of the monthly means for the period 1951-1980 at Tahiti, minus that at Darwin, Australia. A negative SOI (lower pressure at Tahiti, higher pressure at Darwin) is known as an *El Niño* or warm ENSO event, because of the arrival of unusually warm surface water off the coast of Peru at the time of Christmas; hence, the term *El Niño*. Warm water also occurs along the coast of California and both regions experience unusually heavy rainfall. A positive SOI is known as *La Niña* and it signals the occurrence of colder than normal surface water in the eastern Pacific, but stronger southwest monsoons in the Indian Ocean with heavy rainfall in India and in the Ethiopian plateau.

ENSO events occur about every 3 to 7 years with dominant spectral peaks at about 3 and 6 plus years. However these ENSO events may induce climate changes that occur on decadal time scales of one quarter to one half century. These changes are often discussed in terms of two atmospheric patterns (PNA, NAO) and a sea surface temperature pattern (PDO). Both PNA and PDO are long period (i.e., interdecadal) analogs of the seasonal (interannual) variations of global pressure and temperature, while NAO is an intensification and relaxation of the January phase of the interannual variation. They are aliased by the interannual changes because they have the same structure and appear as extreme cases of the interannual patterns. This aliasing has delayed the general understanding and acceptance of these concepts.

The Pacific/North American (PNA) pattern is associated with an atmospheric dipole in pressure anomaly over the Pacific Ocean/North America region whose

polarity reversals lead to wet and dry climate along the Pacific coast of North America (Wallace & Gutzler, 1981). High pressure anomaly over the North Pacific Ocean and low pressure anomaly over the North American Continent result in dry (La Niña) climate along the coast of central and southern California; while the opposite polarity in these longitudinal (zonal) dipole patterns leads to wet (El Niño) climate. Inman & Jenkins (1999) show that the coastal rivers of central and southern California have streamflow and sediment fluxes during the wet phase of PNA (1969-1995) that exceed those during the preceding dry phase (1944-1968) by factors of 3 and 5 respectively.

The Pacific (inter) Decadal Oscillation (PDO) is a sea surface temperature pattern associated with the La Niña/El Niño phases of ENSO cycles, with the leading pattern of PDO situated in the tropical Pacific Ocean (Goddard & Graham, 1997; Mantua et al., 1997). The El Niño phase of the PDO cycle is characterized by a weakening of the trade winds that results in an eastward movement (slosh) of the warm pool of equatorial water normally contained in the western Pacific by the trades during La Niña conditions. The stronger trade wind systems during the La Niña phase of PDO are part of a general spin-up of the atmospheric circulation which causes the North and South Pacific Gyres to rotate faster. Both effects (wind and current) induce upwelling that maintains cold water masses along the west coast of the Americas, which sustains the typically cool dry coastal climate of these regions during the La Niña dominated periods of the PDO and PNA.

3.2) Boundary Conditions

A) Bathymetry

Bathymetry provides a controlling influence on all of the coastal processes at work in both the nearfield and farfield of Encina. The bathymetry consists of two

parts: 1) a stationary component in the offshore where depths are roughly invariant over time, and 2) a non-stationary component in the nearshore where depth variations do occur over time. The stationary bathymetry generally prevails at depths that exceed *closure depth* which is the depth at which net on/offshore transport vanishes. Closure depth is typically -12 m to -15 m MSL in the Oceanside Littoral Cell, [Inman et al. 1993]. The stationary bathymetry was derived from the National Ocean Survey (NOS) digital database as plotted in Figure 1.4. 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. Grid cell dimensions along the x-axis (longitude) are 77.2 meters and 92.6 meters along the y-axis (latitude). This small amount of grid distortion is converted internally to Cartesian coordinates, using a Mercator projection of the latitude-longitude grid centered on Agua Hedionda Lagoon. The convention for Cartesian coordinates uses x-grid spacings for longitude and y-grid spacings for latitude. Any depths below 305 meters are assigned default values of 305 m. while any land masses or shoals above 0-MSL are assigned default values of -1.14 m.

For the non-stationary bathymetry data inshore of closure depth (less than -15 m MSL) a precision GPS nearshore and beach survey was conducted in September 2000 [Dyson, 2000]. These nearshore and beach survey data are plotted in Figure 3.1 and were used to update the NOS database for contemporary nearshore and shoreline changes that have occurred following the most recent NOS surveys. The September 2000 nearshore bathymetry database was merged with the NOS database to generate the bathymetry for both the farfield computational cell in Figure 1.4 and the nearfield computational cell shown in Figure 1.1.

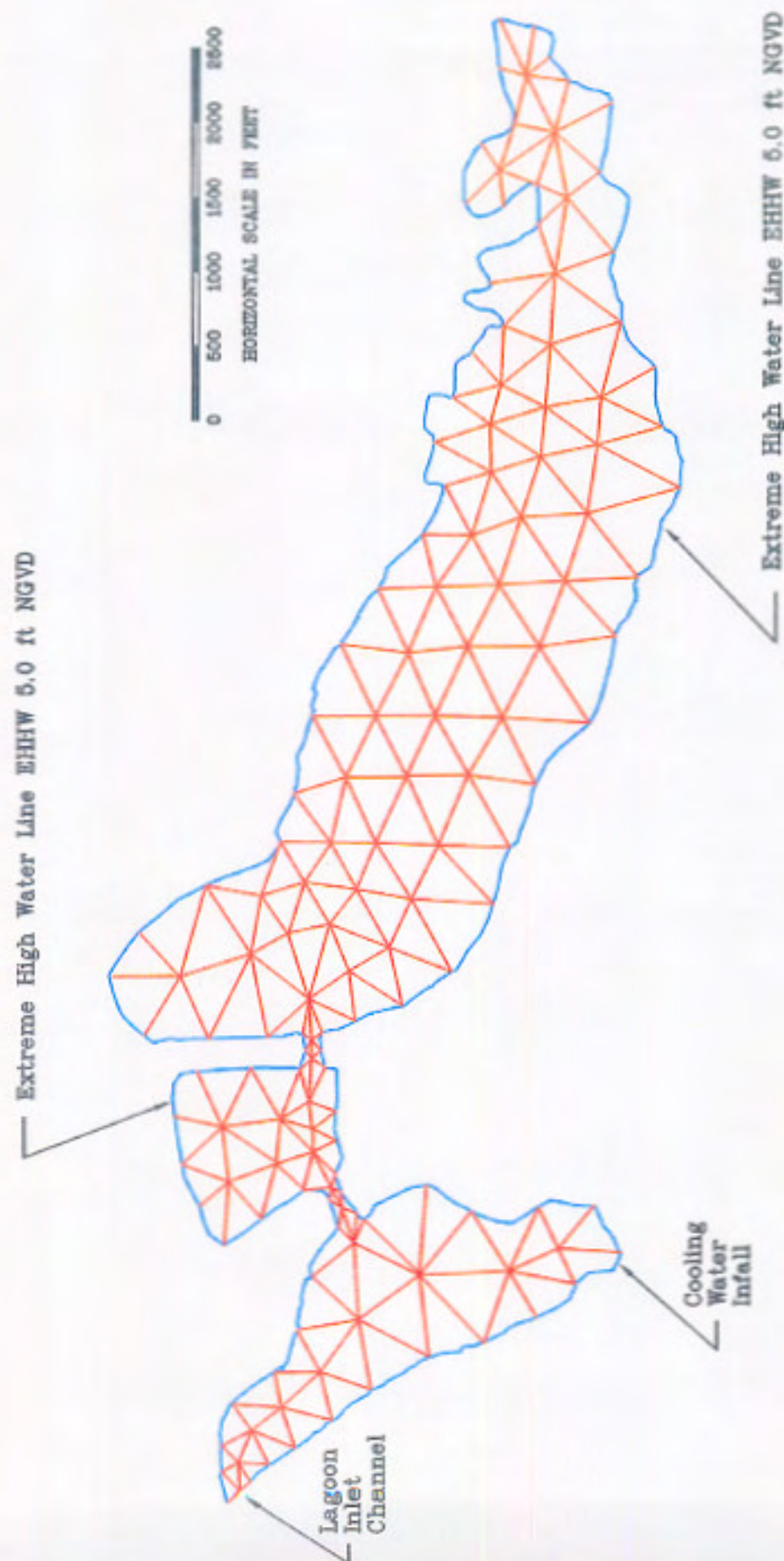


Figure 3.1 Precision nearshore survey from Dyson (2000) for near field bathymetry.

The lagoon bathymetry grid has been structured as a finite element mesh consisting of triangular grid elements (Figure 3.2) with depth assignments of each node point according to lagoon bathymetry in Figure 3.3. These elements have been formulated as 3-node triangular elements with one curved side based upon the cubic-spline matrices developed by Weiyan (1992). These two sets of elements were assembled into a computational mesh of the lagoon conforming to the lagoon extreme high waterline defining the grid perimeter in Figure 3.2. The wet-dry boundary coordinates of the curved waterline, (x', y') , are linearly interpolated for any given water elevation from the contours stored in the lagoon bathymetry file based on the updated lagoon bathymetry following the east basin dredge improvements (Figure 3.3). For more details, refer to the TIDE_FEM code in Appendix B, and Gallagher (1981) or Oden & Oliveira (1973).

B) Power Plant Flow Rates

The power plant cooling water is drawn from the lagoon and is discharged into the ocean through an independent discharge channel located between Middle Beach and South Beach in Figure 1.2 and 1.3. The utilization of lagoon water by the power plant makes Agua Hedionda distinctly different from natural tidal lagoons. Power plant cooling water uptake acts as a kind of “negative river.” Whereas most lagoons have a river adding water to the lagoon, causing a net outflow at the ocean inlet, Agua Hedionda’s power plant inflow removes water from the lagoon, resulting in a net inflow of water through the ocean inlet referred to as *flood dominance*. That net inflow diminishes or at times cancels the ebb flow velocities out of the inlet, thereby inhibiting or preventing tidal flushing and increasing the likelihood for recirculation of concentrated seawater into the lagoon from RO by-product discharge. The plant demand for lagoon water is directly



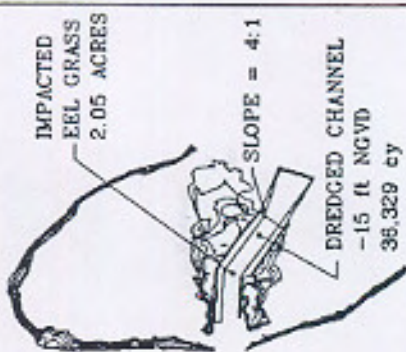
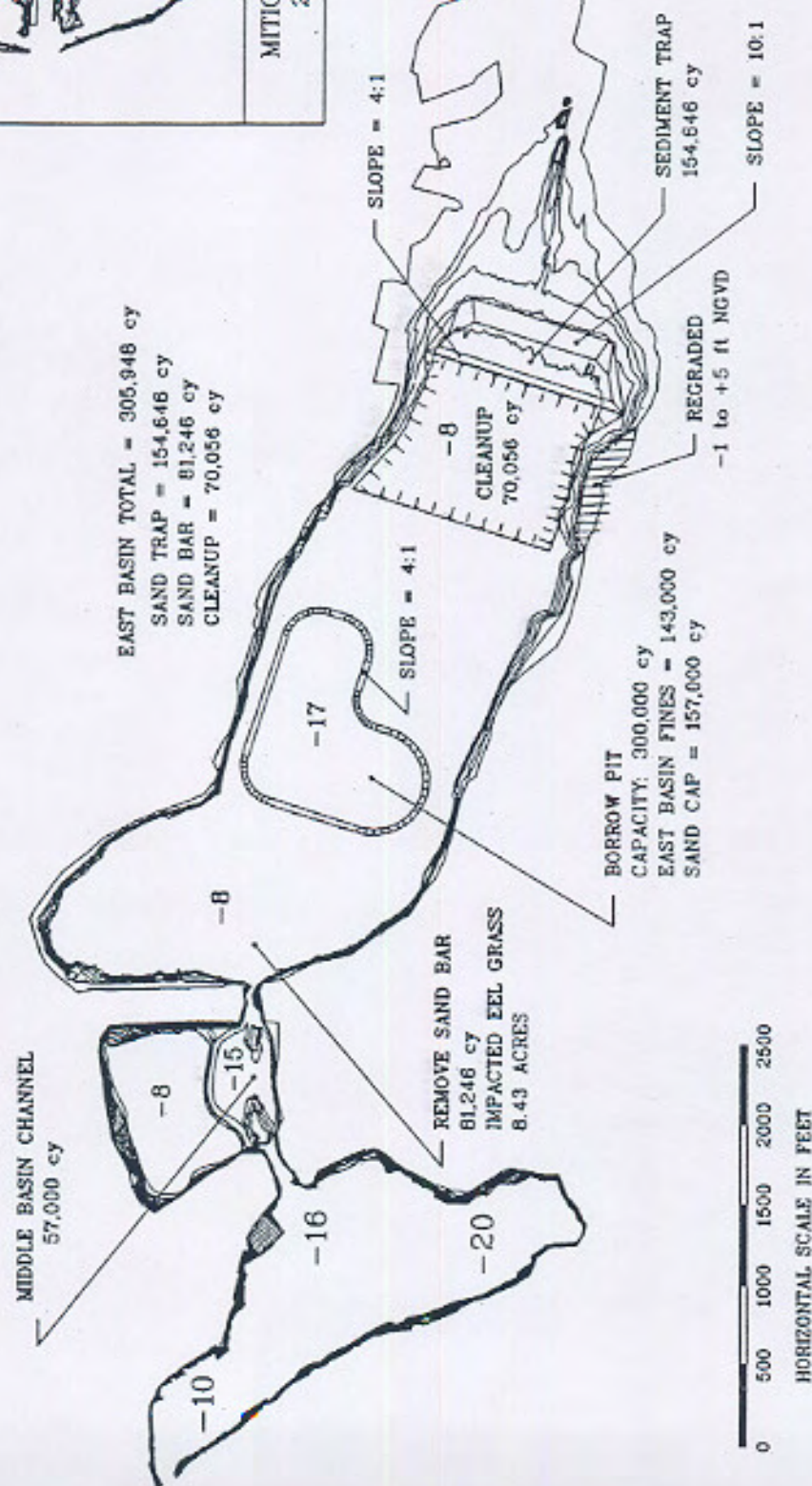
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Agua Hedionda Finite Element Mesh

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Figure 3.2. Computational mesh for TIDE_FEM tidal hydraulics model of Agua Hedionda Lagoon.

FULLY IMPLEMENTED 4 STAGE DREDGE PLAN
AGUA HEDIONDA LAGOON, CA



MITIGATED STAGE 3
261,031 cy

DR. SCOTT A. JENKINS CONSULTING

TOTAL DREDGE VOLUME = 600,000 cy

SCOTT A. JENKINS PhD & JOSEPH WASYL

Figure 3.3. Layout of a four-stage reconstruction dredging plan completed February 1998.

proportional to the degree of flood dominance and thereby directly proportional to the potential for recirculation.

Plant flow rate data was provided in hourly increments on an ASCII-formatted diskette by the power plant owner/operator, Cabrillo Power I LLC, for the calendar year of 1999. These data are plotted in Figure 3.4a. Inspection of Figure 3.4a indicates that flow rates of 735-800 mgd are fairly representative of the high user demand during warm weather. The average rate of cooling water flow was 550 mgd which is very close to a rate of utilization at 70% of maximum capacity (570 mgd), where maximum capacity is 808 mgd. It is also noted that inflow rates vary at most on a daily rather than hourly basis, and often remain constant for a week or longer. This is a fortunate circumstance from the hydraulic modeling standpoint because the tidal hydraulics model must be run at 0.1 hr. time steps to insure numerical stability. The slow variability of the plant inflow rate allows simple interpolations to 0.1 hr. increments without introducing aliasing errors. The plant inflow rate file was interpolated to 0.1 hr. time step intervals, and input to the tidal hydraulics model as a time varying sink (suction) in the lagoon computational mesh (Figure 3.2).

The final construction dredging report by Ellis (1954) indicated that the lagoon system initially had a mean tidal prism of 55 million cubic feet and a maximum diurnal or spring tidal prism of 80 million cubic feet. Since that time, five power-generating units have been brought on line, increasing the maximum flow rate diverted from the lagoon through plant condenser systems to 808,000,000 gallons/day. Plant diversion of lagoon waters at this flow rate reduces the volume of water flowing out the ocean inlet during ebb flow by 27,939,664 cubic feet, or about 51% of the original mean tidal prism or 35% of the original maximum spring

prism. During high user demand periods, plant flow rates typically reduce the volume of water available to flush ocean inlet by 42% for mean tidal ranges.

A histogram of the plant flow rates for 1999 was constructed in Figure 3.4b and is compared against the flow rate histogram for 1993-94 from Jenkins & Wasyly (1994). Although flow rates above 70% capacity were more common in 1999 than 1994, the mean flow rate is relatively unchanged. This is due to the fact that the plant operates pumps according to a number of operational requirements of the western power grid that often reflect factors other than local user demand for electrical power. Because of the apparent minor differences in annual flow volume from year to year, the 1999 flow rate history will be utilized as a surrogate for all years in the model problem. This was done to project contemporary high user demand on all historic worst case scenarios so as not to underestimate the potential for recirculation of the concentrated seawater by-product. The resulting 20.5 year long time series for project flow rate obtained by looping the 1999 year record is shown in Panel-a of Figure 5.3.

C) Ocean Salinity

Since the discharge channel at Encina discharges into the surfzone, the surface salinity monitoring data from Scripps Pier was used for reconstruction of a 20.5 year record of ocean salinity in the nearshore of Encina, as shown in Panel-b of Figure 3.5. In the period of record from 1980 through mid 2000, the maximum recorded salinity was 34.44 ppt (parts per thousand) and the minimum was 31.26 ppt. Smaller variations occurred over daily and seasonal time scales, while the maximum range of salinity variation (10%) was concurrent with the powerful 1993 (ENSO cycle). The 20.5 year average salinity was 33.52 ppt.

D) Ocean Temperature

Again, because the Encina Power Plant discharges into the surfzone, we use ocean surface temperature off Scripps Pier to characterize the temperature environment off Encina. The 20.5 year long reconstruction of surface temperatures from the Scripps Pier Shore Station monitoring is given in Panel-c of Figure 3.5. A pronounced seasonal variation in these temperatures is quite evident with the maximum recorded daily mean temperature reaching 25.1 °C during the summer of the 1993 El Niño and the minimum falling to 9.9 °C during the winter of the 1999-2000 La Niña. The 20.5 year mean temperature was found to be 17.6 °C. Consequently natural temperature variability of the coastal waters in the vicinity of the Scripps Pier and Encina Power Plant is on the order of 86%.

E) Ocean Water Levels

Dilution levels in the discharge channel (Figure 1.3) and the recirculation of concentrated seawater into the lagoon is driven by the time variation in ocean water level, and by the rate of cooling water consumption by the Encina power plant. The nearest ocean tide gage station that measures ocean water levels near Encina is located at Scripps Pier, La Jolla, CA. This tide gage (NOAA #941-0230) was last leveled using the 1960-78 tidal epoch, which resulted in the following tidal datum:

MEAN HIGHER HIGH WATER (MHHW) = +2.81 FT. NGVD

MEAN HIGH TIDE (MHT) = +2.06 FT. NGVD

MEAN SEA LEVEL (MSL) = +0.19 FT. NGVD

MEAN LOWER LOW WATER (MLLW) = -2.56 FT. NGVD

It is interesting to note that mean sea level as determined by the 1960-78 tidal epoch statistics is higher than the level at which mean sea level was measured in 1929 to establish the National Geodetic Vertical Datum (NGVD). Furthermore, tide tables based on the 1960-78 tidal epoch frequently under estimate high tide

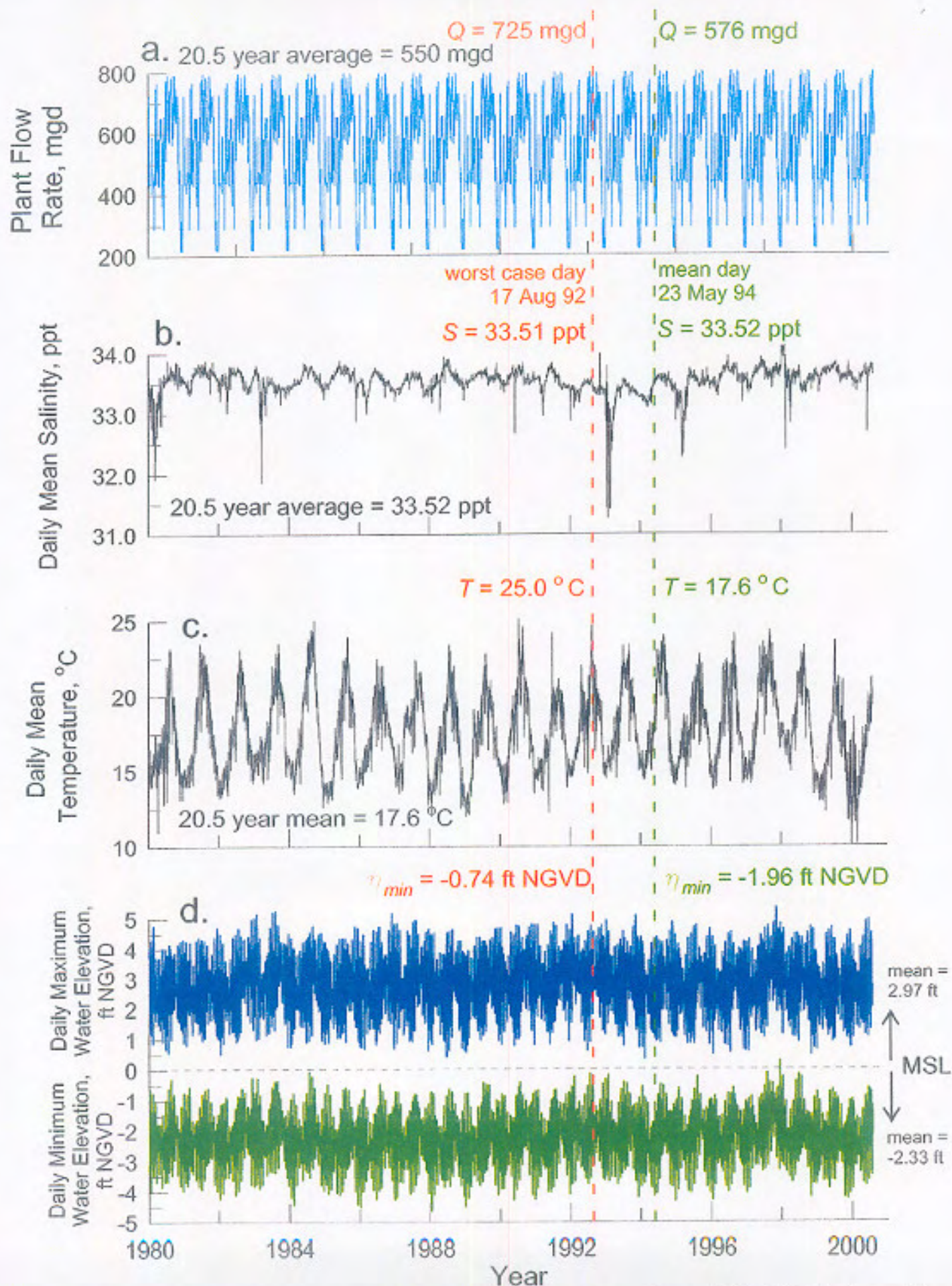


Figure 3.5. Period of record of boundary conditions, Encina Power Plant, 1980-2000.5: a) plant flow rate b) daily mean salinity, c) daily mean temperature, and d) daily high and low water elevations.

elevations. This is due to several factors including: 1) the long-term upward creep in eustatic sea level during the last part of the modern sea level high stand 2) seasonal warming and cooling of the ocean and 3) climate effects. These are shown schematically in Figure 3.6. Global warming is believed to be a factor in the gradual rise of mean sea which has been estimated at 0.7 ft./100 yr. in this century. However, there are other factors which also influence the mean sea level about which the astronomic tides oscillate. Flick & Cayan (1984) have shown that seasonal warming and cooling accounts for an interannual variation in mean sea level of about 0.5 ft. El Niño or ENSO events can result in sea level anomalies of 1.0 ft. or more due to the thermal expansion effects of the coastal warm water anomalies of El Niño and by the inverse barometer effects on sea level associated with the ENSO induced North Pacific low pressure anomaly (see Figure 3.8 in Section 3.3.A for more detail).

Water levels measured by the Scripps Pier Tide Gage (#941-0230) have been archived by NOAA (2000) for the preceding 20.5 year period, 1980 through mid 2000. Time series of the daily high and low ocean water levels were reconstructed from these archival measurements for each year from 1980 through 1999. (This is the longest time period for which an uninterrupted record of directional wave data can be assembled in this region). Figure 3.7 shows the numbers of diurnal tidal cycles in a 20 year period that the ocean water level reached a particular incremental range of values. In this case, the increment of tidal elevation used to construct the histogram is 0.25 ft. Inspection of Figure 3.7 reveals that the total ensemble of observed daily high and low water levels between 1988 and 1997 exhibit bell-shaped distributions, but both are centered at elevations higher than the MHHW and MLLW tidal datum established by the 1960-78 tidal epoch [see

Climate Effects on Absolute Tidal Elevation

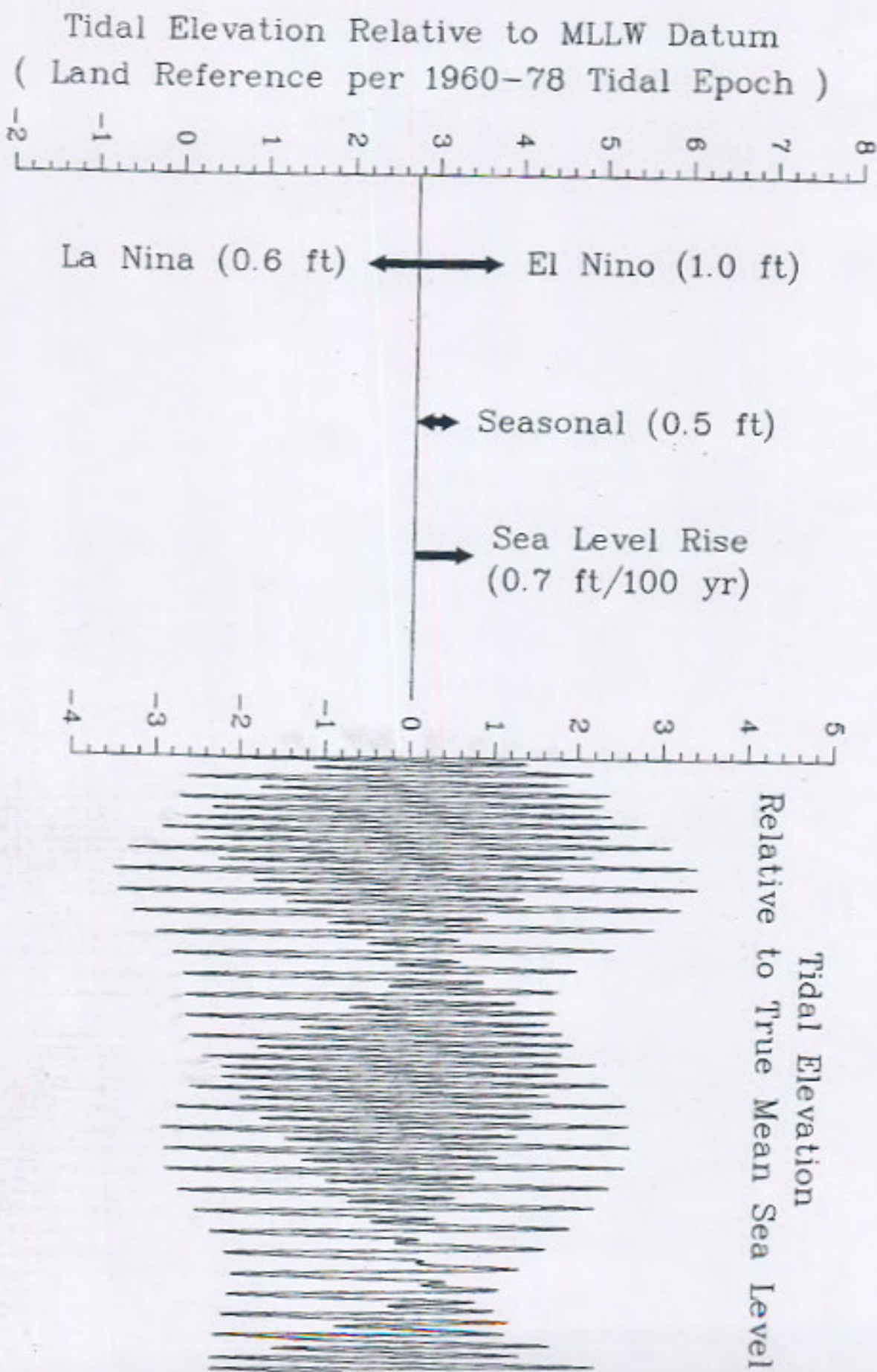


Figure 3.6. Seasonal and long-term effects of climate changes on sea level and tidal elevations.

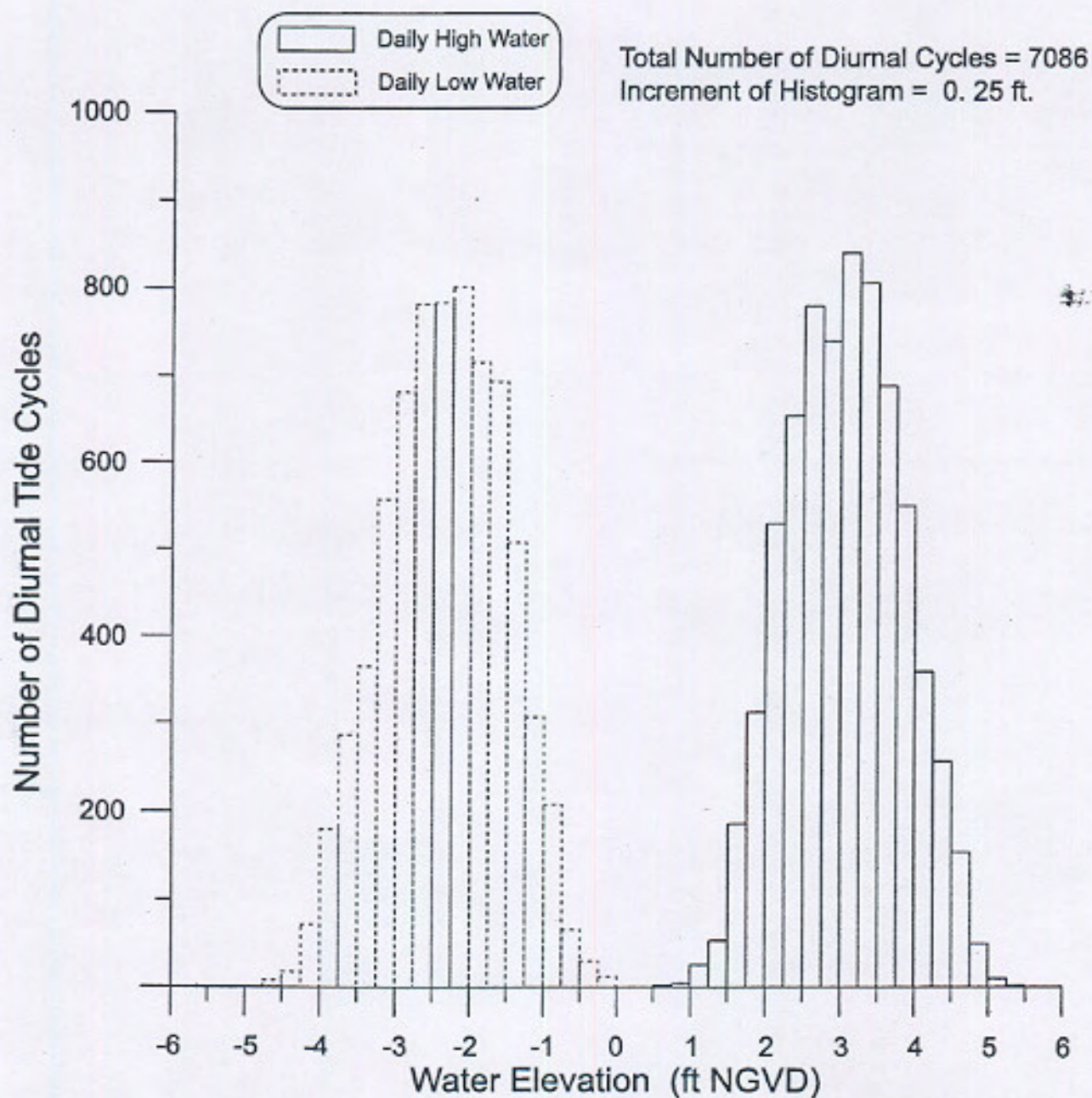


Figure 3.7. Histogram of daily extreme water elevations from measured Scripps Pier tide gage records for 1980-2000; NOAA #941-0230.

above]. Figure 3.7 shows that the observed distribution of daily high water levels is centered around the histogram increment extending from +3.0 ft. NGVD to +3.25 ft. NGVD. This is significantly higher than the NOAA standard MHHW tidal datum of +2.81 ft. Similarly the observed distribution of daily low water levels in Figure 3.7 is centered around the histogram increment extending from -2.0 ft. NGVD to -2.25 ft. NGVD, vs the NOAA standard MLLW tidal datum of -2.56 ft. NGVD. Therefore, the phenomena of positive sea level anomalies is a persistent and sustained occurrence in the observations of ocean water levels during the last 20 years. Moreover, Figure 3.7 reveals that a very significant number of diurnal tide cycles during the last 20 years (466) have produced water level elevations well in excess of the extreme higher-high water levels (EHHW) of the astronomic tides, where EHHW = +4.28 ft. NGVD for a perigean spring tide occurring once every 4.5 years. Therefore, the occurrence of extreme water levels in excess of the astronomic tides are not merely rare, isolated events; but rather events which occur a significant number of days per year.

Because tidal flow is extremely sensitive to water depth in inlet channels, it was deemed essential that observations of ocean water levels be used to prescribe the ocean water level forcing in any long-term simulation of tidal flux into Agua Hedionda Lagoon. This requirement is in preference to analysis based only on the astronomic tidal constituent of the ocean water level. Although the sea level anomaly is small relative to the amplitudes of the astronomic tides, its effect on the volume of water entering and leaving the lagoon every tide cycle can be quite large particularly since the lagoon stores the preponderance of its water volume in the intertidal zone. This in turn effects the tidal velocities entraining beach sand into the lagoon. Since sediment transport responds at a high power of the velocity,

small errors in prescribing the water elevation using only the astronomic tidal constituent create large errors in estimating the resulting sediment transport into or out of the lagoon. However, the use of observations of historic ocean water levels in hydraulic modeling exercises requires reconstruction of the water level time series at time steps much shorter than the observation intervals (typically 6 minutes to 1 hour).

It can be shown that the historic ocean water levels may be reconstructed from astronomic tidal constituents with reasonable accuracy over short term records by a constant offset to the astronomic tidal elevations. The astronomic tides from the TID_DAYS code (Appendix C) have been corrected by daily offsets that minimize the mean squared error between the predicted and measured water level. Reconstruction of a 20.5 year water level time series was performed on the entire set of 1980-2000 NOAA measurements. The resulting time series of daily maximum and minimum ocean water levels is plotted in Panel-d of Figure 3.5. The maximum ocean water level was +5.35 ft. NGVD during the 1997 El Niño, 1.31 ft. higher than the astronomic tides of the tide tables. The minimum ocean water level was -4.66 ft. NGVD, occurring during the 1988 winter.

F) Power Plant Operating Temperatures

Section 316(a) of the Clean Water Act requires compliance with the State water quality standards for the discharge of thermal effluent. The State of California Regional Water Resources Control Board accepted delegation of the National Pollutant Elimination System permit program from the U.S. Environmental Protection Agency in 1972.

California's Thermal Plan incorporates provisions of Section 316(a) of the Federal Water Pollution Control Act of 1972 and defines the relevant regulatory

requirements for cooling water discharge from the Encina Power Plant. The applicable regulatory requirements are found in those sections of the Thermal Plan dealing with Specific Water Quality Objectives, General Water Quality Provisions, and provisions within the implementation section. As an existing discharge to coastal waters, Encina Units 1 through 5 have the following Specific Water Quality Objectives:

- 3A(1) - Elevated temperature wastes shall comply with limitations necessary to assure protection of beneficial uses and areas of special biological significance.
- 3B(1) - Elevated temperature wastes shall be discharged to the open water away from the shoreline to achieve dispersion through the vertical water column.
- 3B(2) - Elevated temperature wastes shall be discharged a sufficient distance from areas of special biological significance to assure the maintenance of natural temperature in these areas.
- 3B(3) - The maximum temperature of thermal waste discharges shall not exceed the natural temperature of receiving waters by more than 20 °F.
- 3B(4) - The discharge of elevated temperature wastes should not result in increases in the natural water temperature exceeding 4 °F at

modulated by seasonal storms and by the ENSO and PNA induced climatic variations described in Section 3.1.

In the eastern North Pacific Ocean (where storms and swells affecting California are spawned) the La Niña condition leads to surface pressure distributions and upper level wind systems that cause frontal cyclones from the Gulf of Alaska to follow storm tracks into the Pacific northwest (Figure 3.9a). During El Niño, surface pressures over the eastern North Pacific decline while jet stream flow develops extreme southward meanders, steering ocean storms into the Southern California Bight (Figure 3.9b).

Along the southern California coast a period of mild-stable weather occurred during the 30 years between the mid-1940's and mid-1970's when La Niña dominated storm systems like Figure 3.9a prevailed. The average SOI for this period was +0.1, with strong La Niña events in 1950, (SOI = +1.4); 1955/56, (+1.2); 1970/71, (+1.0); 1973/74, (+1.0); and 1975/76 (+1.4). Winters were moderate with low rainfall, and winds were predominantly from the west-northwest. The principal wave energy was from Aleutian lows having storm tracks which usually did not reach southern California (Figure 3.9a). Summers were mild and dry with the largest summer swells coming from very distant southern hemisphere storms.

The wave climate in southern California changed, beginning with the El Niño years of 1978-79 and extending at least until 1999. The average SOI for this period was -0.5, with the 1978-79 El Niño averaging -1.2; the 1980-83 El Niño averaging a record -1.7; the 1987-88 El Niño averaging -1.3, the 1990-95 El Niño recording a mean of -1.0; and the 1997-98 El Niño averaging -1.3. Altogether there were 11 years during the 19.4 year model period that recorded negative SOI values indicative of El Niño climate. During these years the prevailing

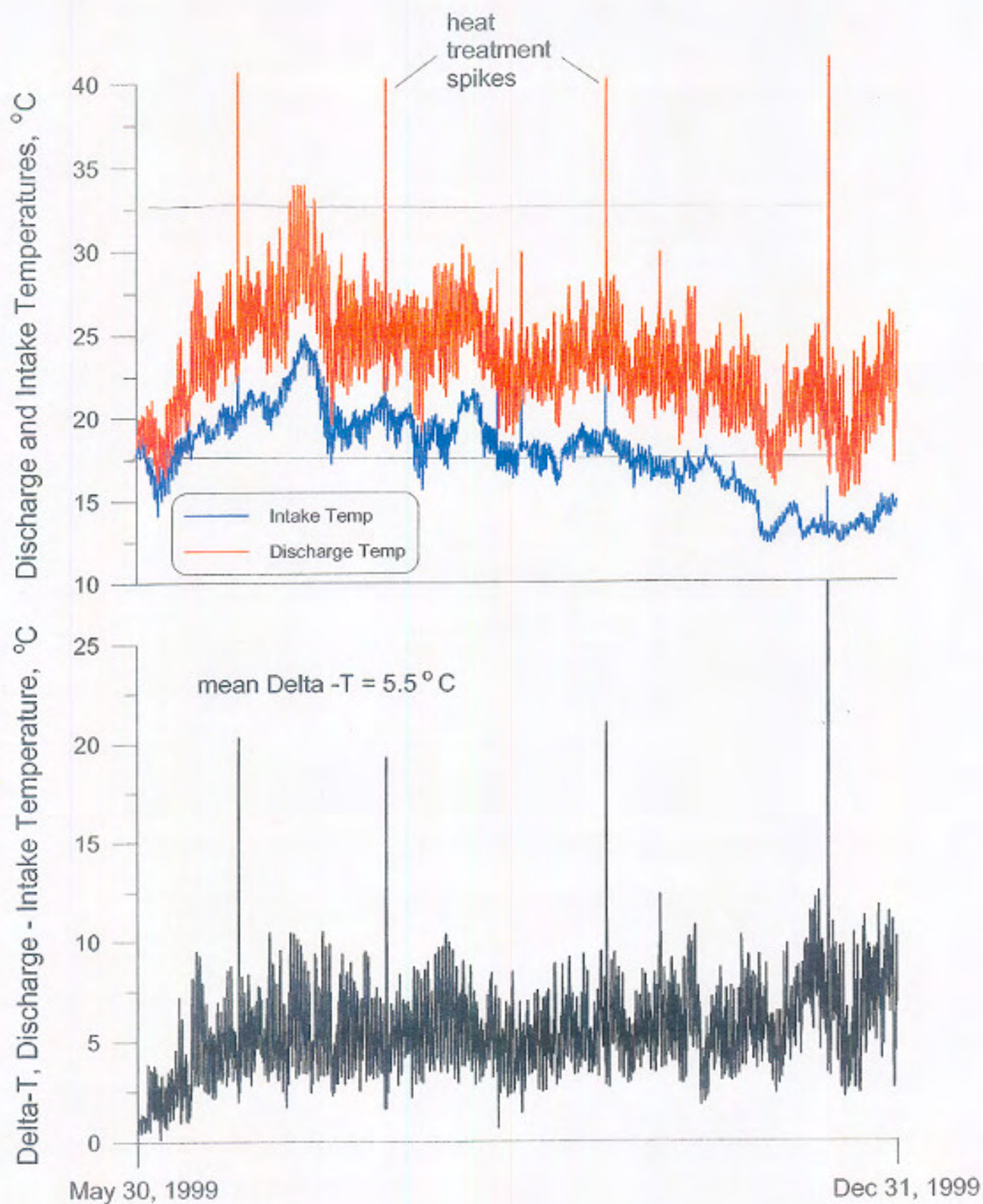


Figure 3.8. Operating temperatures, Encina Power Plant, a) Intake and discharge temperatures; b) Delta-T

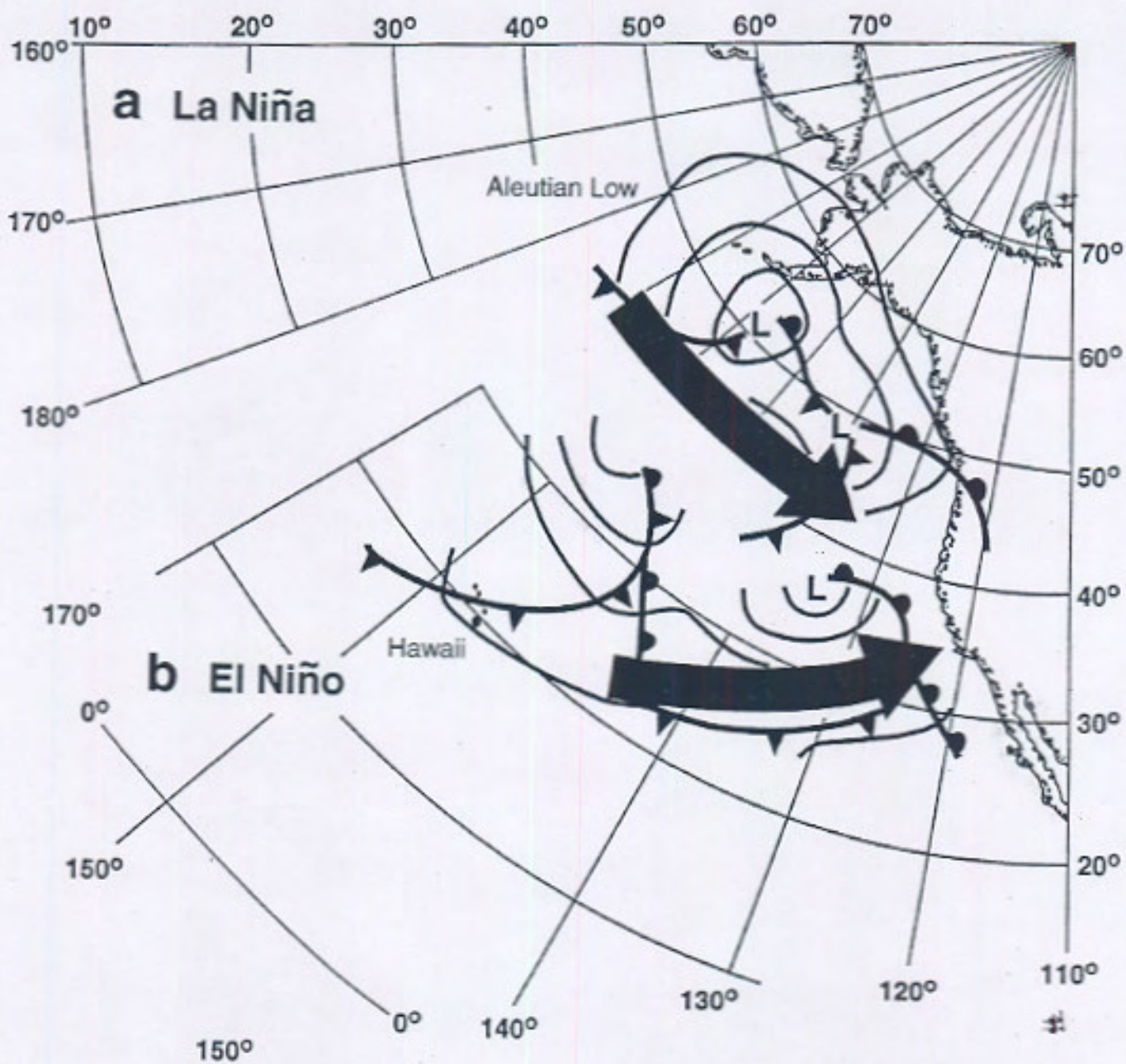


Figure 3.9. Typical storm track for a) La Nina and b) El Nino winter seasons.

northwesterly winter waves were often replaced by high energy waves approaching from the west or southwest, and the previous southern hemisphere swell waves of summer have been replaced by shorter period tropical storm waves during late summer months from the more immediate waters off Central America.

Data of instrumented buoys and light vessels in the North Pacific show that wave heights have increased significantly and continuously during the past 25 years. The measurements of six buoys between latitude 34°N and 56°N in the eastern North Pacific cover the 25 year time interval from 1975-1999 [Allen & Komar, 2000]. Over this period, the average annual (root-mean square) wave height increased progressively from about 1.6 m. to 1.9 m, generating a landward wave energy flux that ranged for these average waves from about 93×10^6 kW to 131×10^6 kW over the same period [Inman & Jenkins, 2000]. This is highly significant because the mixing and dilution in the nearshore are directly proportional to the wave energy flux. To account for this recent trend, the model results of this study are based on the contemporary wave climate record of 1980 to mid 2000. El Niño storms generate two distinct swell patterns. These storms typically have an intense low pressure cyclone with an associated cold front, Figure 3.10. They are distinctive from the frontal cyclones occurring during La Niñas in that the cyclone portion of the storm tracks to much lower latitudes, (Figure 3.9b), and the associated cold front is very long, extending well into subtropical latitudes and entraining sub-tropical moisture. Consequently the pre-frontal winds which blow along the leading edge of the cold front have a very long fetch, while the warm subtropical moisture intensifies these winds through cyclogenesis. The intense, long fetch of the pre-frontal side of an El Niño storm gives rise to very high energy swells from the south-southwest. On the cold post frontal side of an El

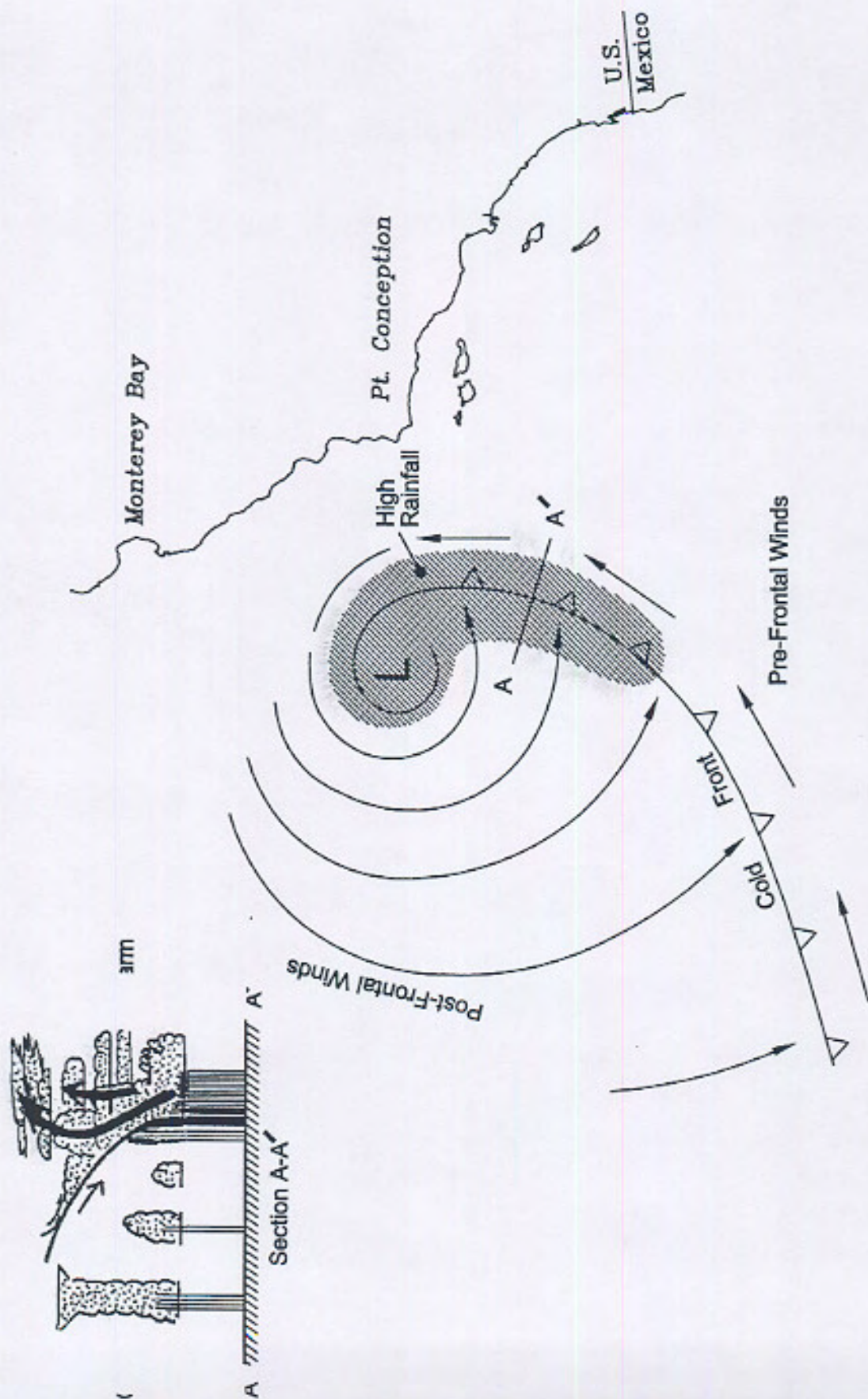


Figure 3.10. Anatomy of El Niño storms.

Niño storm, the winds blow from the west-northwest, but decrease rapidly with distance away from the cyclone (labeled L in Figure 3.10). Consequently the post frontal winds have a much shorter effective fetch and the post frontal north-northwesterly swells are less intense than the pre-frontal south-southwesterly swells. On the other hand the propagation of these storms is retarded when they encounter the orography of the Southern California Bight, and thus the post-frontal swells are often more persistent and longer lived. In total, the El Niño storms have two distinct swell patterns that are directionally bipolar with regard to littoral drift along the lower reaches of the Bight. These directional characteristics tend to diminish the typical southward directed littoral drift, and instead act to drive the littoral drift back and forth along the coast with a small net direction.

In considering the predominant wave directions for high energy swells reaching the Carlsbad/Encina area, the sheltering effects of the Channel Island System must be taken into account. Figure 3.11 shows that only certain gaps or “*wave windows*” between the islands and intervening land masses will allow the high energy, long period swells of distant storms to reach the Agua Hedionda Lagoon. There are three distinct wave windows: 1) a *south window* providing wave exposure to swells approaching from between 160° and 249° true; 2) a *west window* open to swells from 261° to 282°, and 3) a *northwest window* through which swells from 287° to 310° will reach Encina. All remaining directions between these wave windows are open only to locally generated wind waves. Although these wind waves are much lower energy events than the significant long swells, they are none-the-less more persistent and may contribute to significant net littoral drift over long periods of time. The most persistent and

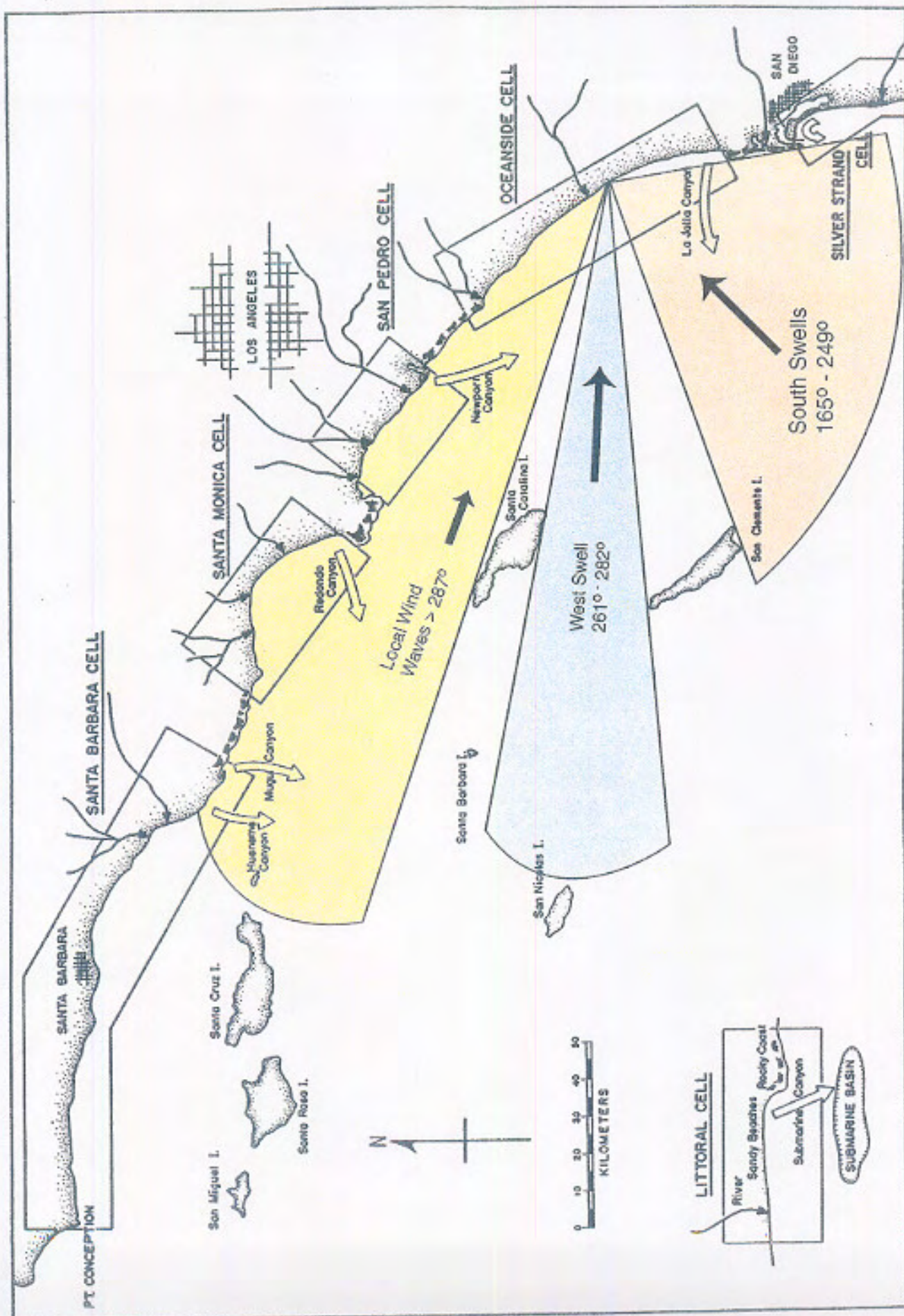


Figure 3.11 Island Sheltering Effects at entrance to Agua Hedionda Lagoon, CA

strongest local winds are the northwesterly diurnal sea breezes producing wind waves typically from 280° - 310° true.

For the probability search of worst case and average case wave statistics and for subsequent dispersion modeling, continuous unbroken wave records are required and must provide wave height, period and direction. Waves have been routinely monitored at several locations in the lower Southern California Bight since 1980 by the Coastal Data Information Program, [CDIP, 2001]. The nearest CDIP directional wave monitoring sites are:

a) Huntington Beach Array

- Station ID: 07201
- Location:
 - 33 37.9'North, 117 58.7'West
 - Approximately 1 mile west of lifeguard headquarters at Huntington Beach, CA
- Water Depth (m): 10
- Instrument Description:
 - Underwater Directional Array
- Measured Parameters:
 - Wave Energy
 - Wave Period
 - Wave Direction

b) San Clemente

- Station ID: 05201
- Location:
 - 33 25.2'North, 117 37.8'West
 - 1000 ft NW of San Clemente Pier
- Water Depth (m): 10
- Instrument Description:
 - Underwater Directional Array
- Measured Parameters:

- Wave Energy
 - Wave Period
 - Wave Direction
- c) **Oceanside Array**
- Station ID: 00401
 - Location:
 - 33 11.4'North, 117 23.4'West
 - 500 feet SW of pier
 - Water Depth (m): 10
 - Instrument Description:
 - Underwater Directional Array
 - Measured Parameters:
 - Wave Energy
 - Wave Period
 - Wave Direction

In addition to these CDIP sites waves have been monitored at Torrey Pines Beach from 1972 until 1984 by the SAS Stations deployed by Scripps Institution of Oceanography, (SIO), Pawka (1982). All data sets possessed gaps at various times due to system failure and a variety of start ups and shut downs and related system maintenance. The undivided data sets were pieced together into a continuous record from 1980-2000 and entered into a structured preliminary data file. The data in the preliminary file represent partially shoaled wave data specific to the local bathymetry around each monitoring site.

To correct these data from the monitoring sites to the nearshore of Encina, they are entered into a refraction/diffraction numerical code, back-refracted out into deep water to remove local refraction and island sheltering effects, and subsequently forward refracted into the immediate neighborhood of Encina.

Hence, wave data off each monitoring site was used to hindcast the waves at Agua Hedionda Lagoon.

The backward and forward refractions of CDIP and SIO data to correct it to Encina was done using a numerical refraction-diffraction computer code called OCEANRDS. The primitive equations for this code are lengthy, so a listing of the FORTRAN codes of OCEANRDS appear in Appendix D. These codes calculate the simultaneous refraction and diffraction patterns propagating over a Cartesian depth grid. A large outer grid was used in the back refraction calculations to correct for island sheltering effects, while a high resolution inner grid was used for the forward refraction over the complex bathymetry around Agua Hedionda Lagoon. "OCEANRDS" uses the parabolic equation method (PEM), Radder (1979), applied to the mild-slope equation, Berkhoff (1972). To account for very wide-angle refraction and diffraction relative to the principle wave direction, "OCEANRDS" also incorporates the high order PEM Pade approximate corrections modified from those developed by Kirby (1986a-c). The Pade approximates in "OCEANRDS" are written in tesseral harmonics, per Jenkins & Inman (1985) in some instances improving resolution of diffraction patterns associated with steep, highly variable bathymetry such as found near the Carlsbad Submarine Canyon. These refinements allow calculation of the evolution and propagation of directional modes from a single incident wave direction; which is a distinct advantage over the more conventional directionally integrated ray methods which are prone to caustics (crossing wave rays) and other singularities in the solution domain where bathymetry varies rapidly over several wavelengths.

To perform both the backward and forward shoaling computations, the refraction/diffraction algorithm requires relatively fine-scale resolution of the

the model: one to propagate back to the deep water; the other to forward refract those results into the Agua Hedionda nearshore. Both the backward and forward refraction grids were rectangular grids and were generated by the "OCEANBAT" code using the National Ocean Survey (NOS) digital database and the precision nearshore surveys by Dyson (2000), discussed previously in Section 3.2.A, Figure 3.1.

An example of a reconstruction of the wave field throughout the Bight is shown in Figure 3.12 using the back refraction calculation of the CDIP data from the San Clemente array. Wave heights are contoured in meters according to the color bar scale and represent 6 hour averages, not an instantaneous snapshot of the sea surface elevation. Note how the sheltering effects of Catalina and San Clemente Islands have induced longshore variations in wave height throughout the Oceanside Littoral Cell. Figure 3.13 shows the deep water significant wave heights, periods and directions resulting from the series of back-refraction calculations for the complete CDIP and SIO data set at $\Delta t = 6$ hour intervals over the simulation period of January 1980 to July 2000. The data in Figure 3.13 are the values used as the deep water boundary conditions of the farfield grid (Figure 1.4) for the forward refraction computations into the Oceanside/Carlsbad region. The deep water wave angles are plotted with respect to the direction (relative to true north) from which the waves are propagating at the deep water boundary of the inner refraction grid. Inspection of Figure 3.13 reveals that a number of large swells lined up with the wave windows open to Agua Hedionda during the El Niño's of 1980-83, 1986-88, 1992-95, and 1997-98. The largest of these swell

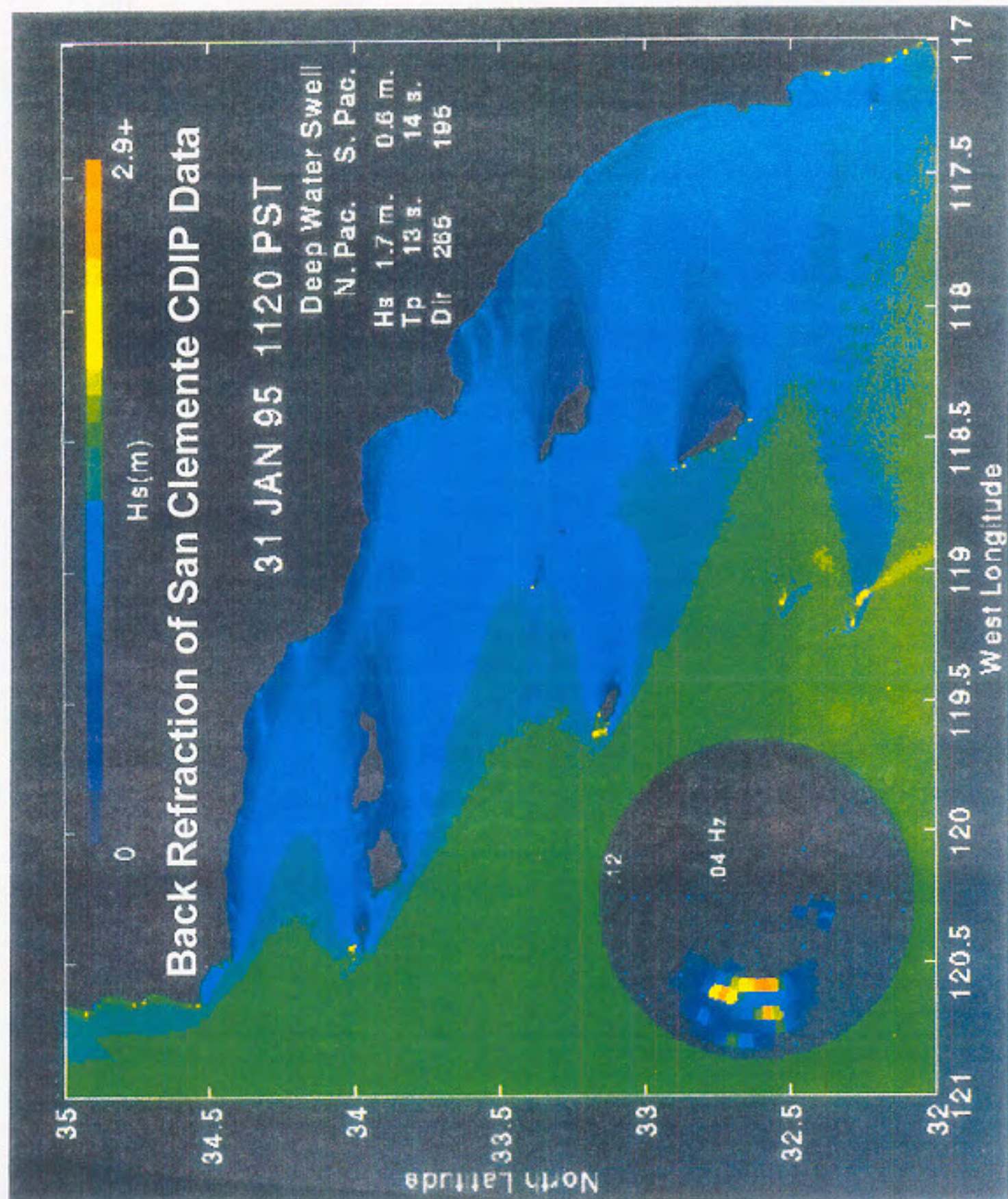


Figure 3.12. Back refraction of San Clemente CDIP data, 31 Jan 1995, 11:20 PST, showing island sheltering.

Data Reconstructed From CDIP and SIO Arrays:
 Oceanside, July 1983-Oct 1991 & May 1998-May 2000
 San Clemente, Aug 1991-Jun 1993 & Sep 1993-Apr 1998
 Huntington Beach, July 1993-Aug 1993
 Torrey Pines, Jan 1980-July 1983

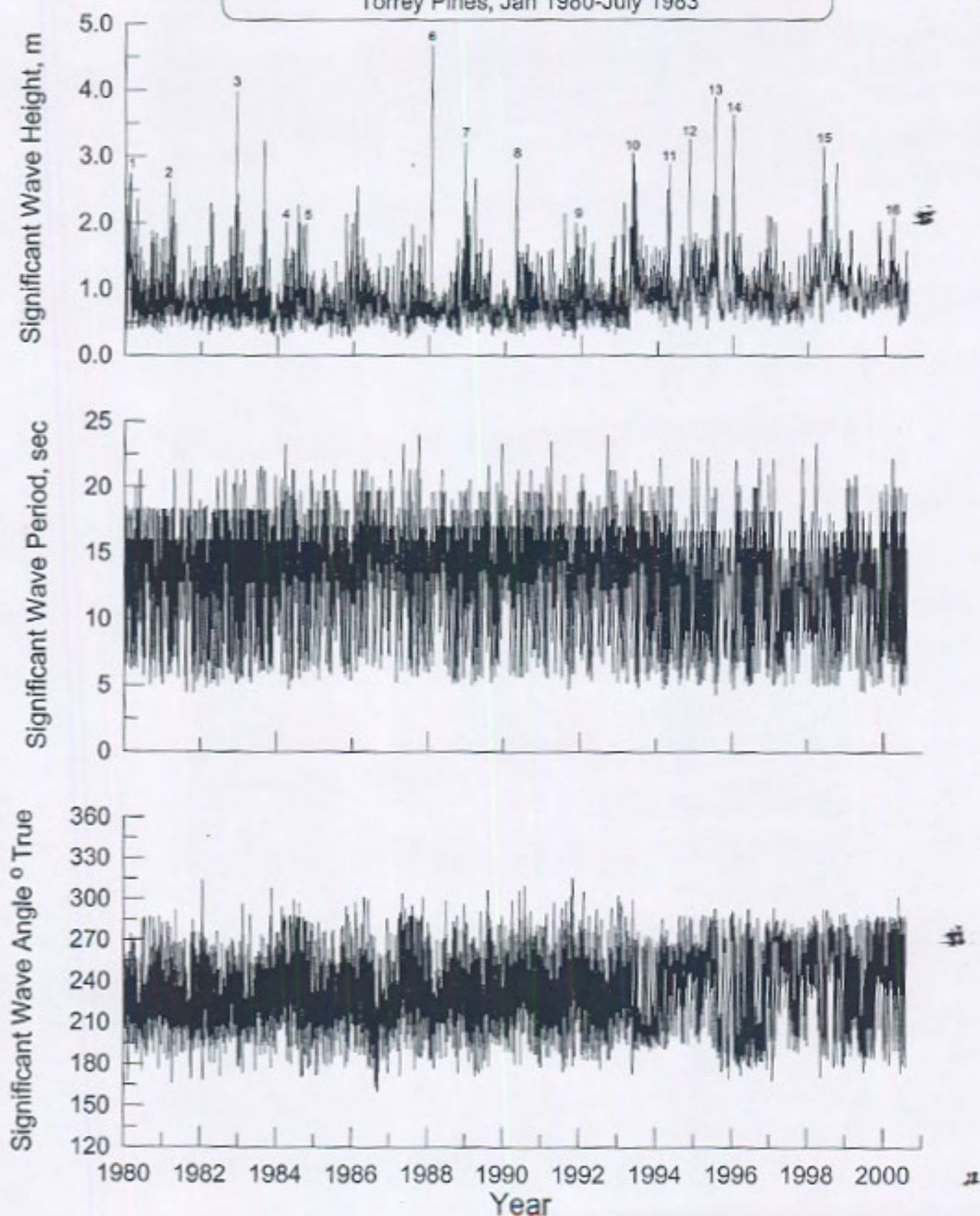
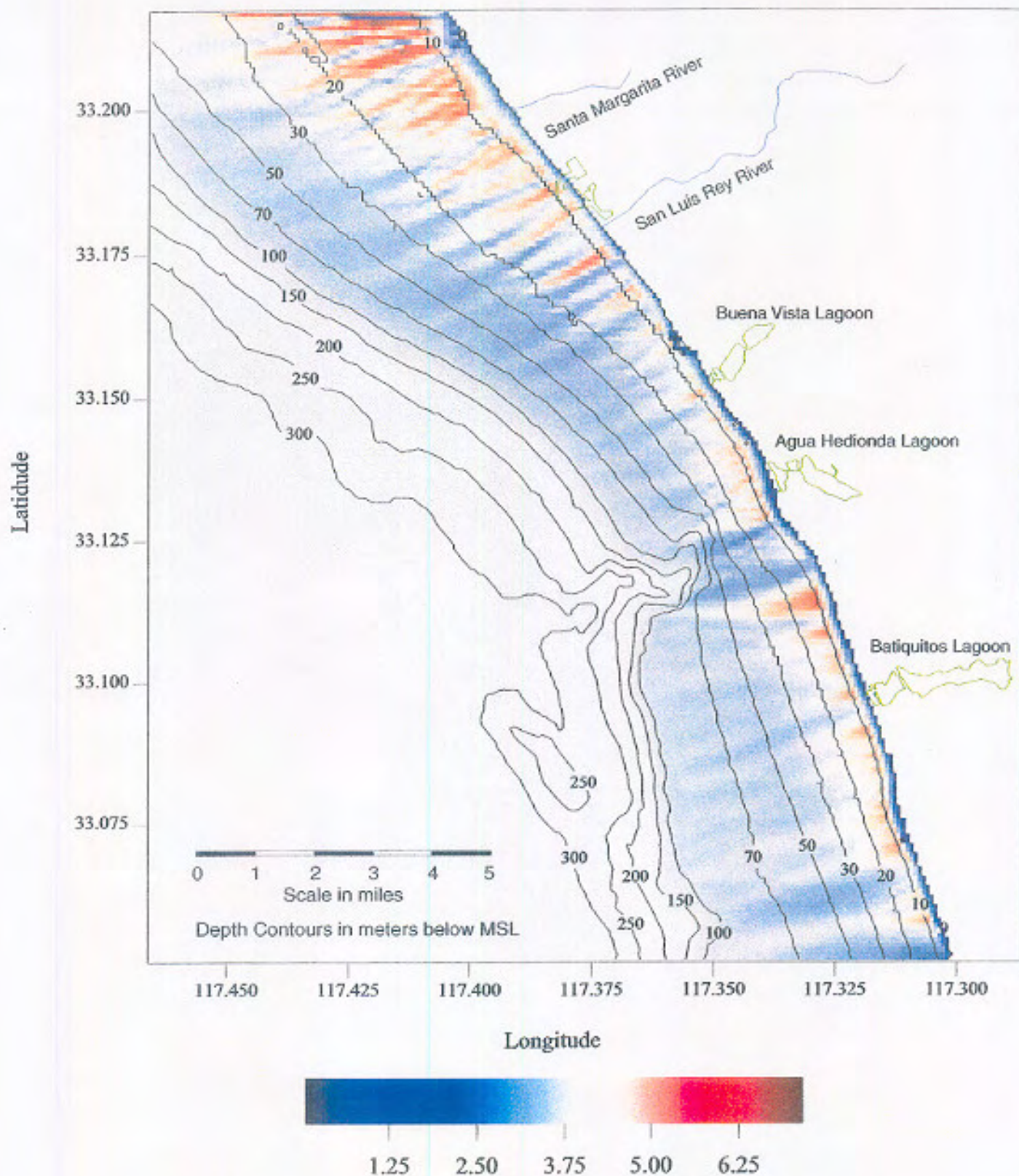


Figure 3.13. Deep Water Wave Data, Downcoast Erosion Analysis for Jetty Extension at Agua Hedionda Lagoon, CA

events was the 18 January 1988 storm, producing 4.5 m deep water swells off Encina (see event #6 in Figure 3.13).

Figure 3.14 gives an example of the forward refraction calculation in the farfield grid of Figure 1.4, showing wave height variations along an 18.5 km section of coastline including the Oceanside and Carlsbad beach nourishment sites around Agua Hedionda. Figure 3.14 gives the distribution of wave heights in meters averaged over a 6 hour interval for the extreme event storm the night of 18 January 1988. These were the largest waves of the 20.5 year long simulation period and had 17 sec swells from 270° true with 4.5 meter deep water significant wave heights inside the Catalina Channel off Encina. The wave height contours in Figure 3.14 are overlaid on the depth contours of the forward refraction grid in units of meters. Refraction diagrams calculated for other extreme events are found in Appendix G. In all of these plots it is noted that the complex shelf bathymetry in the neighborhood of the Carlsbad Submarine Canyon gives rise to refraction patterns with significant variability between "bright spots" (regions of enhanced wave heights) and "shadows" (regions of diminished wave heights). In general, the Carlsbad Submarine Canyon causes a systematic shadow zone at the head of the canyon between Terra Mar and Batiquitos Lagoon, with progressive bright spots further downcoast of Terra Mar. These alongshore variations in wave height will lead to alongshore variations in longshore transport rates referred to as divergence of drift, per Equation (3). A positive divergence of drift (as observed in the Terra Mar region in Figure 3.14) can lead to offshore transport of surfzone constituents, (Jenkins, et al., 1989, 2002).

The wave height record from Figure 3.13 has been overlaid on the ensemble records of forcing function in Panel-a of Figure 3.15 for subsequent probability



Wave Height = 4.09 m, Period = 14.22 sec, Direction = 270 deg

Figure 3.14. Maximum Event Wave Refraction for Period of Record 1980-2000 (18 January 1988)

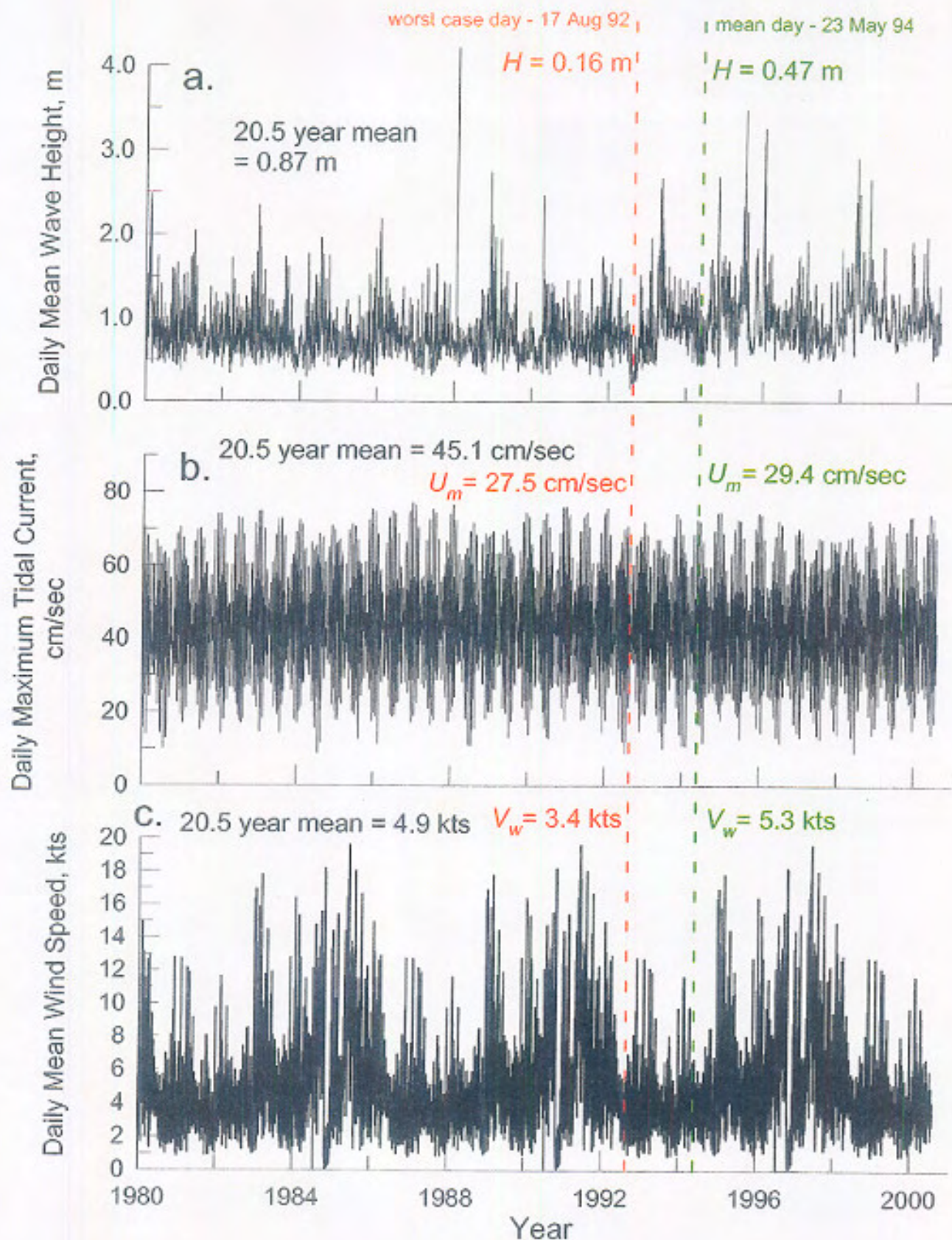


Figure 3.15. Period of record of forcing functions in the nearfield of Encina Power Plant, 1980-2000.5: a) daily mean wave height, b) daily maximum tidal current velocity, and c) daily mean wind.

analysis. The average wave height at Encina over this 20.5 year period is 0.87 m while the maximum is 4.51 m occurring during the January 1988 storm, and the minimum is 0.16 m occurring on 17 August 1992 during the building phase of the 1993 El Niño.

B) Currents

While waves dominate the initial dilution and dispersion of heat and concentrated seawater in the inshore domain, the tidal currents control dilution and dispersion in the offshore domain, particularly in the neighborhood of the kelp beds to the south of the power plant. Examples of the three generic categories of tidal circulation on the continental shelf are shown in Figures 3.16 thru 3.18. Figure 3.16 shows the predominant progressive tidal field with southward flowing current along the shelf during an ebbing tide; Figure 3.17 shows a standing dominated tidal field with a northward flowing countercurrent near the shoreline during an ebbing tide; and Figure 3.18 shows the mixed tidal field with a weak southward flowing coastal current and a northward flowing countercurrent beyond the shelf break during a flooding tide. There are virtually no cases of a pure standing tidal field, and most are progressive dominated mixed tidal fields producing southward net tidal transport. Each plot in Figures 3.16 thru 3.18 is composed of self-scaling vectors in units of cm/sec proportional to the vector length in the lower left hand corner, which represents the largest current vector found anywhere on the plot in terms of an e-format. A southward net tidal drift is produced by the daily average of all the potential combinations of standing and progressive mixed tides. This net southward drift is an indication that the tidal transport in this region is *ebb dominated*.

In Panel-b of Figure 3.15 the daily maximums of the tidal currents on the

Agua Hedionda Recirculation Study: Tidal Currents; July 19, 1996, 09:00 PST

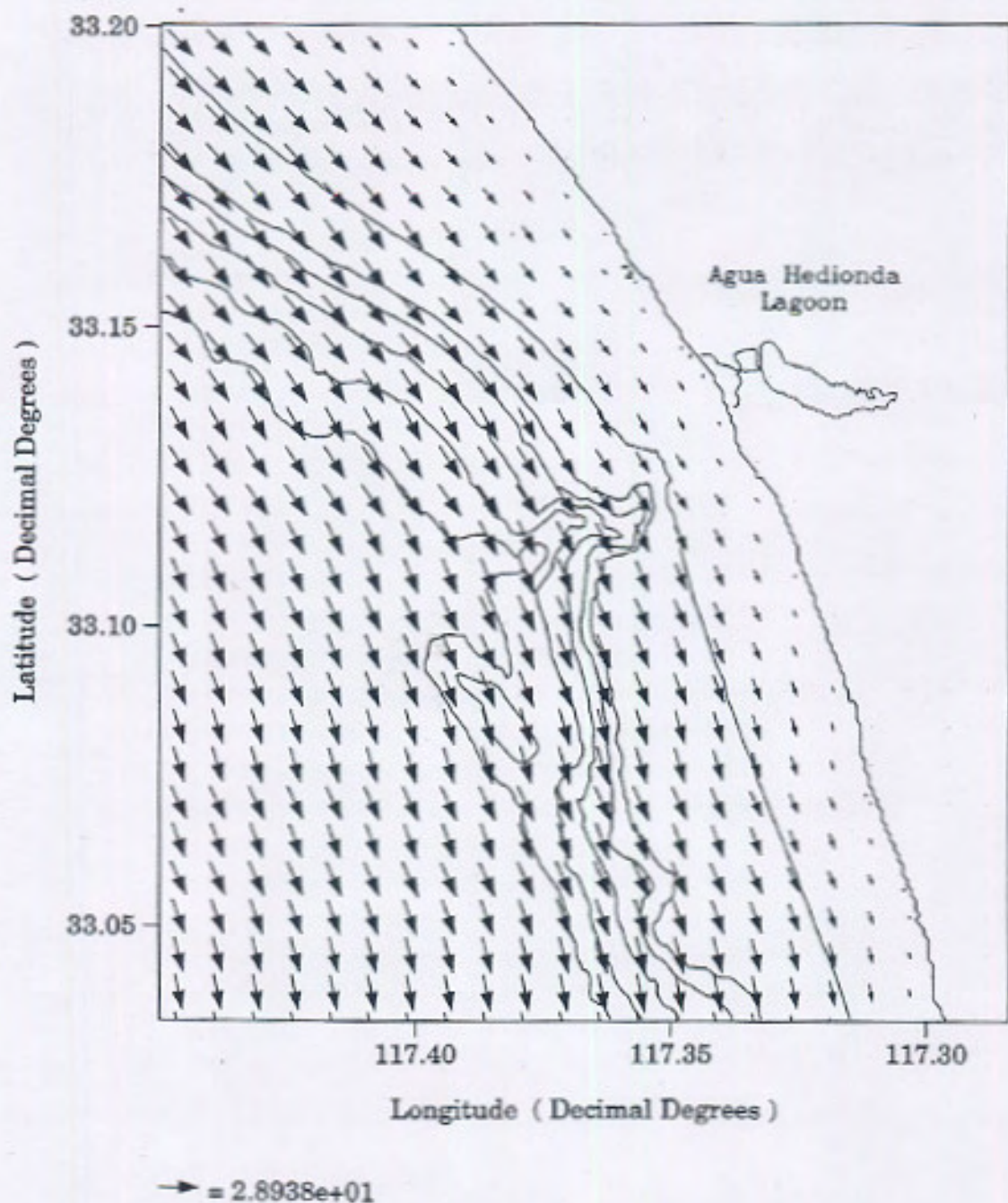


Figure 3.16. Progressive vector plots of tidal currents July 19, 1996 at 09:00 PST.

Vectors are self-scaling in units of cm/sec according to the vector dimension appearing in the bottom left hand corner. This current field structure is typical of a coastal boundary layer dominated by the progressive component.

Agua Hedionda Recirculation Study: Tidal Currents; August 19, 1996, 16:00 PST

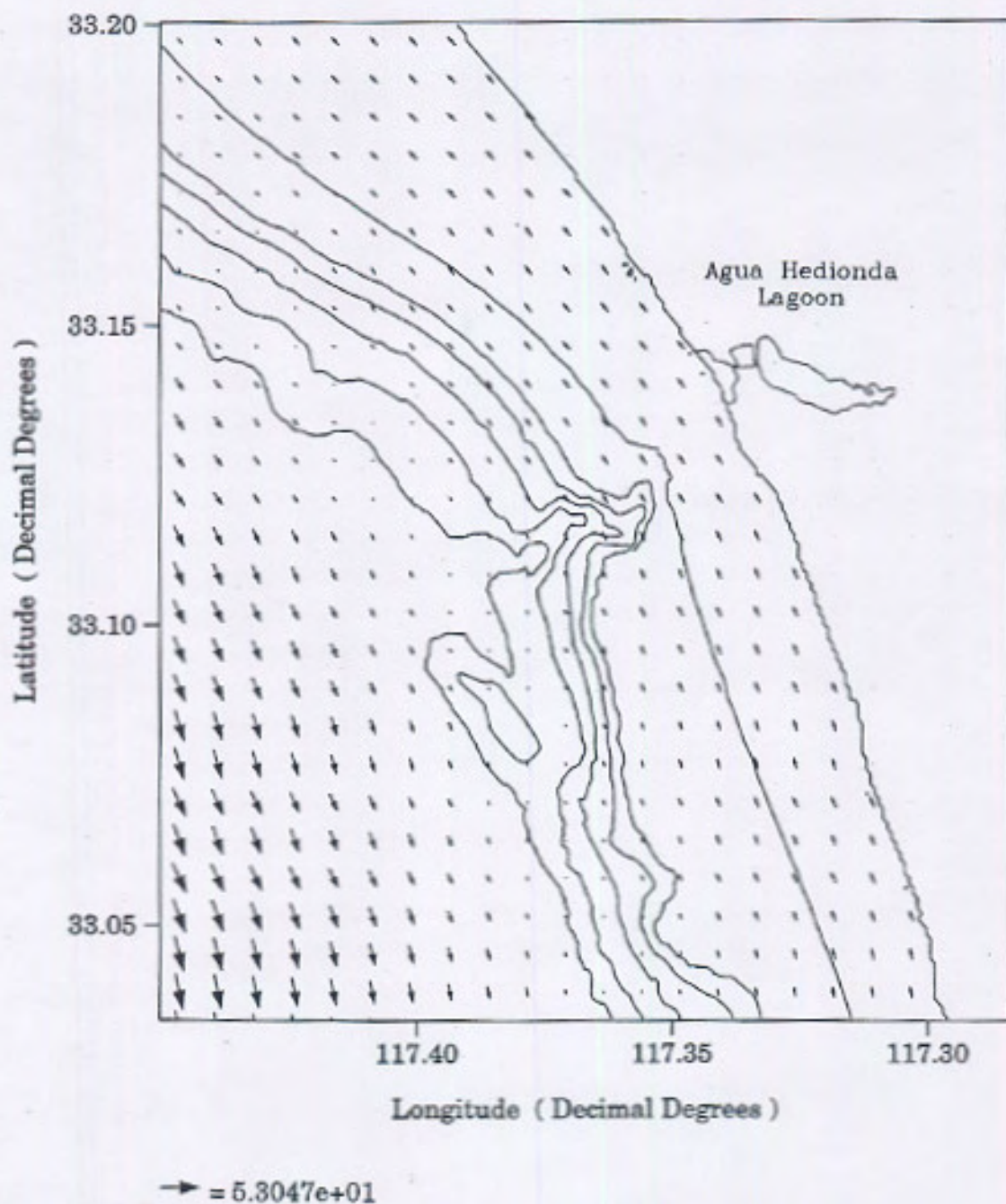


Figure 3.17. Progressive vector plots of tidal currents August 19, 1996 at 16:00 PST. Vectors are self-scaling in units of cm/sec according to the vector dimension appearing in the bottom left hand corner. This current field structure is typical of a coastal boundary layer dominated by the standing component.

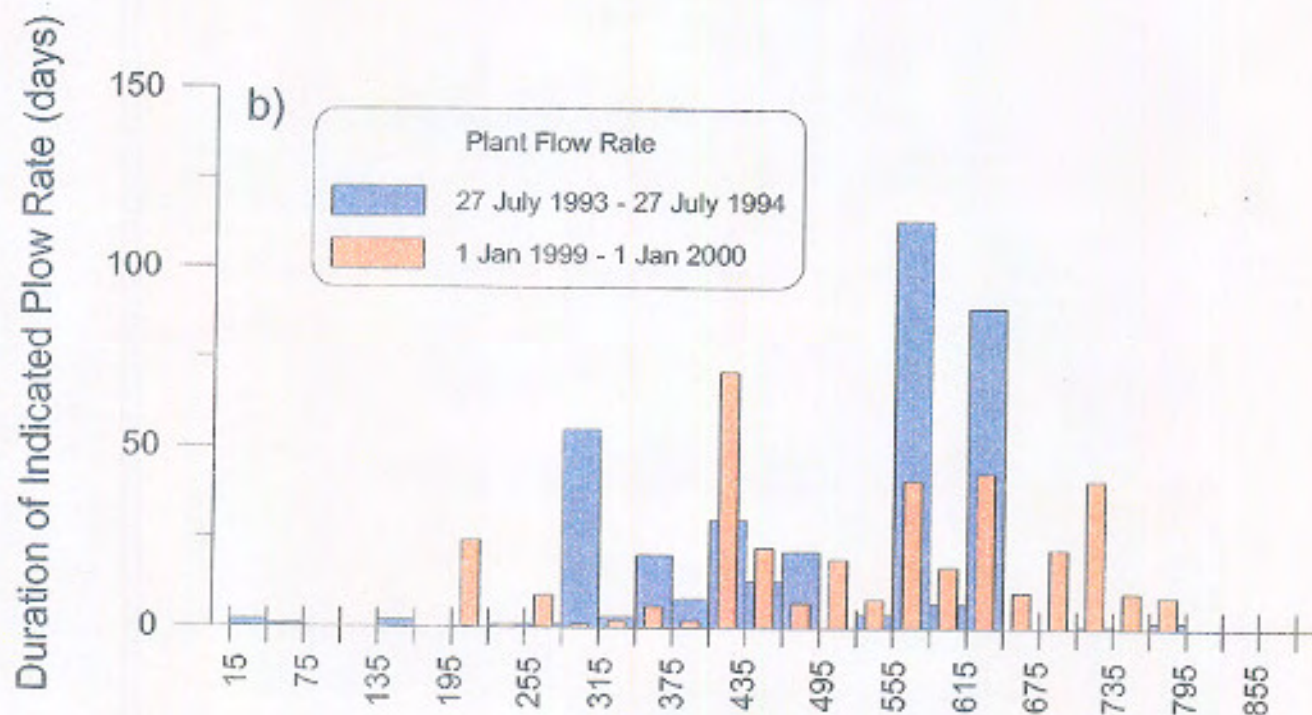
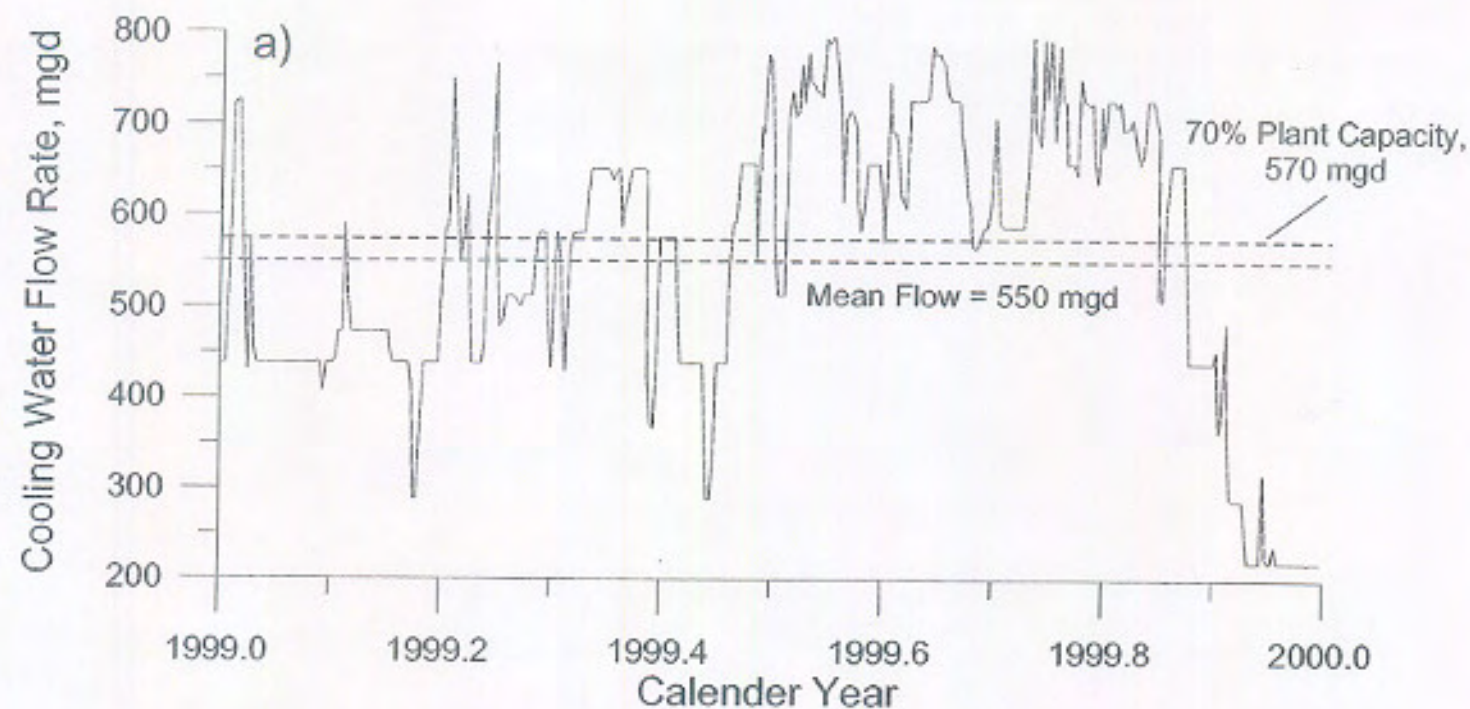
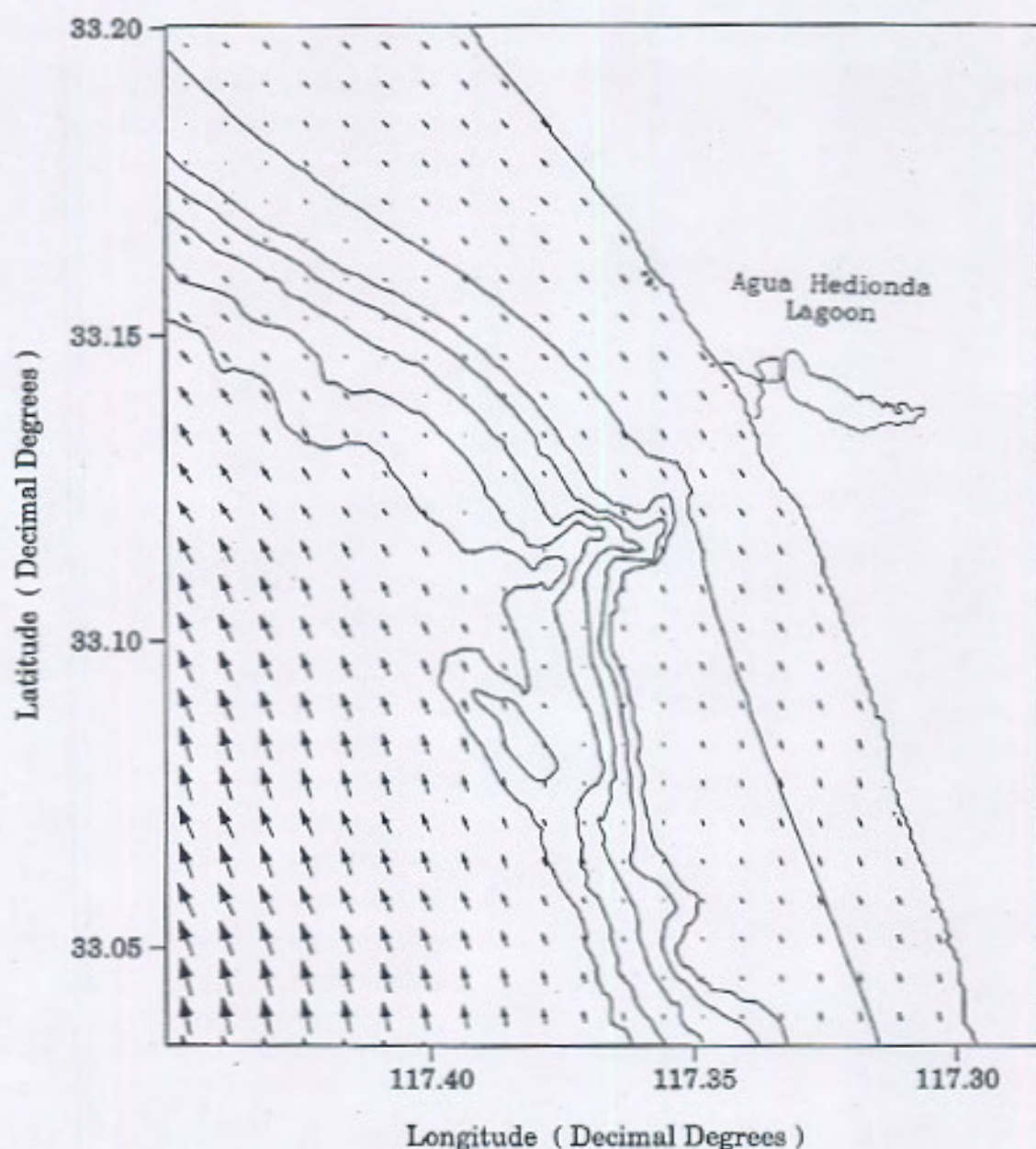


Figure 3.4. Cooling water flow rate - Encina Power Plant: Carlsbad, California

Agua Hedionda Recirculation Study: Tidal Currents; August 8, 1996, 09:00 PST



→ = 2.4824e+01

Figure 3.18. Progressive vector plots of tidal currents August 8, 1996. Vectors are self-scaling in units of cm/sec according to the vector dimension appearing in the bottom left hand corner. This current field structure is typical of a coastal boundary with both progressive and standing components of comparable magnitude.

shelf off Encina are reconstructed over a 20.5 year period from January 1980 through July 2000. The largest daily maximum tidal current during this period was 77.1 cm/sec (1.49 knots) while the smallest daily maximum current was 8.7 cm/sec (0.17 knots). The 20.5 year average daily maximum current in this region is 45.1 cm/sec (0.88 knots).

C) Wind

Daily mean winds from the Scripps Pier Shore Station (SIO,2001) and the Scripps Pier CDIP station (CDIP, 2002) were compiled over the 20.5 year period from January 1980 thru July 2000. This wind record is plotted in Panel-c of Figure 3.15. Because the lower Southern California Bight is a "wind drought" region due to orographic blocking by the Penninsular Range, the 20.5 year mean wind speed is only 4.9 knots. However, El Niño storms and North Pacific cold fronts (Figure 3.10) episodically increase daily wind speeds with the maximum sustained 24 hour mean wind speed reaching 19.6 knots during the 1997 El Niño storms. The minimum daily mean wind speed is 0 knots. Indeed the coastal winds off Scripps Pier and Encina Power Plant are generally very benign, thereby limiting the degree of wind mixing of the surface water mass.

3.4) Model Scenarios

The 20.5 year long records of the 4 controlling boundary condition variables in Figure 3.5 and the 3 controlling forcing function variables in Figure 3.15 were subjected to a joint probability analysis for the simultaneous recurrence of the *worst* combination of these 7 variables and for the average daily and monthly combination of these variables (*average case*). The criteria used to define worst case combinations in this analysis is outlined in Table 1 below:

Table 1: Search Criteria and Ecological Significance for Worst Case Combinations of Controlling Variables.

Variable	Search Criteria	Ecological Significance
Plant Flow Rate	Maximize	Higher flow rate results in more waste heat to stress marine biology and increases potential for recirculation
Ocean Salinity	Maximize	Higher salinity leads to higher concentrations of RO by-product causing greater stress on marine biology
Ocean Temperature	Maximize	Higher temperature leads to greater stress on marine biology
Ocean Water Levels	Minimize	Lower water levels result in less initial dilution in the discharge channel
Waves	Minimize	Smaller waves result in less mixing in surfzone and less inshore dilution
Currents	Minimize	Weaker currents result in less advection and less offshore dilution
Winds	Minimize	Weaker winds result in less surface mixing and less dilution in both the inshore and offshore

The joint probability analysis involved 7,523 historic combinations of the 7 controlling variables, for which the maximization/minimization criteria in Table 1 were applied.

A) Worst Day

The joint probability analysis produced a worst day solution for 17 August 1992. This day is represented by the vertical dashed red line in Figures 3.5 and 3.15. The environmental factors of this day were associated with a building El Niño that subsequently climaxed in the winter of 1993. The ocean temperature was

25.0 °C, within 0.1 °C of the 20.5 year maximum. The waves were only 0.16 m, which was the 20.5 year minimum. Winds were 3.4 knots and the maximum tidal current in the offshore domain was only 27.5 cm/sec (0.53 knots). The sluggish tidal current was due to neap tides occurring on this day with a minimum water level of -0.74 ft NGVD. Indeed, this was a very hot, calm summer day and the high user demand for electricity had the plant operating close to maximum generating capacity with a flow rate of 725.8 mgd. The ocean salinity was 33.51 ppt.

This combination of environmental variables represents a situation that would place maximum thermal stress on the marine biology; and one in which the dilution of the concentrated seawater by-product of the desalination plant would occur very slowly due to minimal ocean mixing. The high flow rate of the power plant in combination with the neap tides create a circumstance in which recirculation of the concentrated seawater by-product back into the lagoon would have a maximum likelihood. The probability of recurrence of all these factors together is 0.013%.

B) Average Day

The average daily combination of the 7 controlling variables over the 20.5 year period of record was found to be represented by the conditions on 23 May 1994. This day is represented in Figures 3.5 and 3.15 by the vertical dashed green line. This was a spring day with moderate temperature, winds, waves, and power generation. The Southern Oscillation Index (SOI) was zero indicating that the climate was in a neutral phase. Plant flow rate was 576 mgd, very near the annual mean of 550 mgd (Figure 3.4a). Ocean salinity was 33.52 ppt and ocean temperature was 17.6 °C, both identically the 20.5 year mean. Wave heights were 0.65 m, slightly below the 20.5 year mean, and maximum tidal currents reached

29.4 cm/sec (0.57 knots), also less than the 20.5 year mean. The daily low water level at -1.96 ft NGVD, very close to the mean low tide (MLT). Winds were 5.3 knots, slightly above the 20.5 year mean.

C) Worst Month

The joint probability analysis found a solution for the worst combination of the seven controlling variables over a 30 day period beginning with 31 July 1992 and ending on 29 August 1992. Boundary condition variables for the worst month are plotted in Figure 3.19 while the corresponding forcing functions are found in Figure 3.20. This worst month solution contained the worst day, 17 August 1992 shown as a dashed red line in Figures 3.19 and 3.10. The same conditions of high ocean temperature, high plant flow rate, and a tranquil low mixing nearshore ocean environment that characterize the worst day also persisted for most of this 30 day period. The 30 day average of the plant flow rate during the worst month was 703 mgd while the ocean temperature averaged 22.66 °C. Thus sustained thermal stress on the marine biology is represented by this period. Furthermore, the waves remained unusually small with a 30 day mean wave height of 0.33 m. Likewise, the winds averaged only 3.26 knots, which in combination with the small waves kept the mixing and inshore dilution low throughout the month. There were two spring tide cycles during this month so that the 30 day average of the minimum water elevation was -1.87 ft NGVD and the maximum tidal current was 43.75 cm/sec, both exceeding the worst day. Ocean salinity averaged 33.49 ppt. The 30 day combination of variables in Figures 3.19 and 3.20 has a probability of recurrence of 0.398%.

D) Average Month

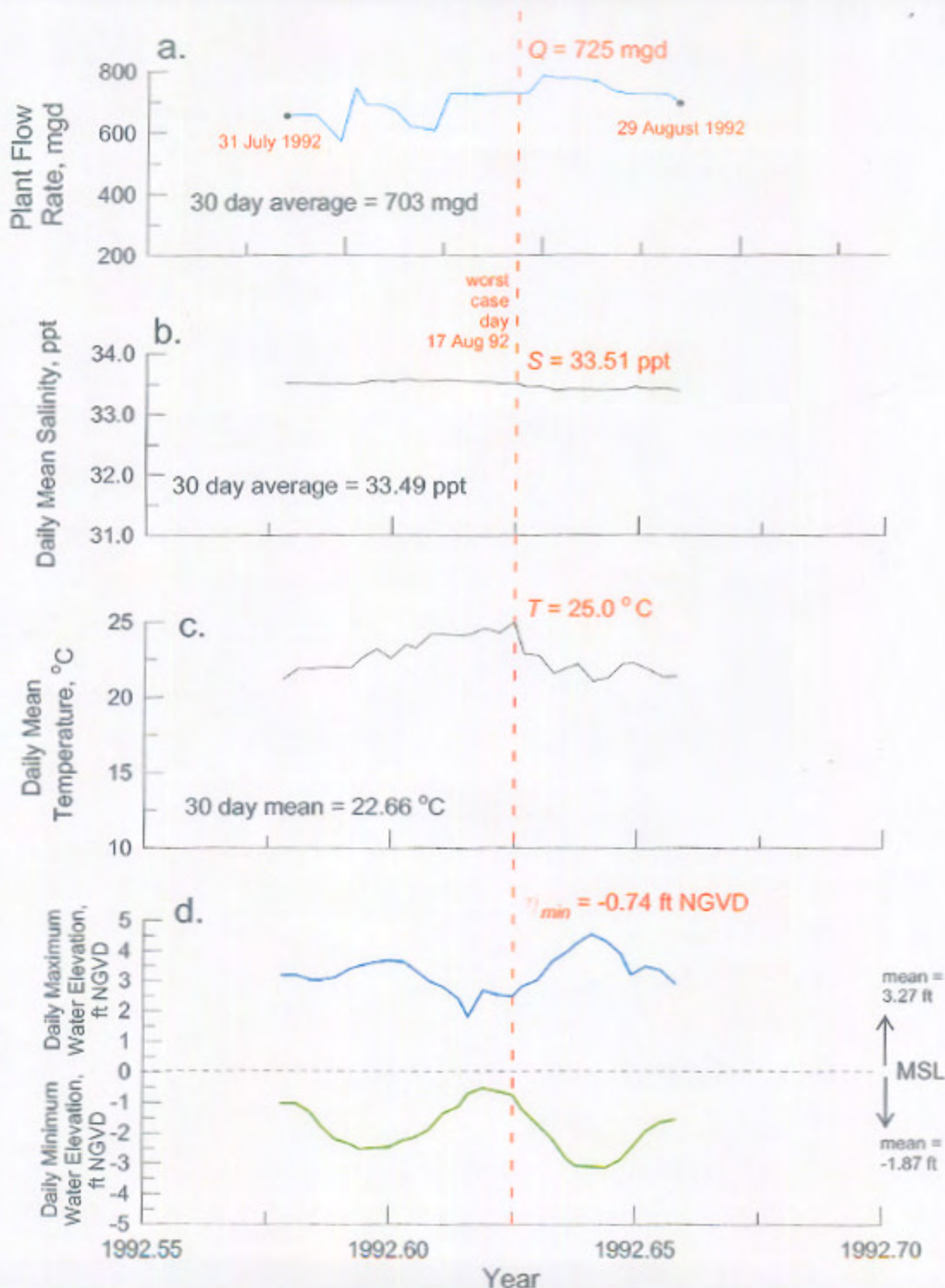


Figure 3.19. Boundary conditions in the nearfield of the Encina Power Plant: worst case 30 day period: a) plant flow rate, b) daily mean salinity, c) mean temperature, and d) high and low water elevations. Copyright © 2005 Poseidon Resources Corporation. All rights reserved.

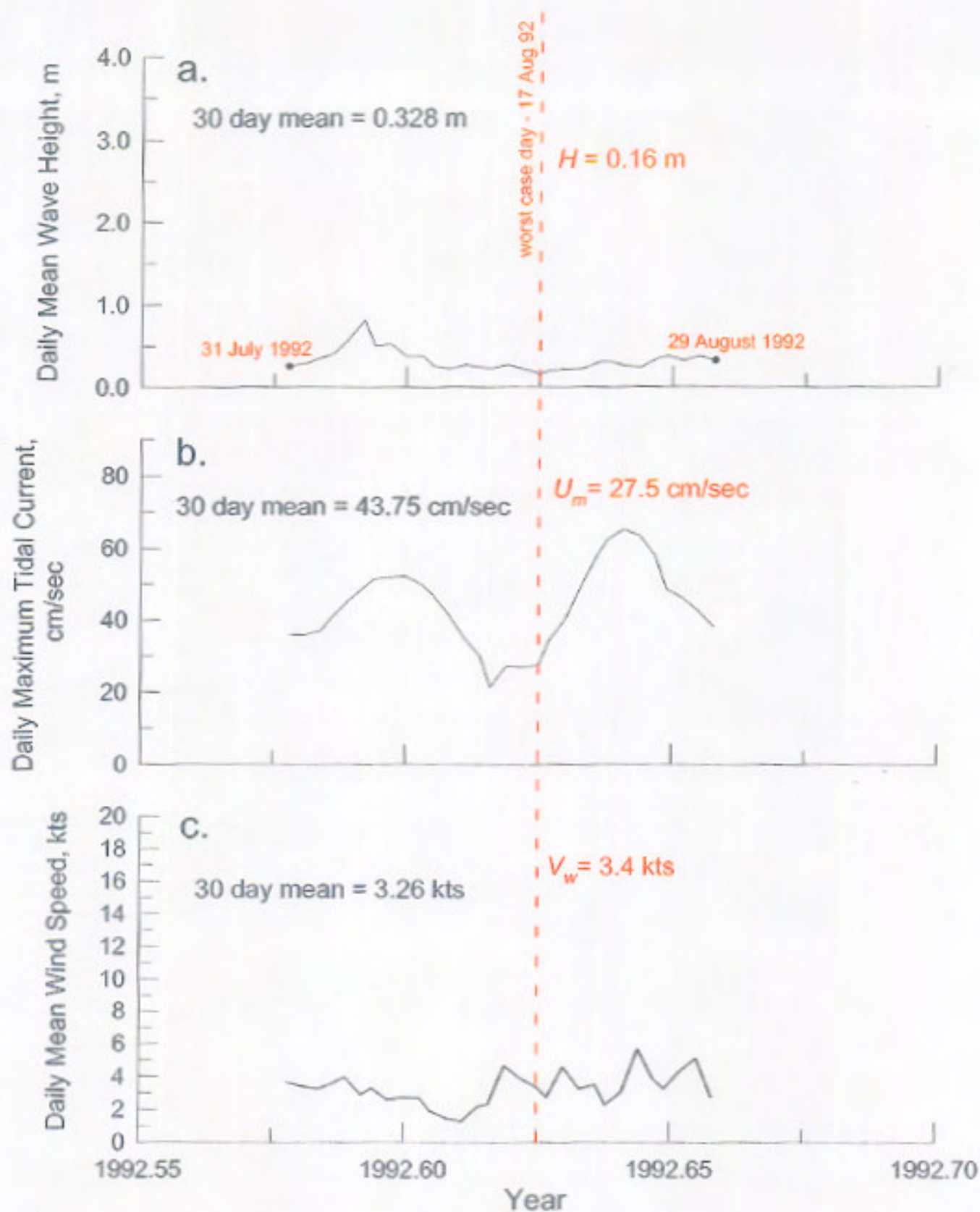


Figure 3.20. Forcing functions in the nearfield of Encina Power Plant, worst case 30 day period: a) daily mean wave height, b) daily maximum tidal current velocity, and c) daily mean wind.

The period from 12 May 1994 to 10 June 1994 was found by joint probability analysis to be the average 30 day combination of the 7 controlling variables during the 20.5 year period of record. Figure 3.21 plots the 4 boundary condition variables for the average month conditions while Figure 3.22 gives the forcing functions. The mean day described in Section 3.4.B appears as a vertical green dashed line in both figures. The 30 day average plant flow rate for the mean month was 527 mgd, slightly less than the 20.5 year mean of 550 mgd. The 30 day average ocean salinity of the mean month was 33.49 ppt and the 30 day average ocean temperature was 17.81 °C. The 30 day average minimum ocean water level was -2.61 ft NGVD, almost identical to the mean low water level from the 1960-78 tidal epoch. These mean range tides produced tidal currents whose 30 day average maximum was 45.3 cm/sec, almost identical to the 20.5 year mean. Average wave heights for the average month were 0.65 m, while average winds were 3.99 knots, both slightly less than the 20.5 year mean. Altogether, the statistics of the average month were an extremely close match to the means of each individual variable taken independently over the 20.5 year period of record.

E) Summary of Model Scenarios

The upper half of Table 2 provides a summary of the model initialization values for the boundary conditions and forcing function variables for the daily and monthly worst and average case modeling scenarios. The lower half of Table 2 gives initialization values for the saline and specific volume properties of the combined power plant and desalination plant discharge.

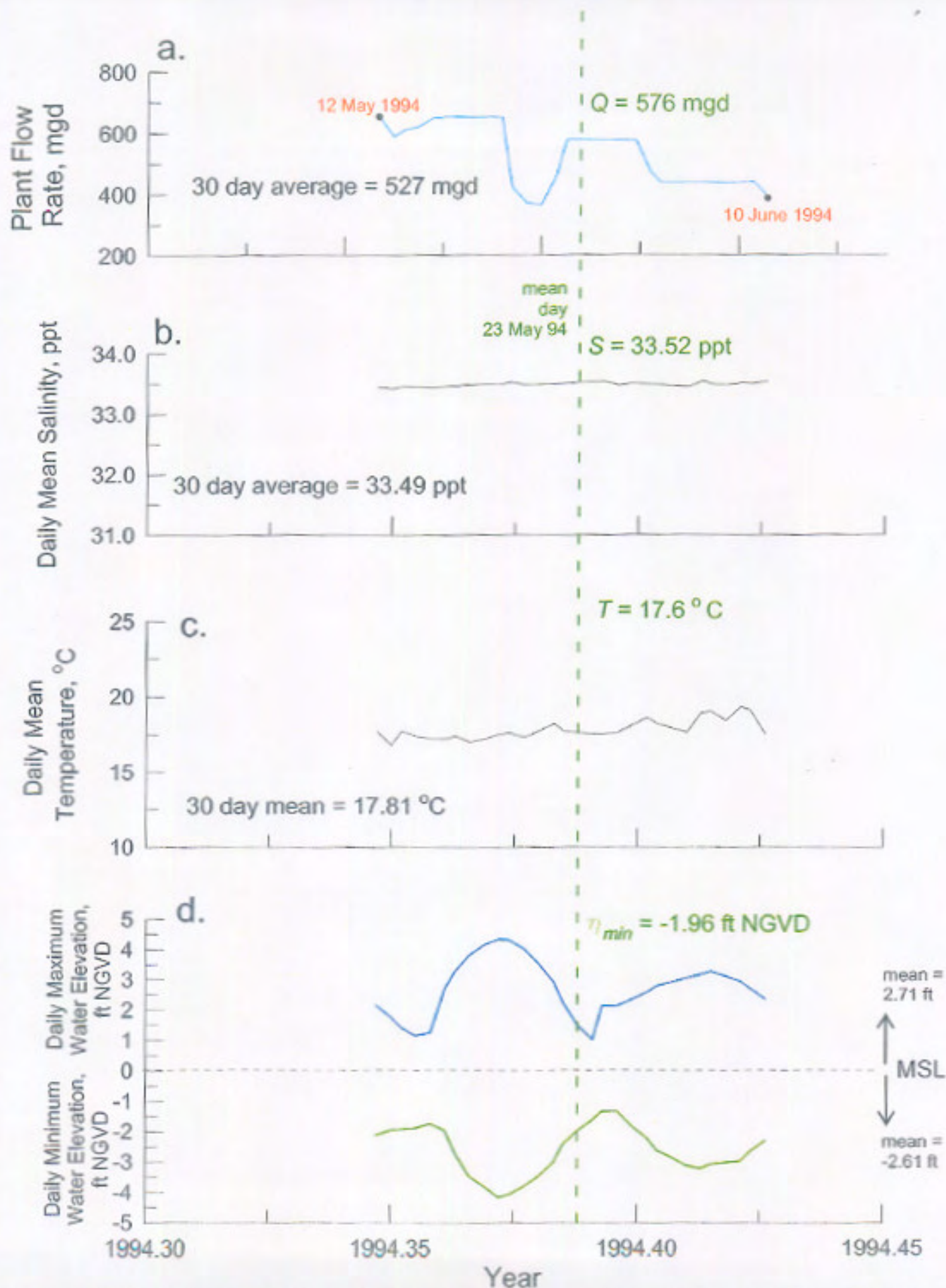


Figure 3.21. Boundary conditions in the nearfield of the Encina Power Plant: mean 30 day period: a) plant flow rate, b) daily mean salinity, c) mean temperature, and d) high and low water elevations. Copyright © 2005 Poscidon Resources Corporation. All rights reserved.

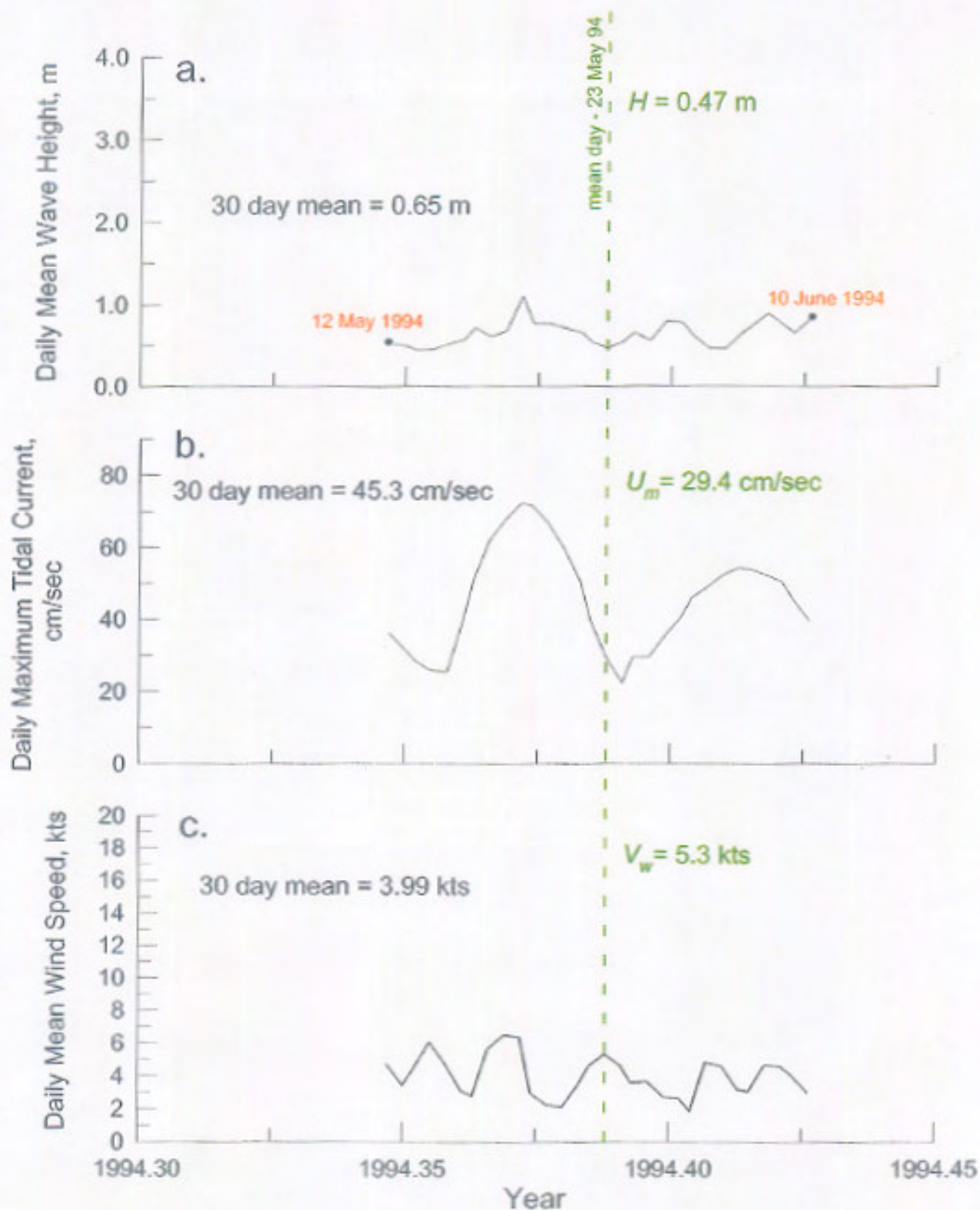


Figure 3.22. Forcing functions in the nearfield of Encina Power Plant, mean 30 day period: a) daily mean wave height, b) daily maximum tidal current velocity, and c) daily mean wind.

Table 2. Summary of Boundary Conditions and Forcing Functions for Dispersion Modeling of the Carlsbad Desalinization Retrofit

Model Conditions	Worst Day	Average Day	Worst Month	Average Month
Power Plan Cooling Water Inflow Rate (mgd)	725.8	576	703	527
Average Ocean Mixed Layer Temperature, °C	25.00	17.60	22.66	17.81
Average Ocean Mixed Layer Salinity, ppt	33.51	33.52	33.49	33.49
Average Wave Height, m	0.16	0.86	0.33	0.65
Average Wind Speed, kts	3.40	5.33	3.26	3.99
Maximum Tidal Current Velocity, cm/sec	27.50	29.43	43.75	45.3
Salinity (ppt) of Combined Discharge for RO = 50 mgd	35.99	36.71	36.05	37.00
In-pipe Dilution of Concentrated Seawater for RO = 50 mgd	13.5 to 1	10.5 to 1	13.1 to 1	9.5 to 1
Specific Volume Change ($d\alpha/\alpha$) of Combined Discharge for R. O. = 50 mgd, $\Delta T = 5.5$ °C	-0.00091	-0.00149	-0.00098	-0.00176
Salinity (ppt) of Combined Discharge for RO = 100 mgd	38.86	40.56	39.04	41.33
In-pipe Dilution of Concentrated Seawater for RO = 100 mgd	6.3 to 1	4.8 to 1	6.0 to 1	4.3 to 1
Specific Volume Change ($d\alpha/\alpha$) of Combined Discharge for RO = 100 mgd, $\Delta T = 5.5$ °C	-0.00327	-0.00466	-0.00344	-0.00532

The RO system will produce 50 mgd of product from the 100 mgd of cooling water diverted from the condenser cooling stream of the power plant. The RO system will discharge 50 mgd of concentrated seawater by-product at twice ambient ocean salinity, which is subsequently diluted in the remaining cooling water discharge stream. If the RO production is 100 mgd, then 200 mgd of cooling water will be diverted from the cooling water stream into the RO system, and 100 mgd of raw

concentrate will then be returned to the cooling water stream prior to discharge out the discharge channel. Based on the plant flow rates for the daily and monthly worst case scenarios, the raw concentrate from the desalination process will be diluted inside the plant circulation system by dilution factors ranging from 9.5 to 1 up to 13.5 to 1 for 50 mgd RO production rates and between 4.1 to 1 and 6.3 to 1 at 100 mgd production rates. Consequently, the salinity of the combined discharge as it first enters the discharge channel will vary between 36 ppt and 37 ppt at 50 mgd production rates and between 39 ppt and 41 ppt at 100 mgd production rates. Given an average Delta-T of 5.5 °C for the power plant discharge, we find that the specific volume change of the combined discharge will always be negative. Consequently, the addition of the concentrated seawater by-product to the power plant's cooling water discharge will cause the effluent to always be heavier than ambient seawater, regardless of environmental or power plant operating conditions.

3.5 Calibration

The coupled sets of models shown in Figure 2.1 were calibrated for end-to-end simulations of known dispersion events off Encina based on temperature depth profile measurements conducted over a nearshore sampling grid during February and March 1989 by Jenkins et al. (1989). This thermal plume data is shown as contour plots in Appendix A and were collected as part of an NPDES compliance monitoring program for Encina Power Plant. Initializations for the model were derived from the historic boundary conditions and forcing functions for February and March, 1989 (Figures 3.5 and 3.15). Free parameters in the subroutines were adjusted iteratively until a best fit was achieved between the measured and simulated temperature fields.

The subroutines of **SEDXPORF** contain seven free parameters which are selected by a calibration data set specific to the coastal type for which the hindcast simulation is run. These parameters are as follows according to subroutine:

BOTXPORF

- *ak2 - stretching factor for vertical eddy diffusivity, ϵ
- *ak - adjusts mixing lengths for outfalls

NULLPOINTF

- *ak7 - adjusts the asymmetry of the bedform distribution curve, μ

SURXPORF

- *aks - adjusts the surf zone suspended load efficiency, K_s
- ak4 - stretching factor for the horizontal eddy diffusivity, ϵ_x

RIVXPORF

- *ak3_1 - adjusts the jetty mixing length and outfall mixing lengths
- *ak3 - stretching factor for the horizontal eddy diffusivity of the river plume, ϵ_H

The set of calibration values for these parameters was used without variation or modification for all model scenarios. Figure 3.23 shows the measured surrogates for worst case and average case scenarios measured during the 1989 field monitoring efforts. Figure 2.23 Panel-a is the worst observed case measured on 7 March 1989 with the power plant operating at its maximum flow rate of 808 mgd with a maximum certified Delt-T of 20 °F (11 °C). This set of measurements provided an upper limit of the maximum heat output and size of the thermal footprint under existing conditions. The area inside the 2 °F (1.1 °C) temperature anomaly contour was measured at 113 acres. Panel-b of Figure 3.23 gives the representative average case scenario measured on 28 February 1989 with the plants

operating at 738.9 mgd and a Delta-T of 10 °F (5.5 °C). The footprint of the 2 °F (1.1 °C) temperature anomaly contour was measured at 65 acres. Note that the thermal plume deflects downcoast to the south in the direction of net transport (Figure 3.16) for both worst case and average case in Figure 3.23 and for all other cases in Appendix A.

SECTION 4: RESULTS

4) Results

The coupled models in Figure 2.1 were initialized for the 4 boundary condition variables and 3 forcing function variables according to the time series in Figures 3.19 and 3.20 for worst day and worst month. Time series of these 7 controlling variables in Figures 3.21 and 3.22 were used to initialize the model for simulation of average day and average month. The salinities and specific volumes of the combined discharge for 50 mgd and 100 mgd RO production were initialized according to the values indicated in Table 2 for worst day and worst month and average day and average month.

4.1) Saline Dispersion of Concentrated Seawater

A) Worst Day

The model simulation of the 24 hour average of the salinity field on the seabed is plotted in Figure 4.1 during the worst day conditions for an RO production rate of 50 mgd and a plant flow rate of 725.8 mgd. Contours of salinity are in parts per thousand (ppt), where the ambient background ocean salinity is 33.51 ppt. The corresponding dilution field of the concentrated seawater by-product on the seabed is plotted in Figure 4.2. Dilution contours are in a log-10 scale relative to the raw concentrate (at twice ambient ocean salinity). Because the combined discharge (at 675.8 mgd) is heavier than seawater, Figure 4.1 and 4.2 delineate the maximum saline impacts and minimum dilutions found anywhere in the water column. Maximum bottom salinities reach 35.4 ppt directly offshore of the discharge. Therefore no benthic area is exposed to a 10% elevation in salinity. The benthic area subjected to a 1% increase in salinity is 273 acres. This area is predominantly offshore and downdrift (to the south) of the discharge channel, consistent with the discharge plume patterns observed in the calibration data under

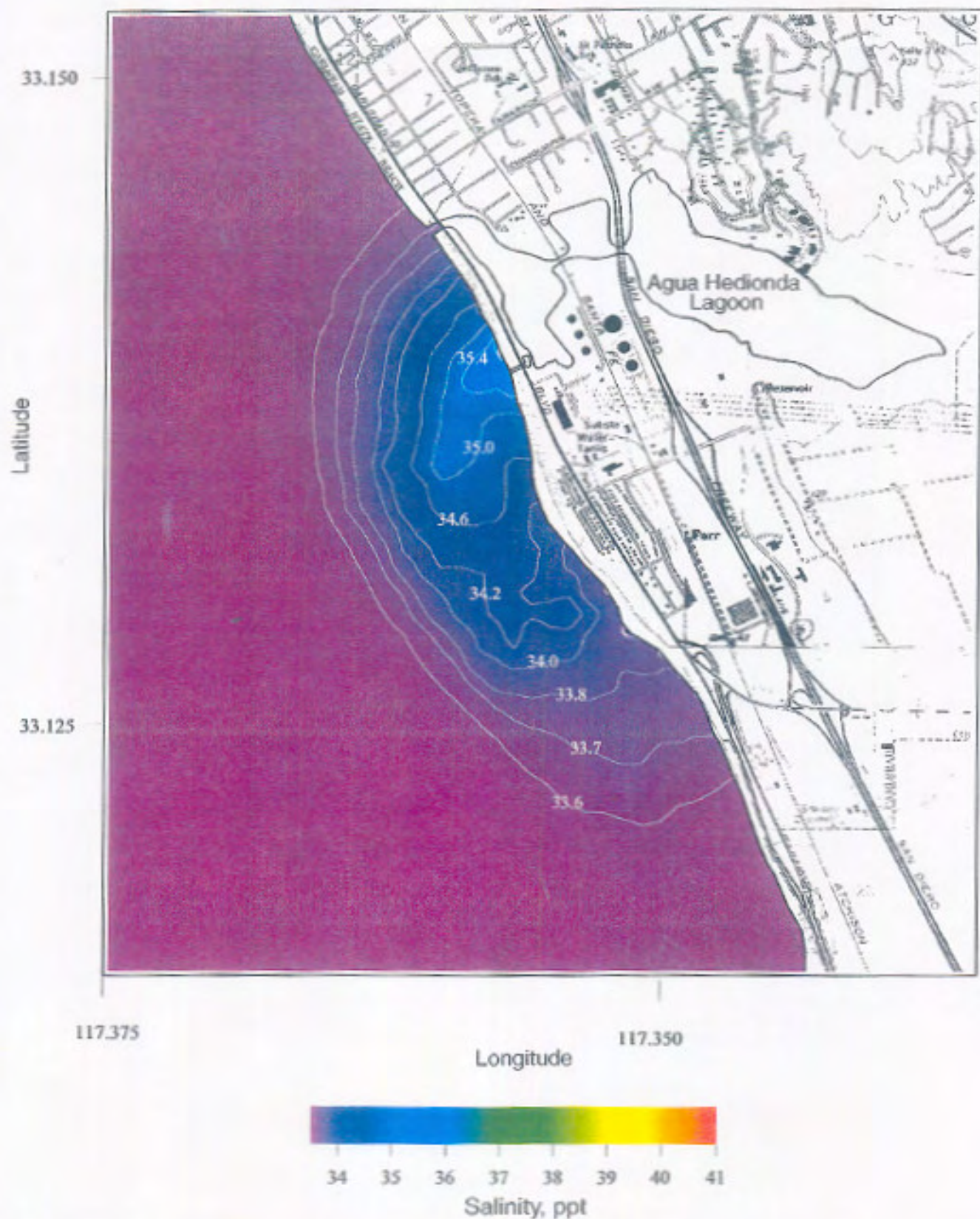


Figure 4.1. Daily **average of the bottom salinity** of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 725.8 mgd, combined discharge = 675.8 mgd, ambient ocean salinity = 33.51 ppt, **worst case day** (17 Aug 1992).

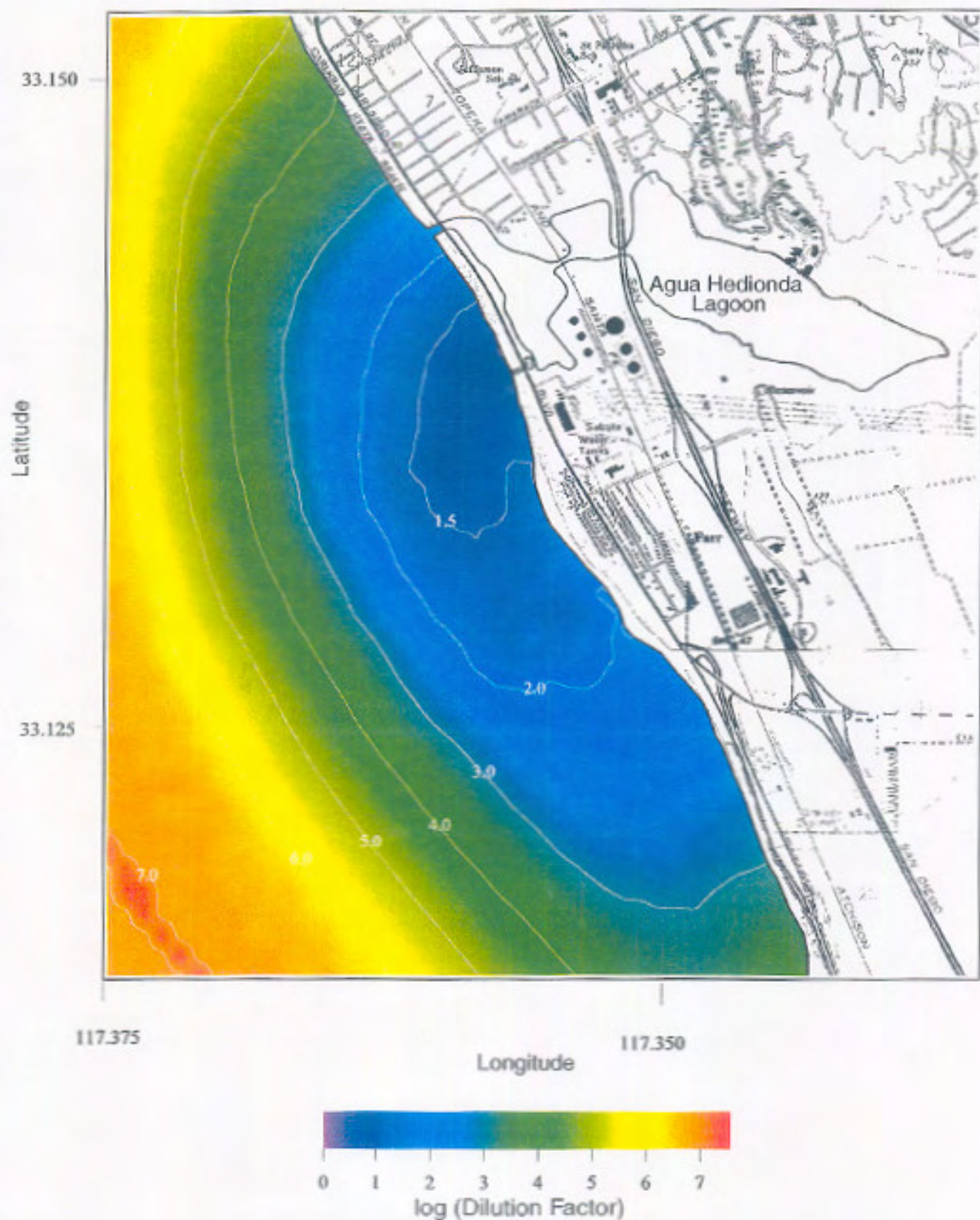


Figure 4.2. Daily average of the bottom dilution of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 725.8 mgd, combined discharge = 675.8 mgd, ambient ocean salinity = 33.51, worst case day (17 Aug 1992).

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existing conditions (Figure 3.23-a and Appendix A). The minimum dilution of bottom salinity at a distance of 1000 ft (305 m) in any direction from the discharge channel is 20 to 1.

The depth-averaged salinity field is plotted in Figure 4.3 for RO production at 50 mgd during the worst day conditions. The corresponding depth-averaged dilution field for concentrated seawater is contoured in Figure 4.4. Because the combined discharge is heavier than ambient seawater, the salinity increases in the water column are much less and the footprint of concentrated seawater is much smaller than what was found on the seabed in Figure 4.1. Maximum depth-averaged salinities reach 34.6 ppt directly seaward of the mouth of the discharge channel. Therefore, no water column saline impacts exceed 10‰ and the total area of pelagic habitat experiencing a 1‰ increase in salinity is only 42 acres. Depth-averaged dilutions 1000 ft seaward of the discharge channel are 140 to 1. These results indicate that the percentage change in local salinities are no greater than the naturally occurring percentage changes in salinity if the RO production is limited to 50 mgd.

Figures 4.5 and 4.6 give the daily average of the bottom salinity distribution and corresponding dilution fields respectively for worst day conditions when the RO production rate is increased to 100 mgd. Maximum seabed salinities reach 38.2 ppt immediately offshore of the discharge channel in the surfzone and 24.4 ppt on the seabed in the immediate nearshore neighborhood of the discharge channel experience a 10‰ increase in salinity. Benthic area subjected to a 1‰ increase in salinity is 415 acres. The minimum bottom dilution of concentrated seawater is 10 to 1 at a distance of 1000 ft in any direction from the discharge channel.

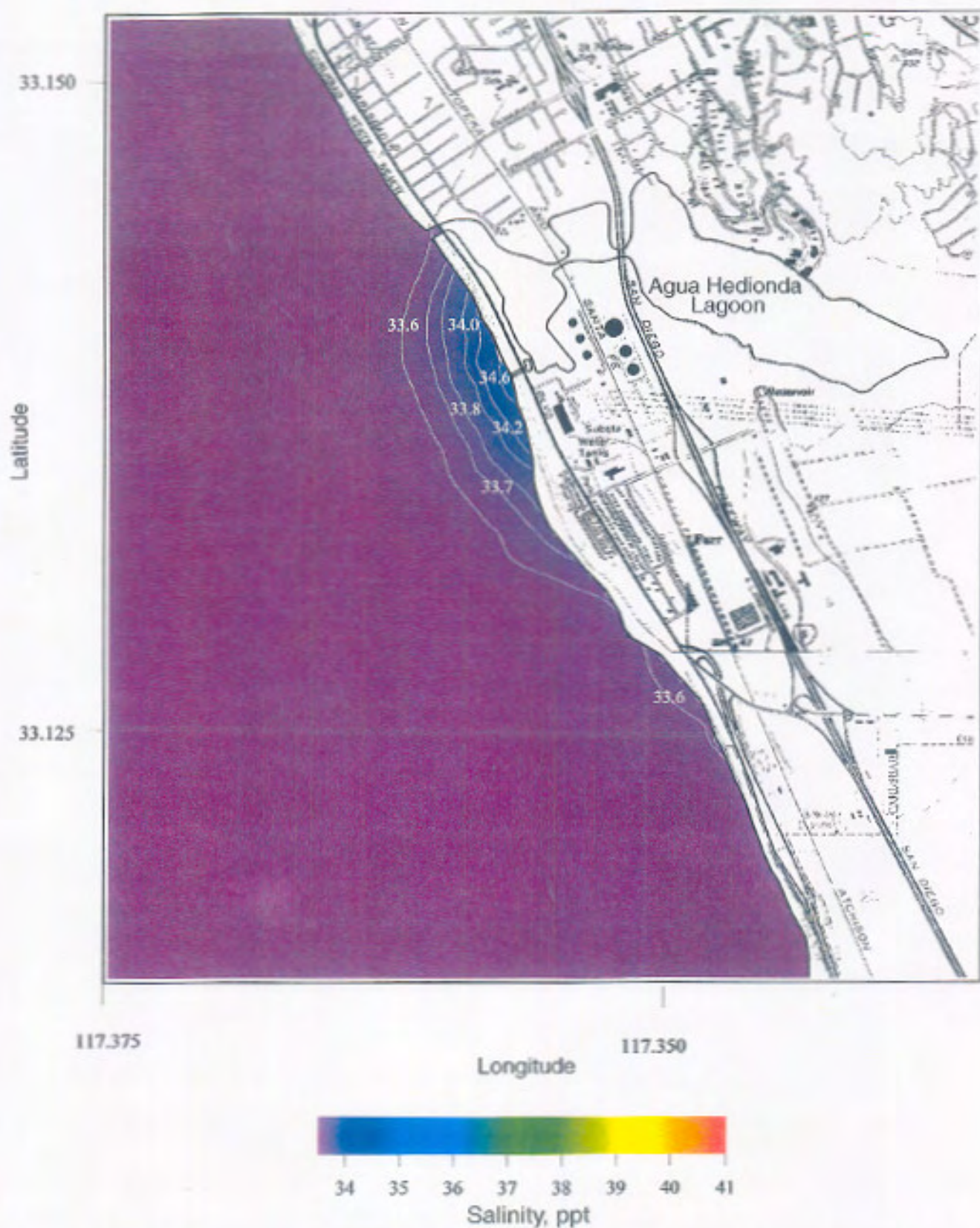


Figure 4.3. Daily average of the depth-averaged salinity of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 725.8 mgd, combined discharge = 675.8 mgd, ambient ocean salinity = 33.51 ppt, worst case day (17 Aug 1992).
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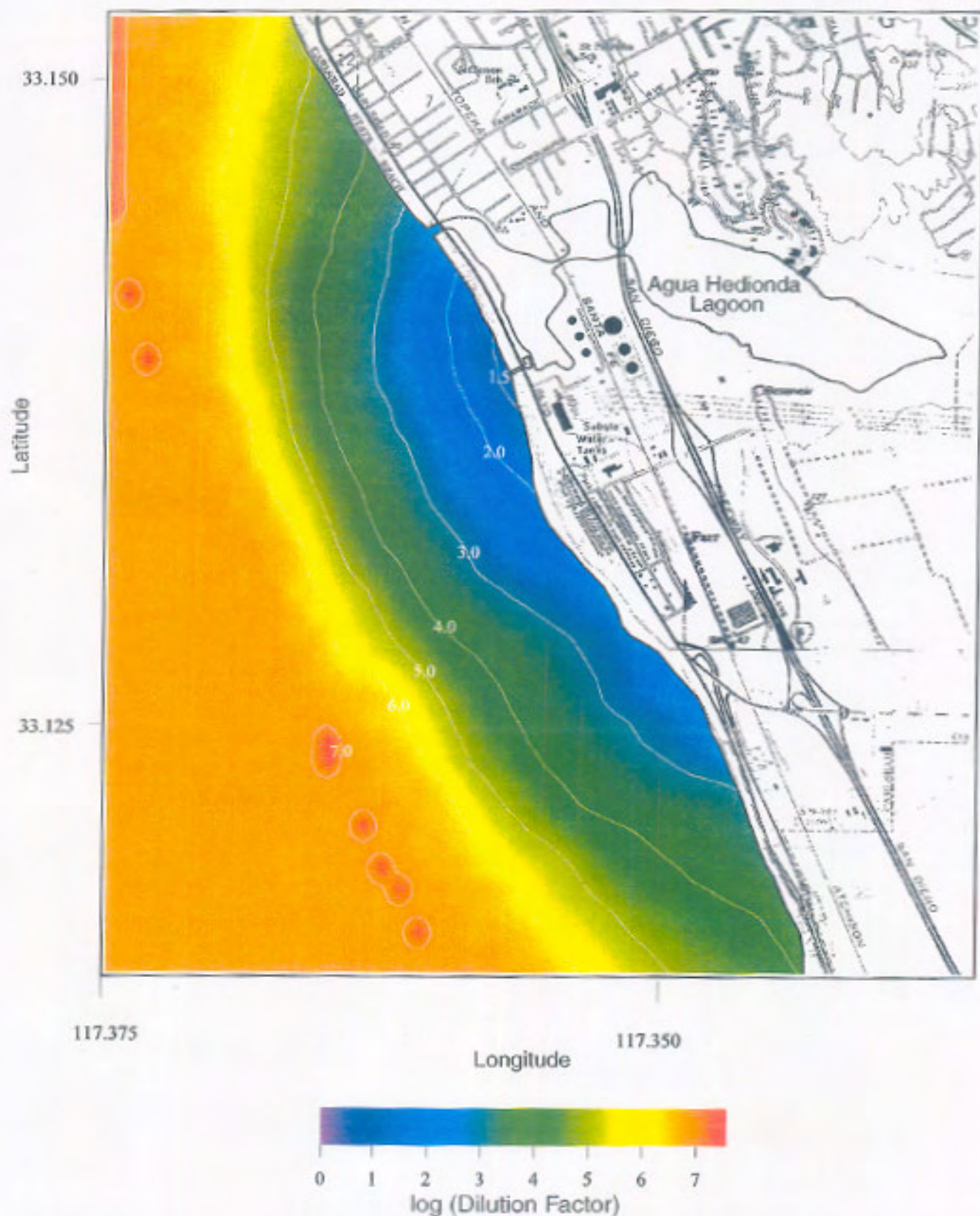


Figure 4.4. Daily average of the depth-averaged dilution of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 725.8 mgd, combined discharge = 675.8 mgd, ambient ocean salinity = 33.51, worst case day (17 Aug 1992).

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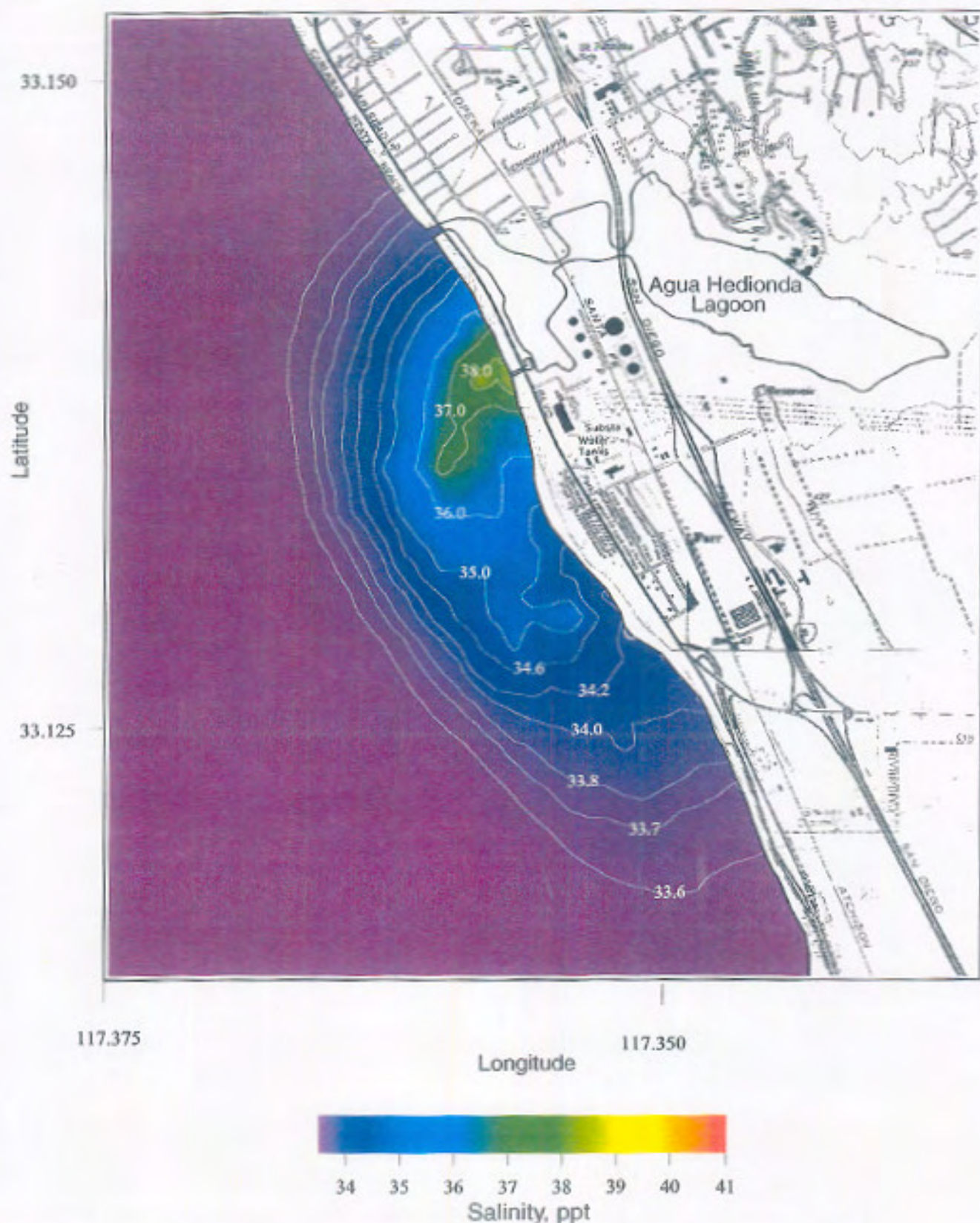


Figure 4.5. Daily average of the bottom salinity of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 725.8 mgd, combined discharge = 625.8 mgd, ambient ocean salinity = 33.51 ppt, worst case day (17 Aug 1992).

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The depth-averaged salinity field is plotted in Figure 4.7 for RO production at 100 mgd during the worst day conditions. The corresponding depth-averaged dilution field for concentrated seawater is contoured in Figure 4.8 on a log-10 scale. Maximum depth-averaged salinities reach 36.0 ppt directly seaward of the mouth of the discharge channel. Therefore, no water column saline impacts exceed 10‰ and the total area of pelagic habitat experiencing a 1‰ increase in salinity is only 94.7 acres. Depth-averaged dilutions 1000 ft seaward of the discharge channel are 63 to 1.

Increasing RO production rates from 50 mgd to 100 mgd increases the footprint and strength of the salinity anomaly and reduces the dilutions of the concentrate seawater effluent. Although this increase leads to saline impacts above the range of natural variability, the effected area at 100 mgd production rate is localized to 24.4 acres *in the surfzone* surrounding the discharge channel. The effected area is sandy bottom habitat subject to large and rapid beach erosion accretion (LePage and Ware, 2001, Jenkins and Wasyi, 2001). These benthic impacts at high production rates have a recurrence probability of 0.013%. There are no such benthic impacts at 50 mgd production rates.

B) Average Day

The model simulation of the 24 hour average of the salinity field on the seabed is plotted in Figure 4.9 during the average day conditions for an RO production rate of 50 mgd and a plant flow rate of 576 mgd. Contours of salinity are in parts per thousand (ppt), where the ambient background ocean salinity is 33.52 ppt. The corresponding dilution field of the concentrated seawater by-product on the seabed is plotted in Figure 4.10. Dilution contours are in a log-10 scale relative to the raw concentrate (at twice ambient ocean salinity). Because the

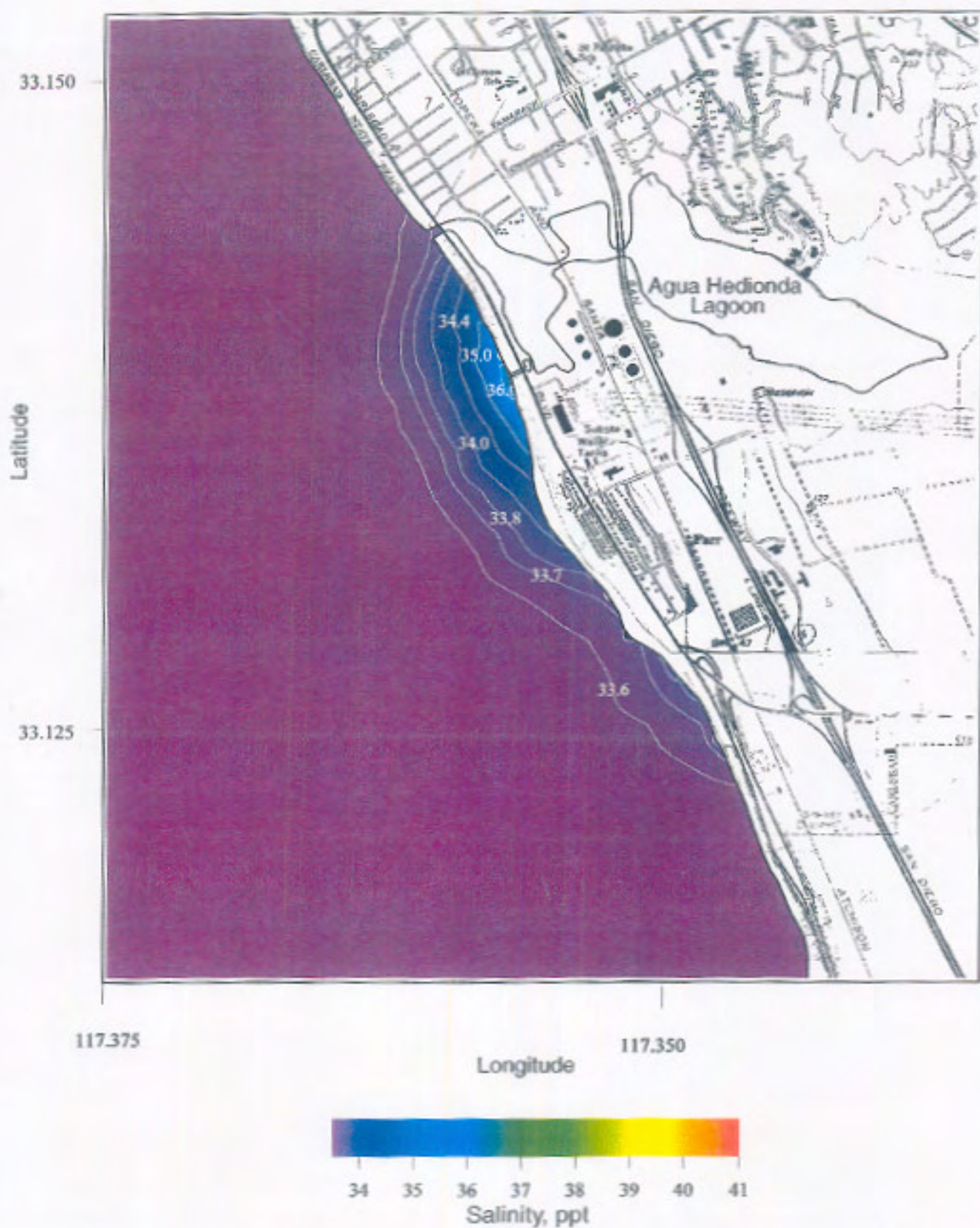


Figure 4.7. Daily average of the depth-averaged salinity of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 725.8 mgd, combined discharge = 625.8 mgd, ambient ocean salinity = 33.51 ppt, worst case day (17 Aug 1992).

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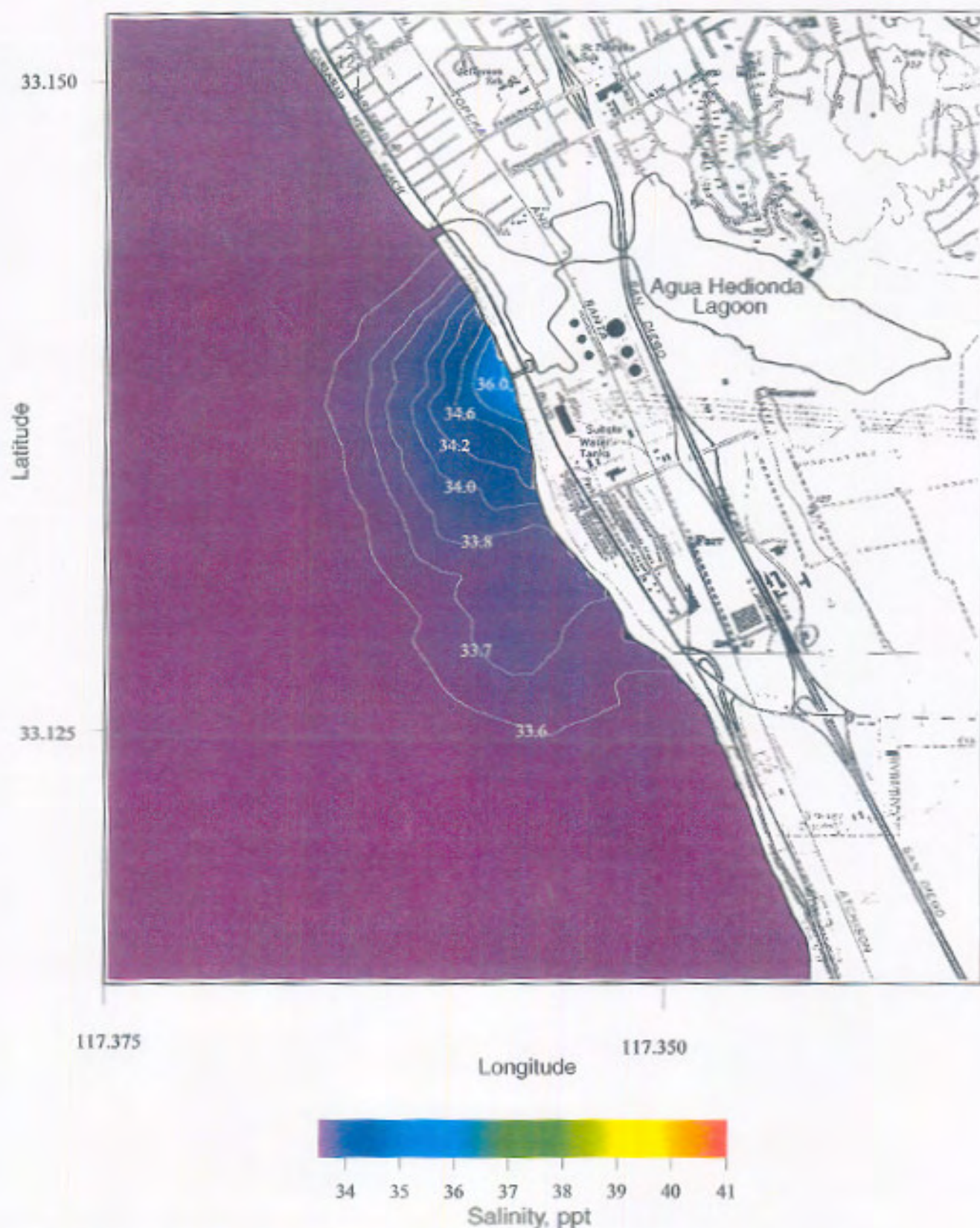


Figure 4.9. Daily **average** of the **bottom salinity** of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 576 mgd, combined discharge = 526 mgd, ambient ocean salinity = 33.52 ppt, **average day** (23 May 1994).

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combined discharge (at 526 mgd) is heavier than seawater, Figure 4.9 and 4.10 delineate the maximum saline impacts and minimum dilutions found anywhere in the water column on an average day. Maximum bottom salinities reach 36.0 ppt directly offshore of the discharge. Therefore no benthic area is exposed to a 10% elevation in salinity. The benthic area subjected to a 1% increase in salinity is 111 acres. This area is predominantly offshore and downdrift (to the south) of the discharge channel, consistent with the discharge plume patterns observed in the calibration data under existing conditions (Figure 3.23-b and Appendix A). The minimum dilution of bottom salinity at a distance of 1000 ft (305 m) in any direction from the discharge channel is 32 to 1.

The depth-averaged salinity field is plotted in Figure 4.11 for RO production at 50 mgd during the average day conditions. The corresponding depth-averaged dilution field for concentrated seawater is contoured in Figure 4.12. Because the combined discharge is heavier than ambient seawater, the salinity increases in the water column are much less and the footprint of concentrated seawater is much smaller than what was found on the seabed in Figure 4.9. Maximum depth-averaged salinities reach 34.4 ppt directly seaward of the mouth of the discharge channel. Therefore, no water column saline impacts exceed 10% and the total area of pelagic habitat experiencing a 1% increase in salinity is only 37 acres. Depth-averaged dilutions 1000 ft seaward of the discharge channel are 170 to 1. As expected, the areas of salinity impacts are smaller and the dilutions are greater on an average day than on a worst case day, but in either case those impacts remain less than natural variability when the RO production is 50 mgd or less.

Figures 4.13 and 4.14 give the daily average of the bottom salinity distribution and corresponding dilution fields respectively for average day

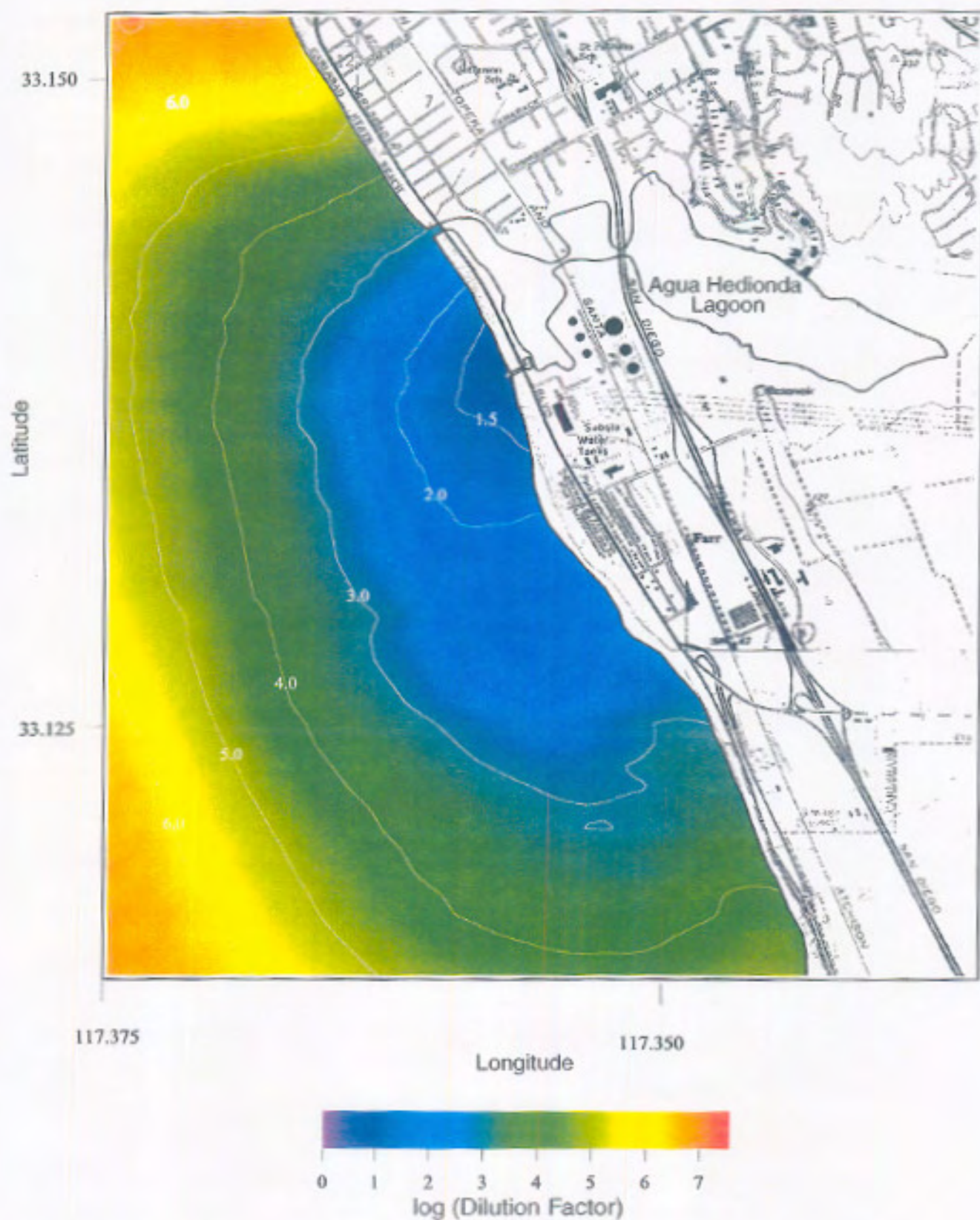


Figure 4.10. Daily average of the bottom dilution of concentrated seawater for
 R.O. = 50 mgd, plant inflow rate = 576 mgd, combined discharge = 526 mgd,
 ambient ocean salinity = 33.52, average day (23 May 1992).

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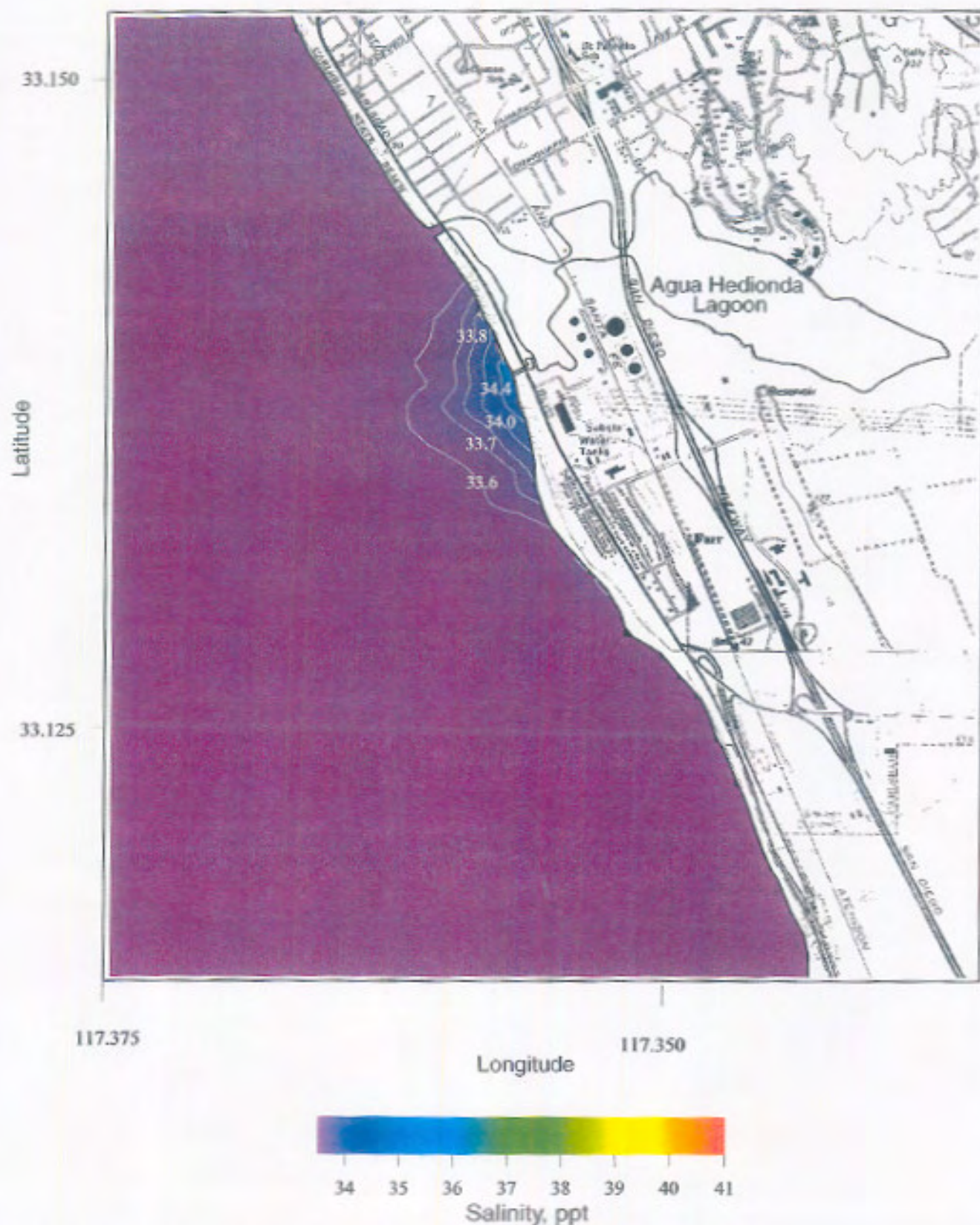


Figure 4.11. Daily average of the depth-averaged salinity of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 576 mgd, combined discharge = 526 mgd, ambient ocean salinity = 33.52 ppt, average day (23 May 1994).

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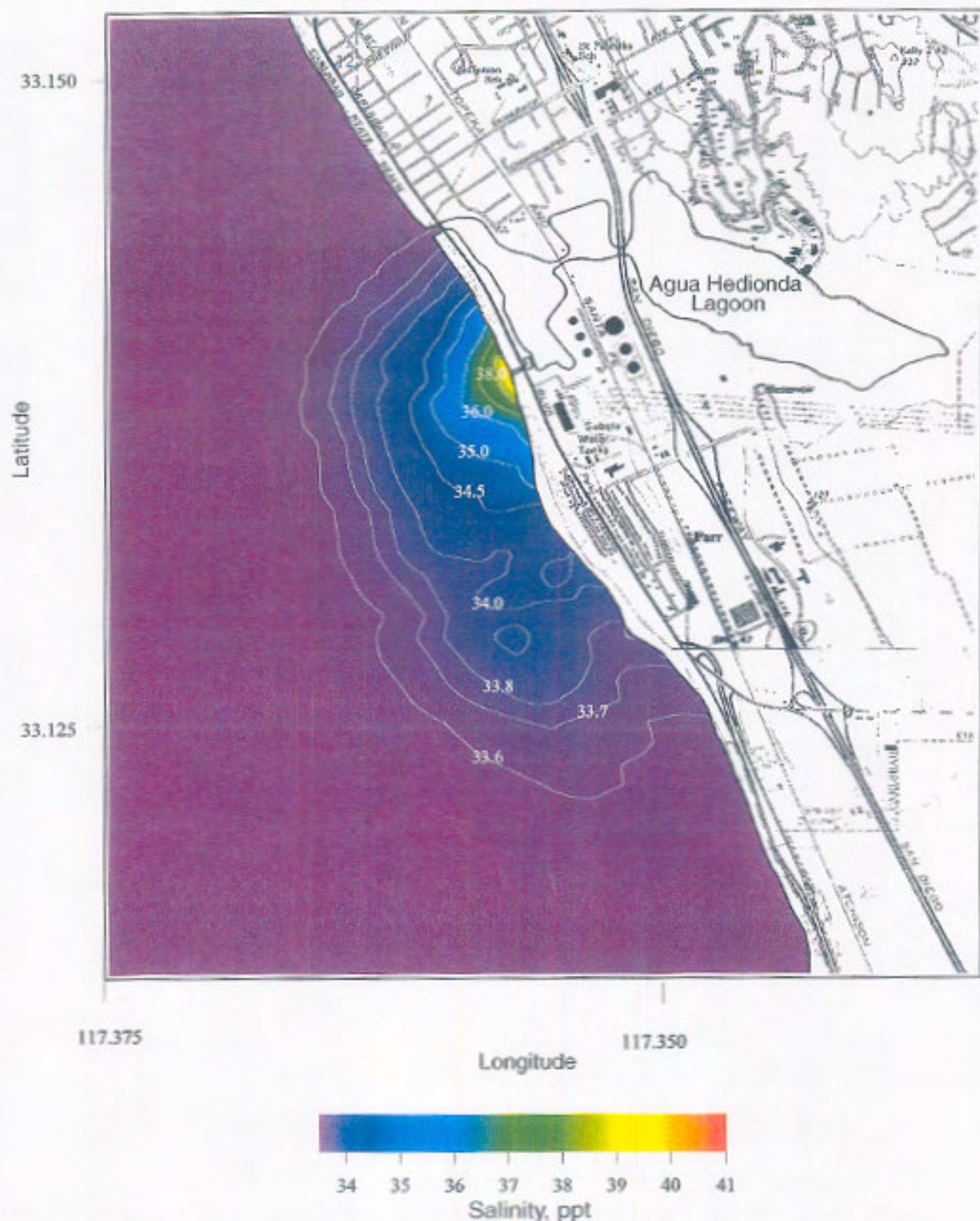


Figure 4.13. Daily average of the bottom salinity of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 576 mgd, combined discharge = 476 mgd, ambient ocean salinity = 33.52 ppt, average day (23 May 1994).
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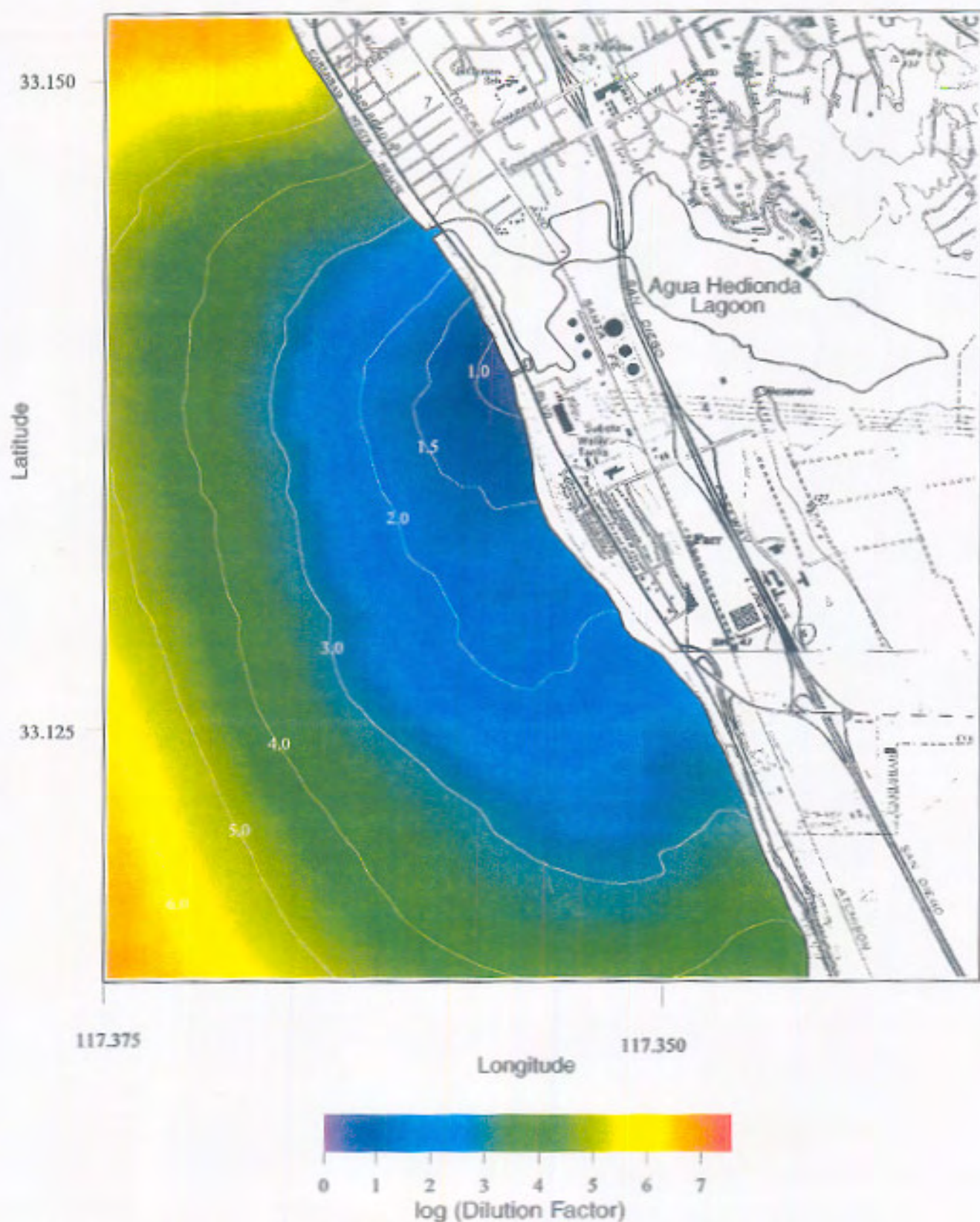


Figure 4.14. Daily average of the bottom dilution of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 576 mgd, combined discharge = 476 mgd, ambient ocean salinity = 33.52, average day (23 May 1992).
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conditions when the RO production rate is increased to 100 mgd. Maximum seabed salinities reach 39.3 ppt immediately offshore of the discharge channel in the surfzone and 7.4 acres of seabed in the immediate nearshore neighborhood of the discharge channel experience a 10% increase in salinity. Benthic area subjected to a 1% increase in salinity is 241 acres. The minimum bottom dilution of concentrated seawater is 22 to 1 at a distance of 1000 ft in any direction from the discharge channel.

The depth-averaged salinity field is plotted in Figure 4.15 for RO production at 100 mgd during the average day conditions. The corresponding depth-averaged dilution field for concentrated seawater is contoured in Figure 4.16. Maximum depth-averaged salinities reach 36.8 ppt directly seaward of the mouth of the discharge channel. Therefore, no water column saline impacts exceed 10% and the total area of pelagic habitat experiencing a 1% increase in salinity is only 54 acres. Depth-averaged dilutions 1000 ft seaward of the discharge channel are 100 to 1.

Increasing RO production rates from 50 mgd to 100 mgd on an average day is again found to increase the footprint and strength of the salinity anomaly and reduce the dilutions of the concentrated seawater effluent. Lower plant flow rates on average days result in higher concentrations of sea salts at "the end of the pipe" than for a worst day. However, the higher ocean mixing levels on average days insure that smaller areas of both benthic and pelagic habitat are effected than on worst case days. These higher dilutions are obtained everywhere beyond the discharge channel on average days.

C) Worst Month

The model simulation of the 30 day average of the salinity field on the seabed is plotted in Figure 4.17 for an RO production rate of 50 mgd and a plant

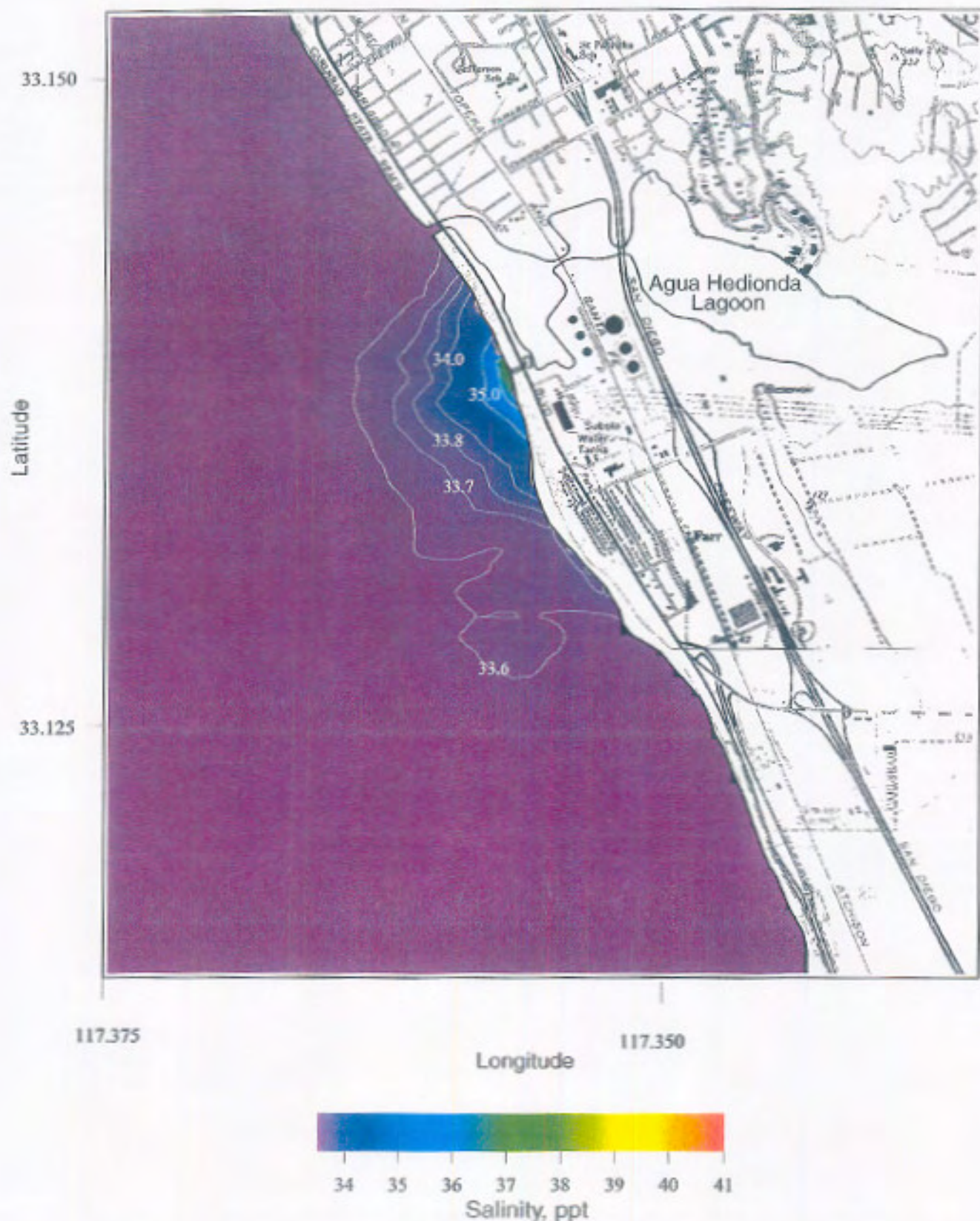


Figure 4.15. Daily average of the depth-averaged salinity of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 576 mgd, combined discharge = 476 mgd, ambient ocean salinity = 33.52 ppt, average day (23 May 1994).

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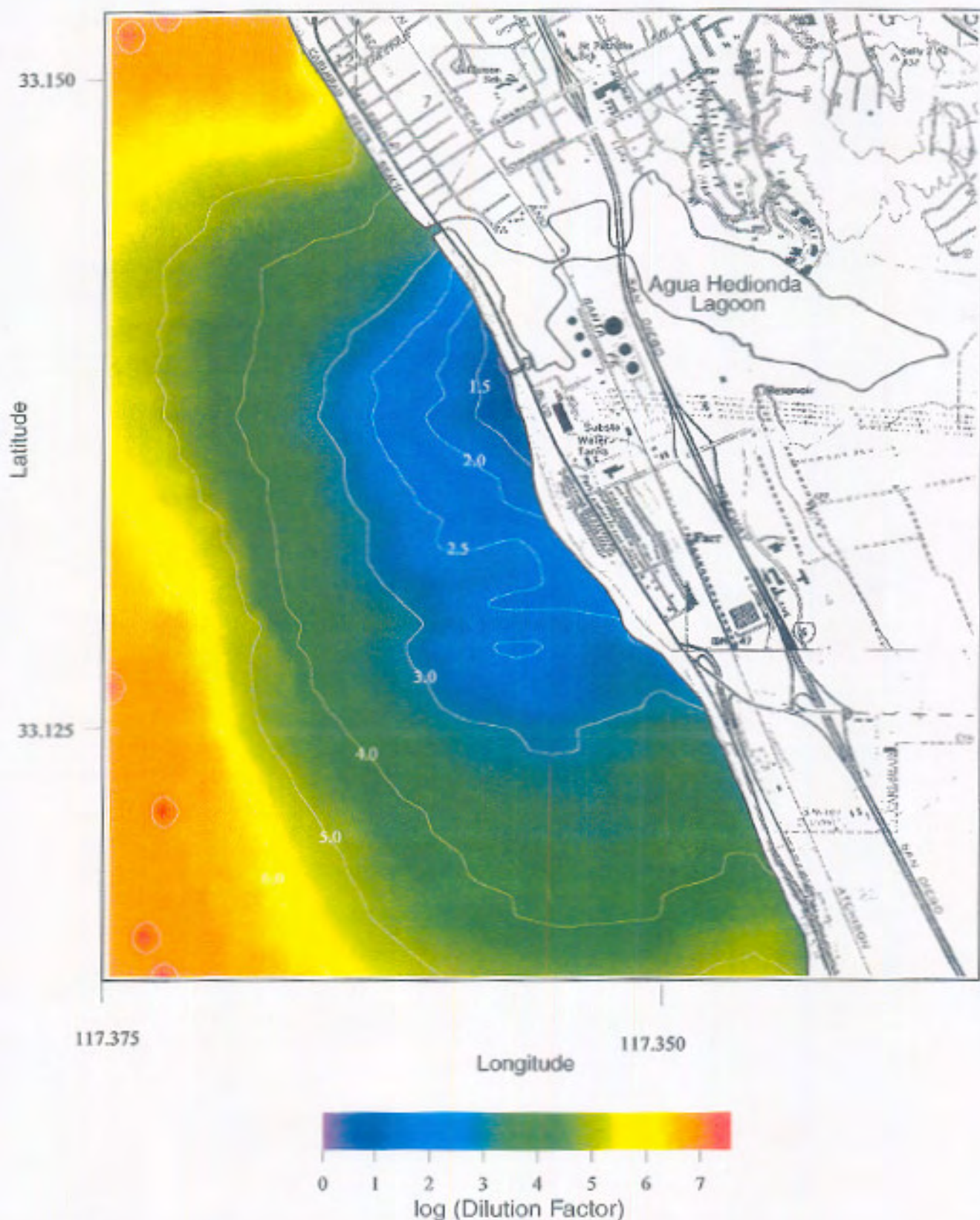


Figure 4.16. Daily average of the depth-averaged dilution of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 576 mgd, combined discharge = 476 mgd, ambient ocean salinity = 33.52, average day (23 May 1992).

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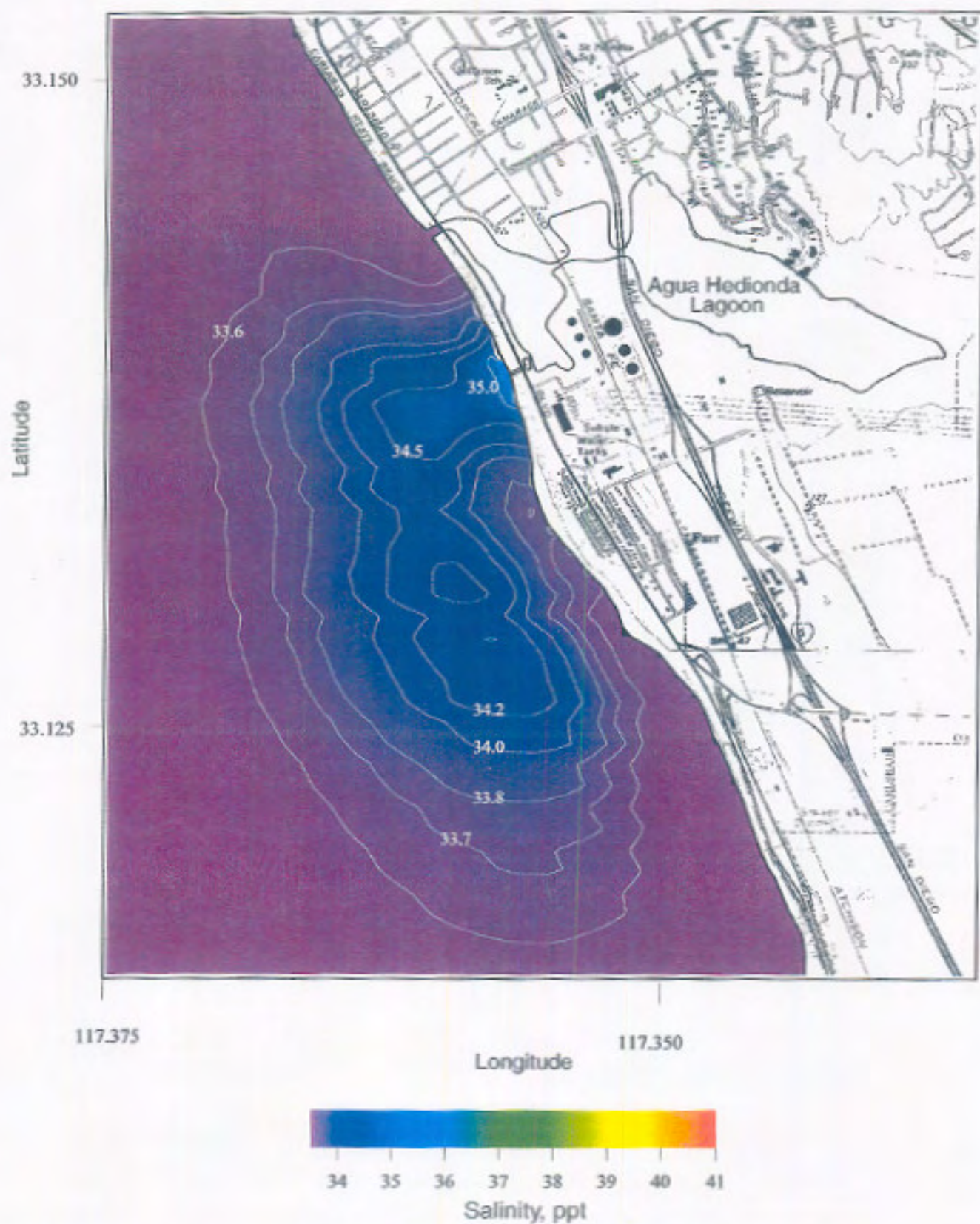


Figure 4.17. 30 day average of the bottom salinity of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 703 mgd, combined discharge = 653 mgd, ambient ocean salinity = 33.49 ppt, worst month (August 1992).

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flow rate of 703 mgd during the worst month conditions. Contours of salinity are in parts per thousand (ppt), where the ambient background ocean salinity is 33.49 ppt. The corresponding dilution field of the concentrated seawater by-product on the seabed is plotted in Figure 4.18. Dilution contours are in a log-10 scale relative to the raw concentrate (at twice ambient ocean salinity). Because the combined discharge (at 653 mgd) is heavier than seawater, Figure 4.17 and 4.18 delineate the maximum saline impacts and minimum dilutions found anywhere in the water column over a 30 day period. Maximum bottom salinities reach 35.0 ppt directly offshore of the discharge. Therefore no benthic area is exposed to a 10% elevation in salinity. The benthic area subjected to a 1% increase in salinity is 465 acres. This area is predominantly offshore and downdrift (to the south) of the discharge channel, consistent with the discharge plume patterns observed in the calibration data under existing conditions (Figure 3.23-a and Appendix A). The minimum dilution of bottom salinity at a distance of 1000 ft (305 m) in any direction from the discharge channel is 25 to 1. The footprint of the salinity field and dilution field has increased over that of the worst day due to the larger currents and wave heights of a 30 day simulation period.

The depth-averaged salinity field is plotted in Figure 4.19 for RO production at 50 mgd during the worst month conditions. The corresponding depth-averaged dilution field for concentrated seawater is contoured in Figure 4.20. Because the combined discharge is heavier than ambient seawater, the salinity increases in the water column are much less and the footprint of concentrated seawater is much smaller than what was found on the seabed in Figure 4.17. Maximum depth-averaged salinities reach 34.0 ppt directly seaward of the mouth of the discharge channel. Therefore, no water column saline impacts exceed 10% and the total area

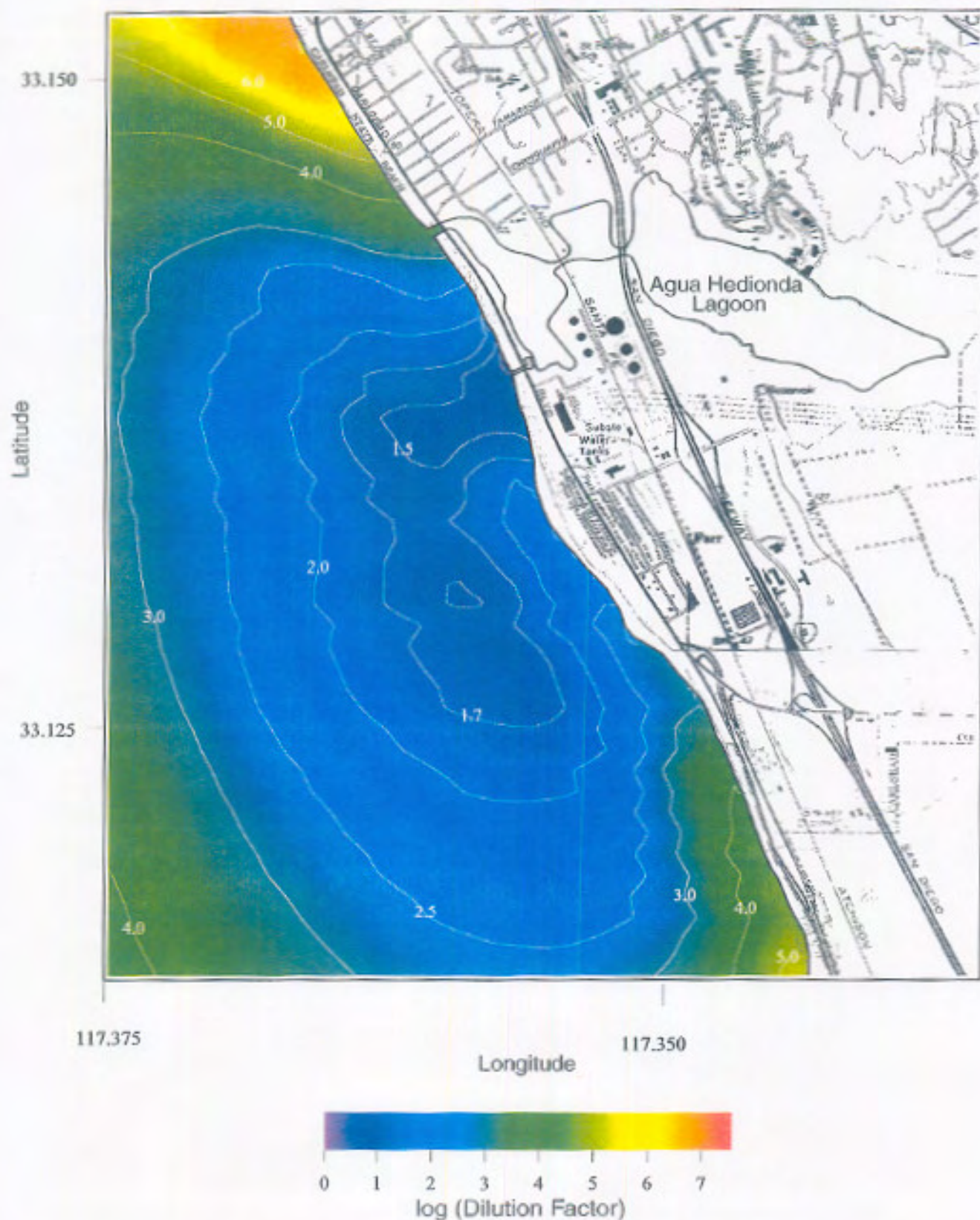


Figure 4.18. 30 day average of the bottom dilution of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 703 mgd, combined discharge = 653 mgd, ambient ocean salinity = 33.49, worst month (August 1992).
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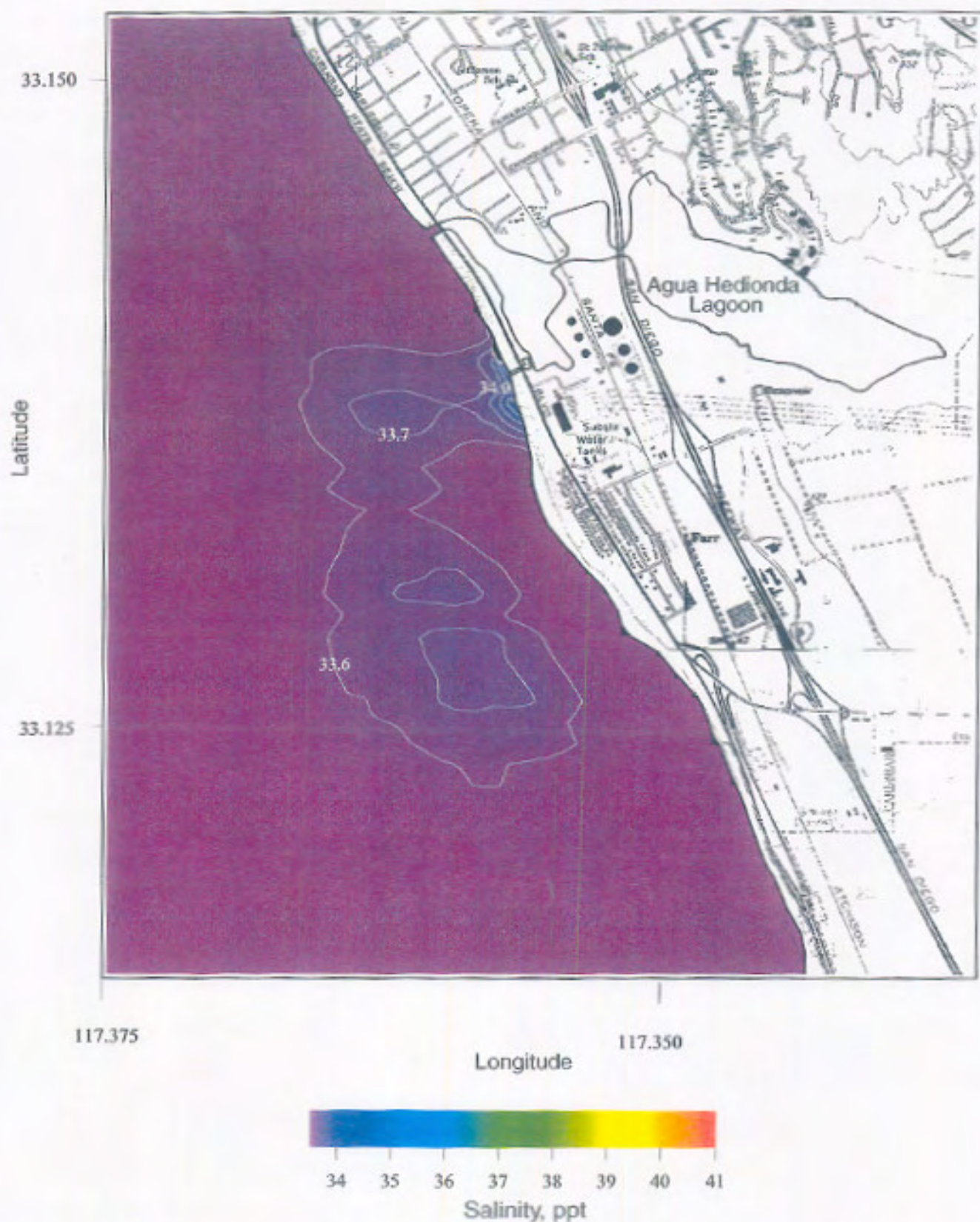


Figure 4.19. 30 day average of the depth-averaged salinity of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 703 mgd, combined discharge = 653 mgd, ambient ocean salinity = 33.49 ppt, worst month (August 1992).

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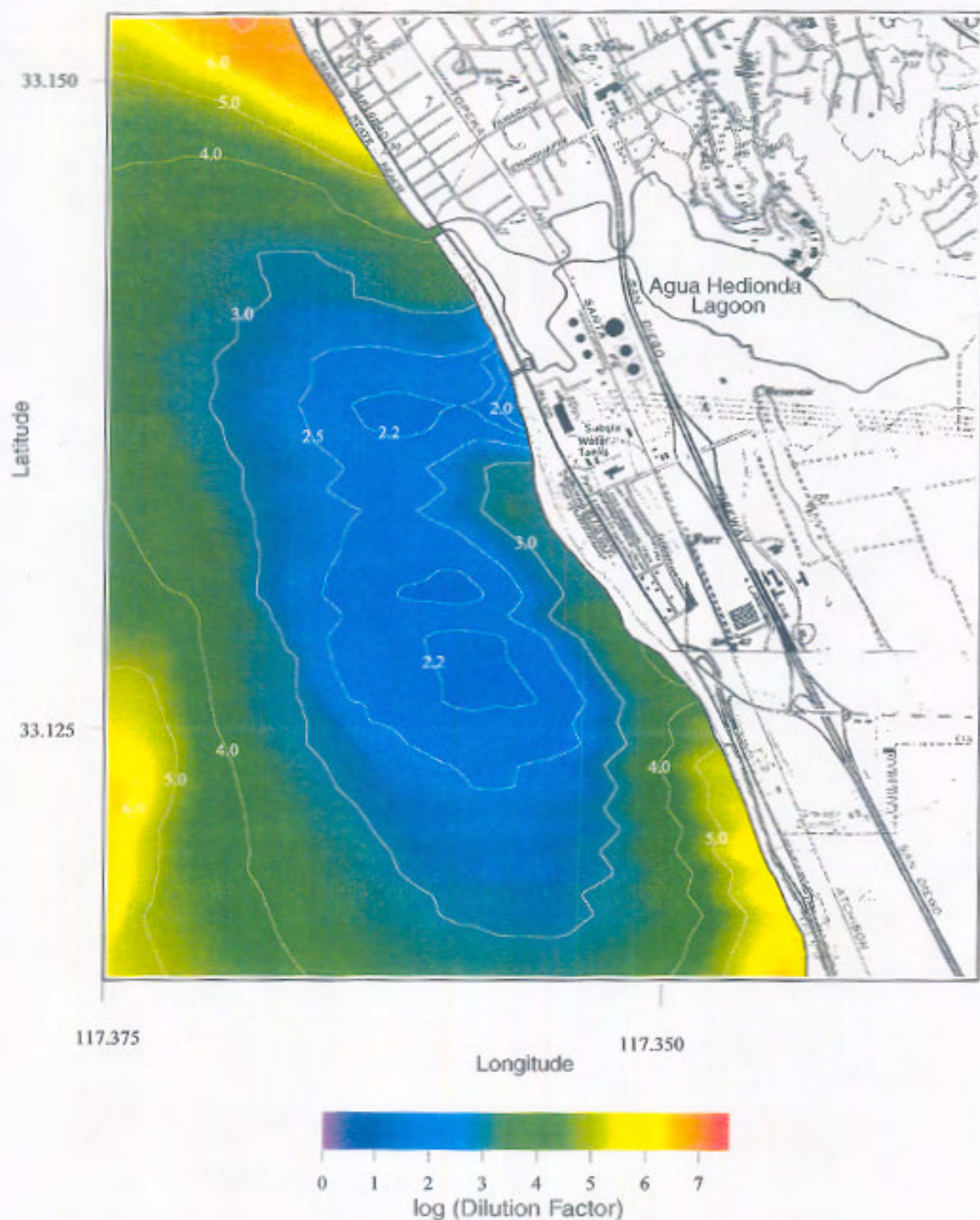


Figure 4.20. 30 day average of the depth-averaged dilution of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 703 mgd, combined discharge = 653 mgd, ambient ocean salinity = 33.49, worst month (August 1992).

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of pelagic habitat experiencing a 1% increase in salinity is only 56 acres. (The footprint is likewise greater than for the worst day due to increased currents and wave heights over a 30 day period). Depth-averaged dilutions 1000 ft seaward of the discharge channel are 160 to 1. These results indicate that the percentage change in local salinities over a 30 day protraction of worst case conditions are no greater than the naturally occurring percentage changes in salinity if the RO production is limited to 50 mgd.

Figures 4.21 and 4.22 give the 30 day average of the bottom salinity distribution and corresponding dilution fields respectively for worst month conditions when the RO production rate is increased to 100 mgd. Maximum seabed salinities reach 38.0 ppt immediately offshore of the discharge channel in the surfzone and 14.8 acres of seabed in the immediate nearshore neighborhood of the discharge channel experience a 10% increase in salinity. Benthic area subjected to a 1% increase in salinity is 855 acres. The minimum bottom dilution of concentrated seawater is 14 to 1 at a distance of 1000 ft in any direction from the discharge channel.

The depth-averaged salinity field is plotted in Figure 4.23 for RO production at 100 mgd during the worst day conditions. The corresponding depth-averaged dilution field for concentrated seawater is contoured in Figure 4.24. Maximum depth-averaged salinities reach 35.1 ppt directly seaward of the mouth of the discharge channel. Therefore, no water column saline impacts exceed 10% and the total area of pelagic habitat experiencing a 1% increase in salinity is 200 acres. Depth-averaged dilutions 1000 ft seaward of the discharge channel are 85 to 1.

Increasing RO production rates from 50 mgd to 100 mgd increases the footprint and strength of the salinity anomaly and reduces the dilutions of the

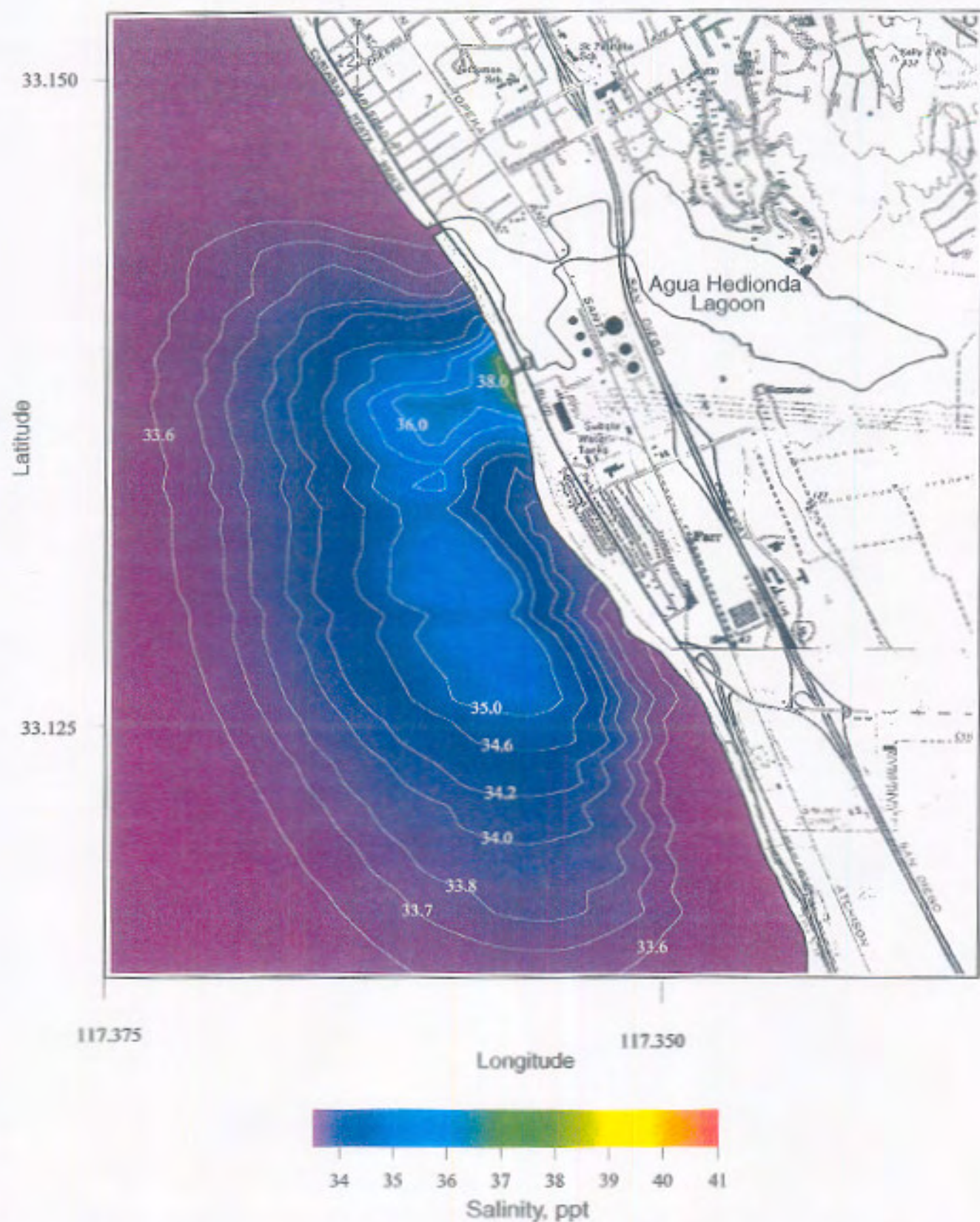


Figure 4.21. 30 day average of the bottom salinity of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 703 mgd, combined discharge = 603 mgd, ambient ocean salinity = 33.49 ppt, worst month (August 1992).

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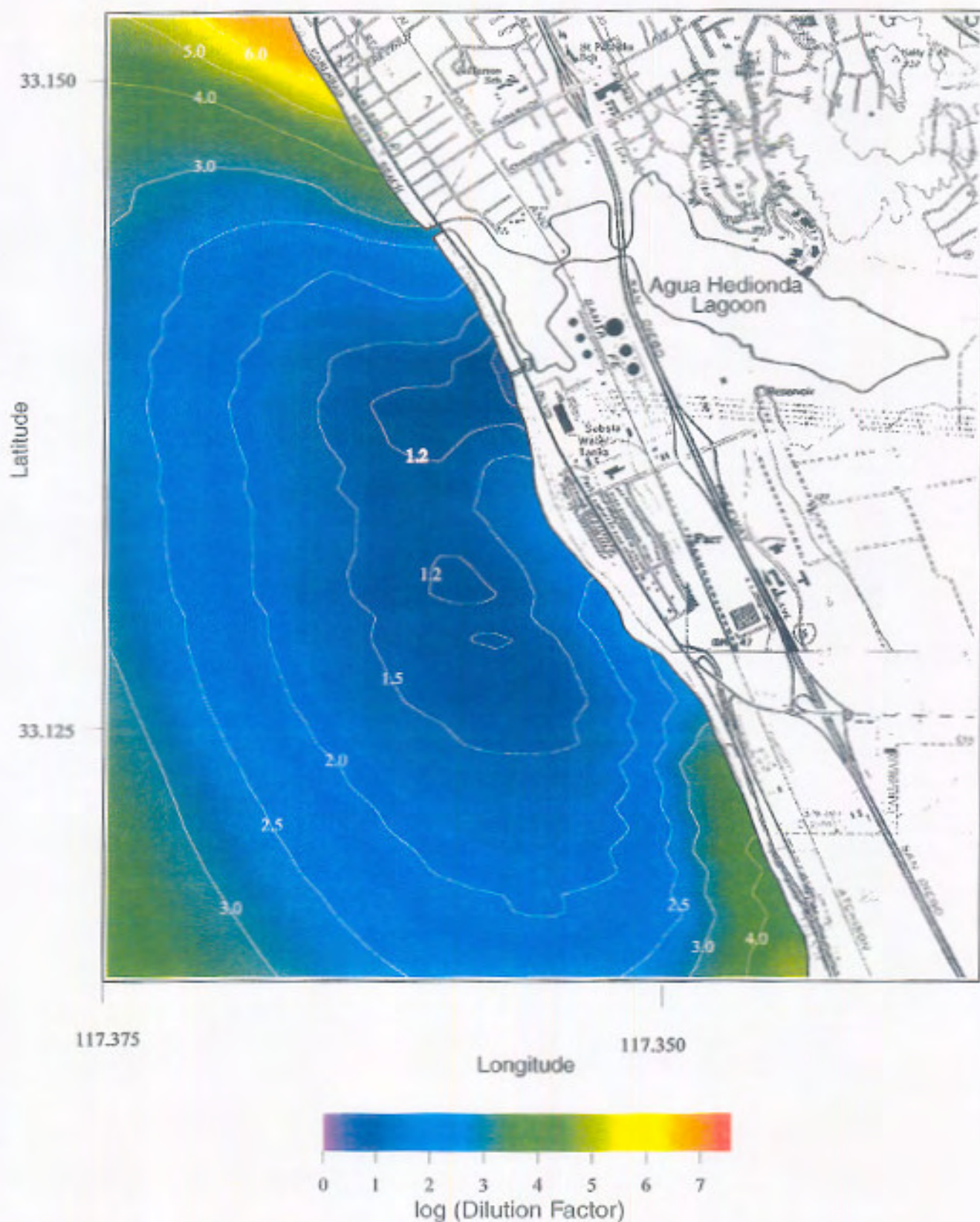


Figure 4.22. 30 day average of the bottom dilution of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 703 mgd, combined discharge = 603 mgd, ambient ocean salinity = 33.49, worst month (August 1992).

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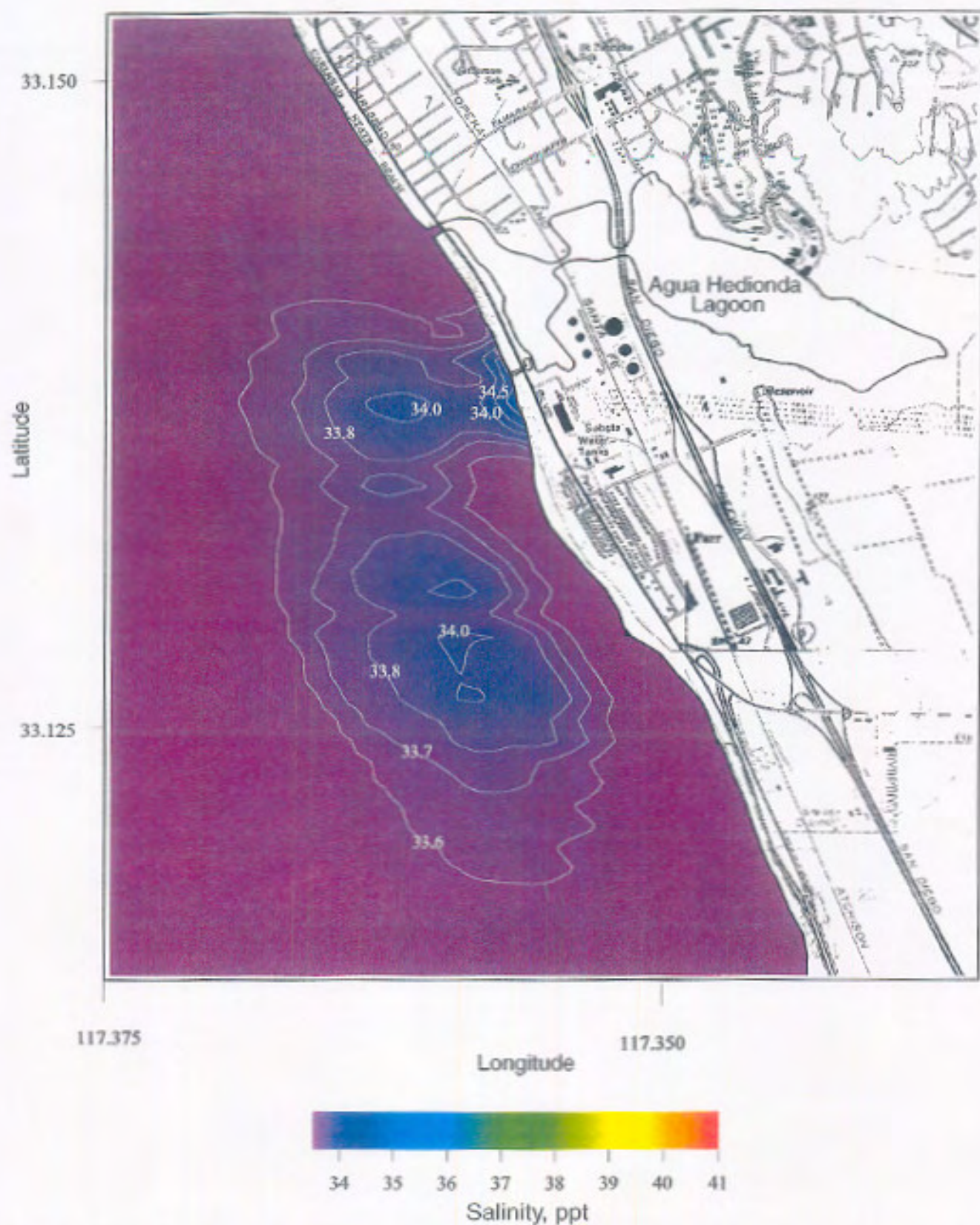


Figure 4.23. 30 day average of the depth-averaged salinity of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 703 mgd, combined discharge = 603 mgd, ambient ocean salinity = 33.49 ppt, worst month (August 1992).

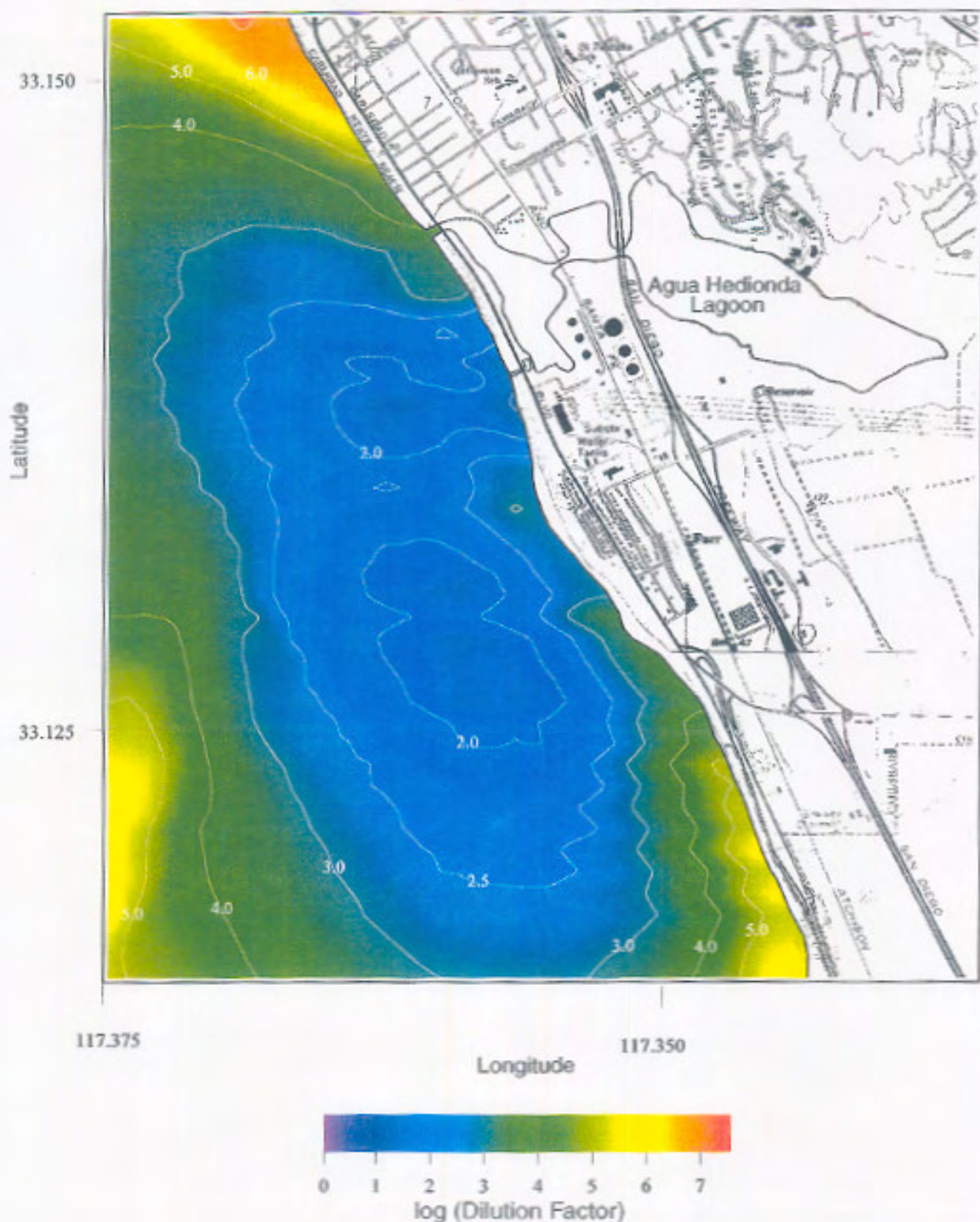


Figure 4.24. 30 day average of the depth-averaged dilution of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 703 mgd, combined discharge = 603 mgd, ambient ocean salinity = 33.49, worst month (August 1992).

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concentrated seawater effluent. Although this increase over a 30 day period leads to saline impacts above the range of natural variability, the effected area at 100 mgd production rate is localized to 14.8 acres in the surfzone surrounding the discharge channel. These impacts at high production rates have a recurrence probability of 0.4%. This area is made up of sandy bottom habitat that is subject to large and rapid beach erosion and accretion events (LePage and Ware, 2001, Jenkins and Wasy1, 2001). There are no such benthic impacts at 50 mgd production rates.

D) Average Month

The model simulation of the 30 day average of the salinity field on the seabed is plotted in Figure 4.25 for an RO production rate of 50 mgd and a plant flow rate of 527 mgd during the average month conditions. Contours of salinity are in parts per thousand (ppt), where the ambient background ocean salinity is 33.49 ppt. The corresponding dilution field of the concentrated seawater by-product on the seabed is plotted in Figure 4.26. Dilution contours are in a log-10 scale relative to the raw concentrate (at twice ambient ocean salinity). Because the combined discharge (at 477 mgd) is heavier than seawater, Figure 4.25 and 4.26 delineate the maximum saline impacts and minimum dilutions found anywhere in the water column during an average month. Maximum bottom salinities reach 36.1 ppt directly offshore of the discharge. Therefore no benthic area is exposed to a 10% elevation in salinity. The benthic area subjected to a 1% increase in salinity is 239 acres. This area is predominantly offshore and downdrift (to the south) of the discharge channel, consistent with the discharge plume patterns observed in the calibration data under existing conditions (Figure 3.23-b and Appendix A). The

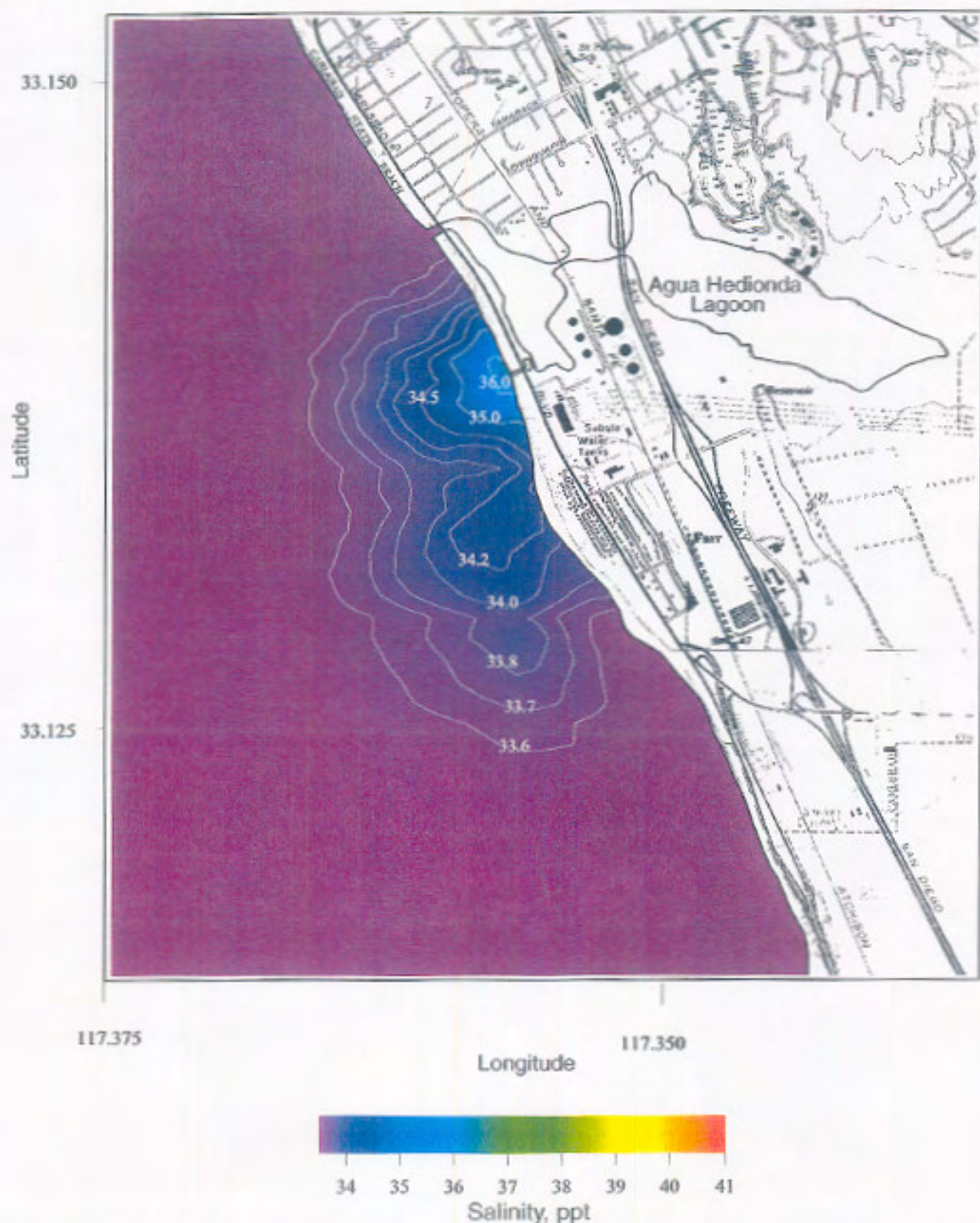


Figure 4.25. 30 day average of the bottom salinity of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 527 mgd, combined discharge = 477 mgd, ambient ocean salinity = 33.49 ppt, 30 day period (May - June 1994).

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minimum dilution of bottom salinity at a distance of 1000 ft (305 m) in any direction from the discharge channel is 35 to 1.

The depth-averaged salinity field is plotted in Figure 4.27 for RO production at 50 mgd during the average month conditions. The corresponding depth-averaged dilution field for concentrated seawater is contoured in Figure 4.28. Because the combined discharge is heavier than ambient seawater, the salinity increases over the water column are much less and the footprint of concentrated seawater is much smaller than what was found on the seabed in Figure 4.25. Maximum depth-averaged salinities reach 34.4 ppt directly seaward of the mouth of the discharge channel. Therefore, no water column saline impacts exceed 10% and the total area of pelagic habitat experiencing a 1% increase in salinity is only 24 acres. Depth-averaged dilutions 1000 ft seaward of the discharge channel are 195 to 1.

Figures 4.29 and 4.30 give the daily average of the bottom salinity distribution and corresponding dilution fields respectively for average month conditions when the RO production rate is increased to 100 mgd. Maximum seabed salinities reach 39.4 ppt immediately offshore of the discharge channel in the surfzone and 11.6 acres of seabed in the immediate nearshore neighborhood of the discharge channel experience a 10% increase in salinity. Benthic area subjected to a 1% increase in salinity is 414 acres. The minimum bottom dilution of concentrated seawater is 12 to 1 at a distance of 1000 ft in any direction from the discharge channel.

The depth-averaged salinity field is plotted in Figure 4.31 for RO production at 100 mgd during the average monthly conditions. The corresponding depth-averaged dilution field for concentrated seawater is contoured in Figure 4.32. Maximum depth-averaged salinities reach 35.5 ppt directly seaward of the mouth of

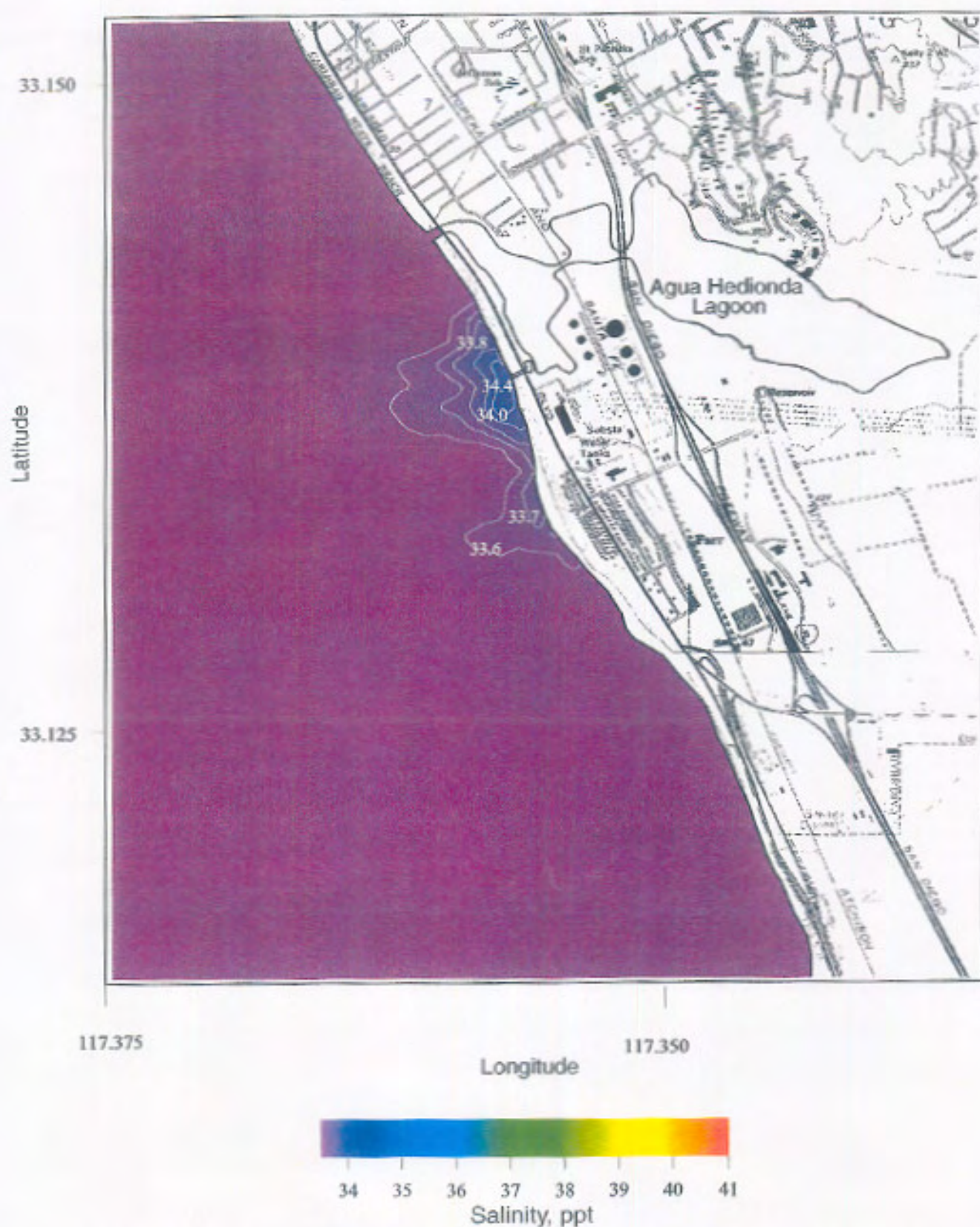


Figure 4.27. 30 day average of the depth-averaged salinity of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 527 mgd, combined discharge = 477 mgd, ambient ocean salinity = 33.49 ppt, 30 day period (May - June 1994).
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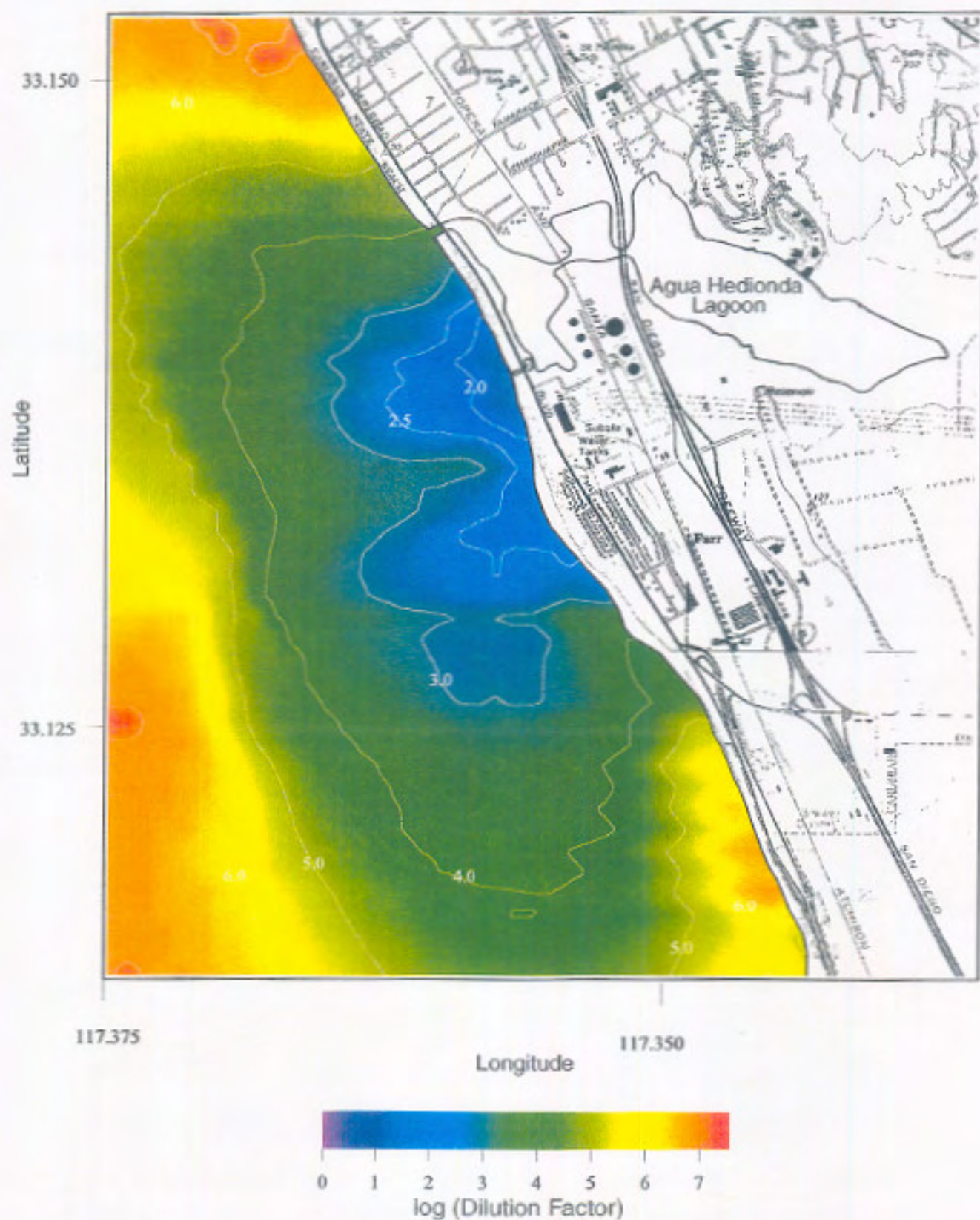


Figure 4.28. 30 day average of the depth-averaged dilution of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 527 mgd, combined discharge = 477 mgd, ambient ocean salinity = 33.49, 30 day period (May - June 1994).

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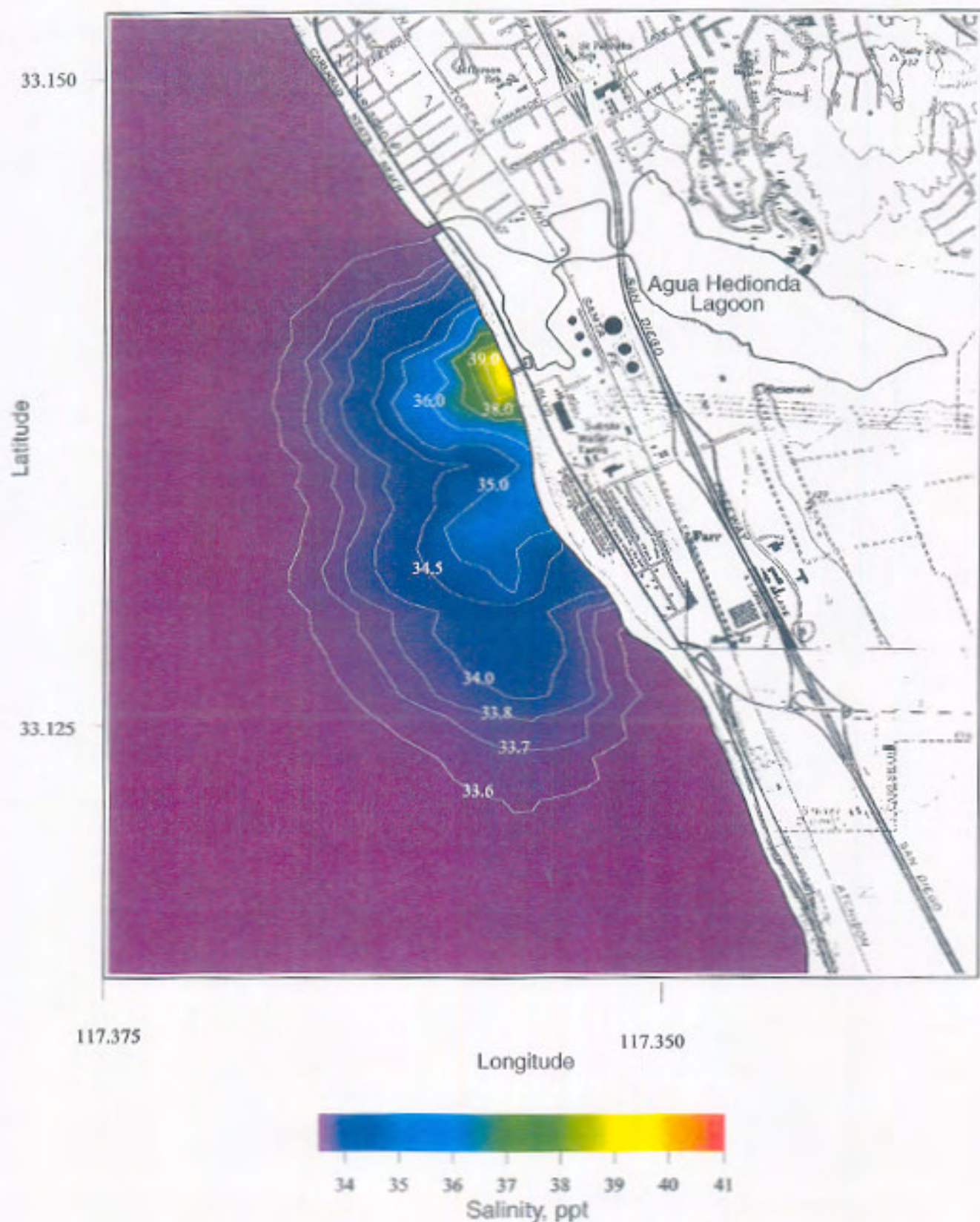


Figure 4.29. 30 day average of the bottom salinity of concentrated seawater for
 R.O. = 100 mgd, plant inflow rate = 527 mgd, combined discharge = 427 mgd,
 ambient ocean salinity = 33.49 ppt, 30 day period (May - June 1994).
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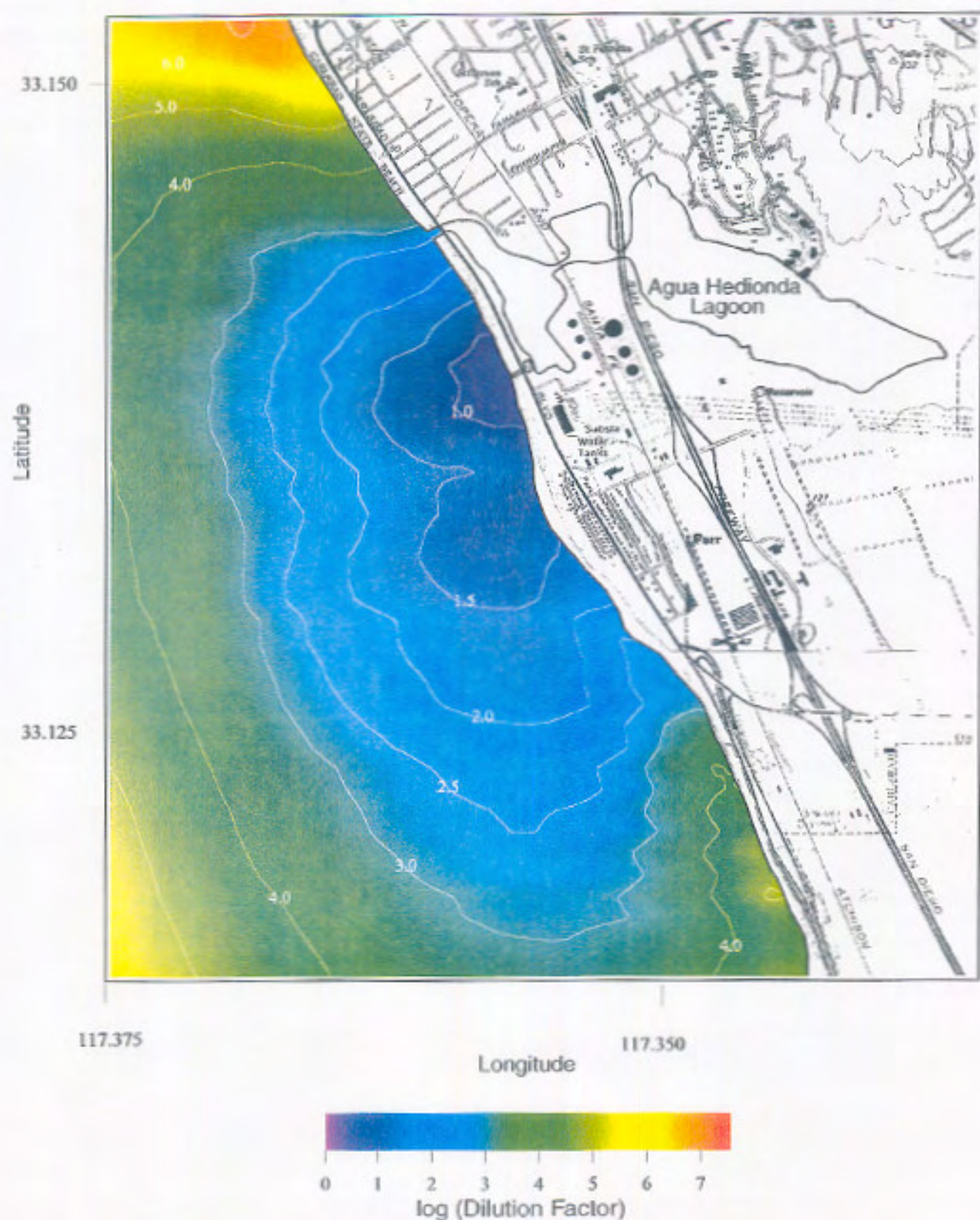


Figure 4.30. 30 day average of the bottom dilution of concentrated seawater for
 R.O. = 100 mgd, plant inflow rate = 527 mgd, combined discharge = 427 mgd,
 ambient ocean salinity = 33.49, 30 day period (May - June 1994).
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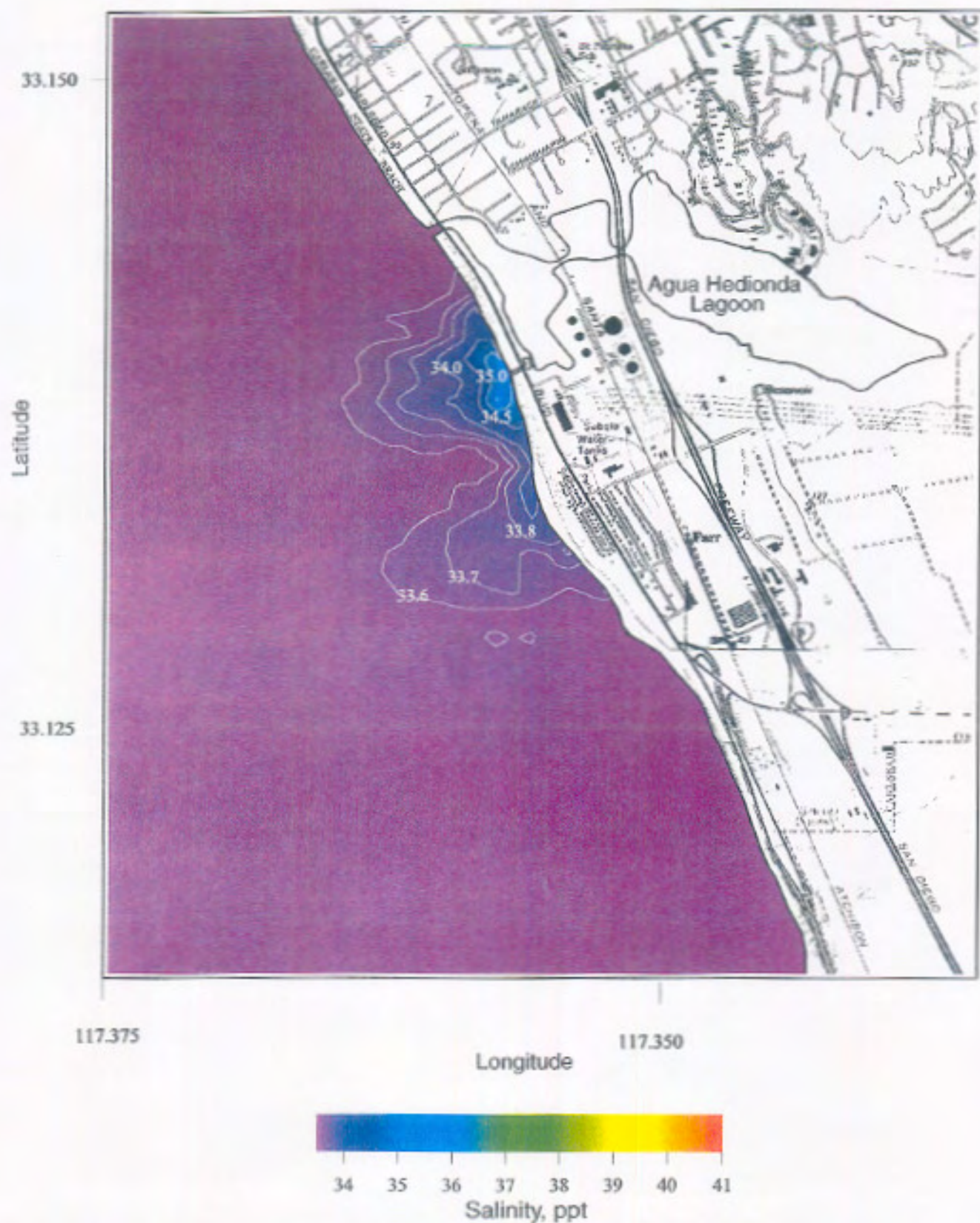


Figure 4.31. 30 day average of the depth-averaged salinity of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 527 mgd, combined discharge = 427 mgd, ambient ocean salinity = 33.49 ppt, 30 day period (May - June 1994).

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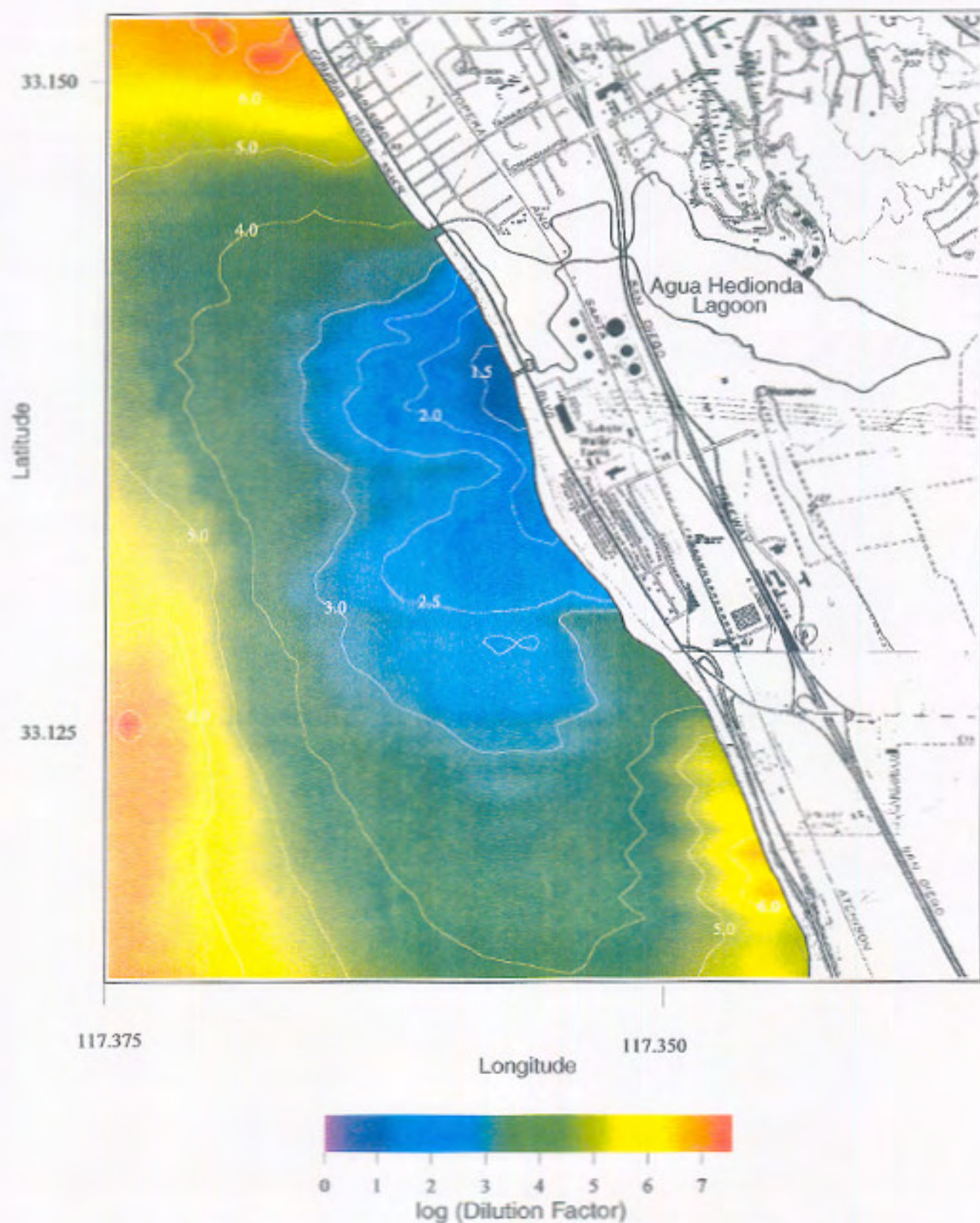


Figure 4.32. 30 day average of the depth-averaged dilution of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 527 mgd, combined discharge = 427 mgd, ambient ocean salinity = 33.49, 30 day period (May - June 1994).

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the discharge channel. Therefore, no water column saline impacts exceed 10% and the total area of pelagic habitat experiencing a 1% increase in salinity is 64 acres. Depth-averaged dilutions 1000 ft seaward of the discharge channel are 70 to 1.

Increasing RO production rates from 50 mgd to 100 mgd over an average month is again found to increase the footprint and strength of the salinity anomaly and reduce the dilutions of the concentrated seawater effluent. Lower plant flow rates over an average month result in higher concentrations of sea salts at “the end of the pipe” than for a worst case month. However, the higher ocean mixing levels during average months insure that smaller areas of both benthic and pelagic habitat are effected than during worst case months. These higher dilutions are obtained everywhere beyond the discharge channel.

4.2 Effects on the Temperature Field due to Concentrated Seawater

The addition of concentrated seawater by-product from RO production to the thermal effluent of the power plant causes a fundamental physical change in that effluent. In particular, the specific volume changes induced by the concentrated seawater are less than zero for all operating levels (Table 2). Consequently, the combined effluent becomes heavier (more dense) than ambient seawater, and the thermal wastefield will no longer float on the sea surface as it does under existing conditions (see Appendix A temperature field measurements as a function of depth). With the addition of the concentrated seawater by-product to the thermal effluent, the maximum thermal footprint is likely to move from the surface towards the bottom. The fundamental concern herein is whether the addition of concentrated seawater to the thermal effluent will lead to violations of Water Quality Objective 3B(4), see Section 3.2.F. Of all the 7 controlling variables the ambient ocean temperature has the largest range of natural variability (86%).

A) Worst Day

The model simulation of the 24 hour average of the temperature field on the seabed is plotted in Figure 4.33 during the worst day conditions for an RO production rate of 50 mgd and a plant flow rate of 725.8 mgd. Contours of temperature are in degrees Celsius ($^{\circ}\text{C}$), where the ambient background ocean temperature is 25.0°C . The “end of the pipe” discharge temperature is 30.5°C with a salinity of 35.99 ppt. Due to tidal variation in ocean water level, some initial dilution occurs in the inlet channel. Over a 24 hour period the maximum temperature in the discharge channel is 29.0°C . A very small area of seabed, 0.8 acres in the surfzone at the mouth of the discharge channel, experiences a 4°F (2.2°C) increase in bottom temperature. The effected area is represented by the 27.2°C temperature contour in Figure 4.33. The seabed in the effected area consists entirely of sandy bottom, and contains no exposed rock or cobble substrate. The habitat in this effected area is well within the nearshore zone of active littoral transport, and is periodically subjected to burial from dredge disposal and beach fill placement associated with Agua Hedionda maintenance dredging (LePage and Ware, 2001, Jenkins and Wasyl, 2001). Furthermore, the bottom temperature measurements in Appendix A (Figures A-3 and A-6) indicate that this inshore region is already subjected to impingement of the 4°F (2.2°C) temperature anomaly contour under existing conditions. The maximum seabed temperature increase at a distance of 1000 ft (305 m) in any direction from the discharge channel is 3.1°F (1.7°C). These temperature increases are within the limits of Water Quality Objective 3D(4).

The depth-averaged temperature field is plotted in Figure 4.34 for RO production at 50 mgd during the worst day conditions. Because the combined

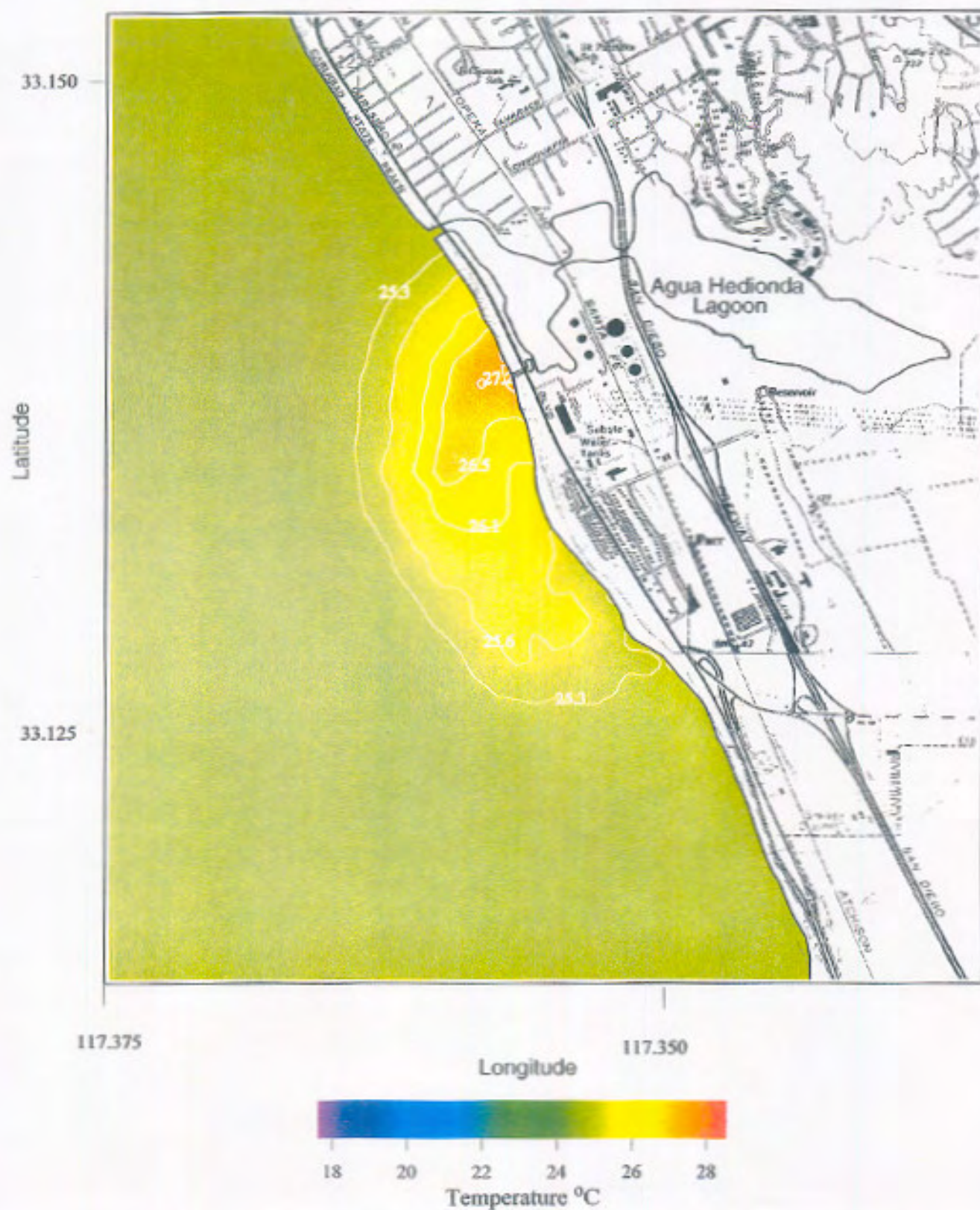


Figure 4.33. Daily average of the bottom temperature of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 725.8 mgd, combined discharge = 675.8 mgd, ambient ocean temperature = 25.0 °C, worst case day (17 Aug 1992).

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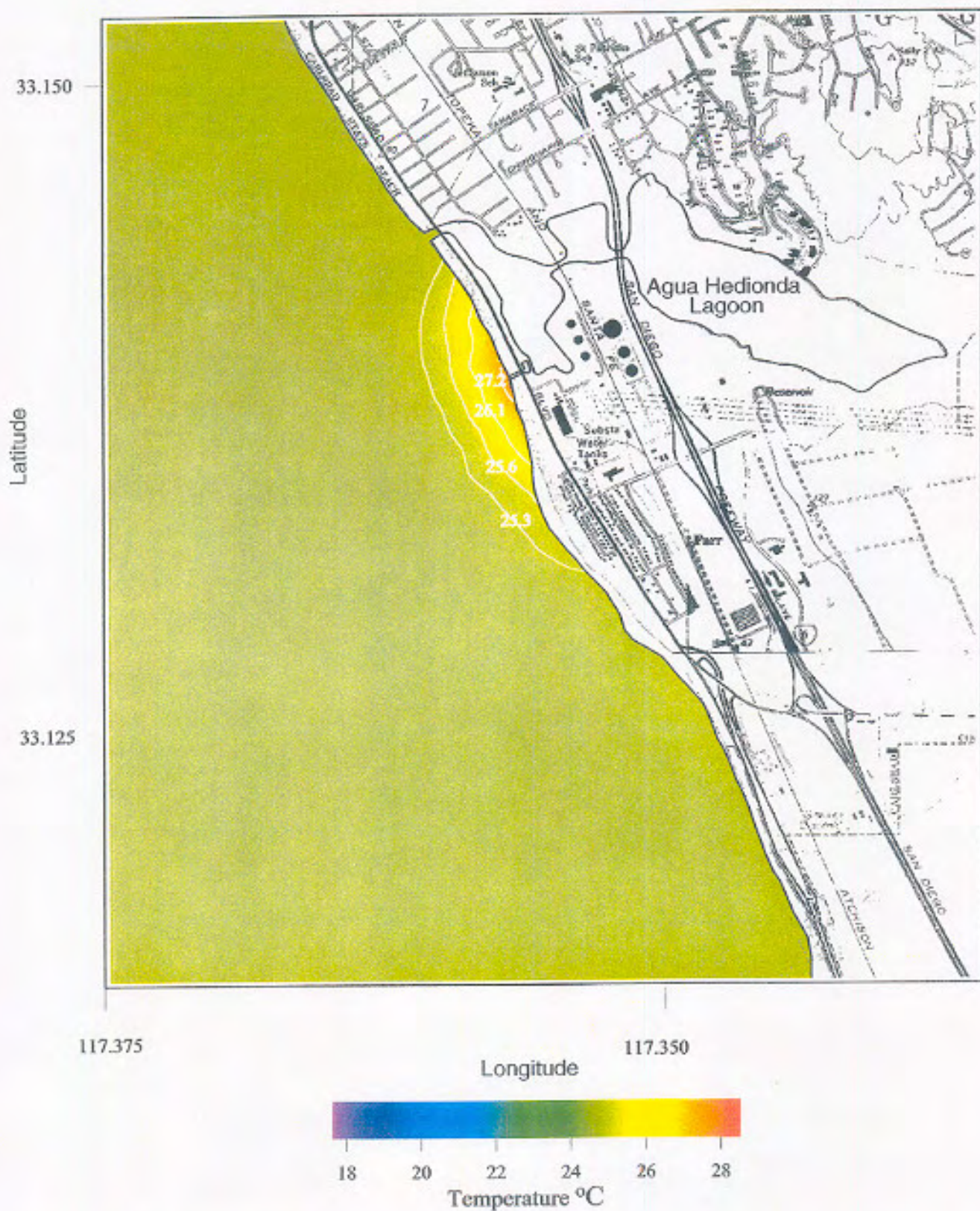


Figure 4.34. Daily average of the depth-averaged temperature of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 725.8 mgd, combined discharge = 675.8 mgd, ambient ocean temperature = 25.0 °C, worst case day (17 Aug 1992).

discharge is heavier than ambient seawater, elevated temperatures within the water column are much less and the thermal footprint is much smaller than what was found on the seabed in Figure 4.33. Maximum depth-averaged temperatures reach 27.2 °C directly seaward of the mouth of the discharge channel. Comparing with Figure 4.33, it is apparent that the concentrated seawater under worst day conditions has caused the maximum thermal footprint to move to the sea floor. The seabed footprint of the 2 °F temperature anomaly (26.1 °C contour) is 57 acres. This compares favorably to the existing 2 °F maximum footprint found on the sea surface, which was found to be 113 acres under worst case conditions during the 1989 field measurements (see Section 3.5 and Appendix A).

If the RO production rate is increased to 100 mgd, then the footprint of the 4 °F temperature anomaly impinging on the sea floor (27.2 °C contour) increases to 8 acres under worst day conditions (see Figure 4.35). The area of seabed effected by the 4 °F anomaly extends beyond the surfzone but still impinges on only sandy bottom seabed that is subject to episodic burial due to dredge disposal activity. The enlargement of this footprint at 100 mgd RO production is primarily due to reduced initial dilution of the "heavier" combined effluent in the discharge channel. Maximum temperatures in the discharge channel reach 29.4 °C. Because of these higher temperatures in the discharge channel, the depth-averaged temperatures in Figure 4.36 show an enlargement of the region of surfzone experiencing a 4 °F increase in temperature (27.2 °C contour). However, the 4 °F temperature anomaly does not extend out to 1000 ft from the discharge jetties. Maximum temperatures increases anywhere in the water column at 1000 ft from the discharge are 3.45 °F (1.9 °C). The bottom footprint of the 2 °F anomaly in Figure 4.35 is similarly enlarged by the retarded mixing of the heavier, more saline discharge at 100 mgd.

RO production. The 2 °F bottom temperature anomaly, (26.1 °C contour in Figure 4.35) encircles 73 acres, which is still less than the 113 acres of thermal footprint under worst case existing conditions.

The results of the thermal field modeling under worst day conditions in Figure 4.33 - 4.36 indicate that more efficient and rapid dissipation of the waste heat is achieved when the concentrated seawater by-product from desalination is added to the power plant's thermal effluent. By causing the combined discharge to sink, the entire volume of the water column is engaged in the dilution process. Furthermore, the persistent wave and current induced "scrubbing" action over the bottom provides a more vigorous mixing mechanism than what is presently available. Under existing conditions the thermal plume floats on the sea surface and the only mixing available seaward of the surfzone is low energy wind mixing. As a result, the addition of concentrated seawater to the thermal effluent causes a 50% reduction in the thermal footprint at 50 mgd RO production rates, and a 36% reduction at 100 mgd production rates. The smaller reduction in footprint at higher production rates is due to increased density stratification from higher discharge salinities.

B) Average Day

The model simulation of the 24 hour average of the temperature field on the seabed is plotted in Figure 4.37 during average day conditions for an RO production rate of 50 mgd and a plant flow rate of 725.8 mgd. Contours of temperature are in degrees Celsius (°C) where the ambient background ocean temperature is 17.6 °C. The "end of the pipe" discharge temperature is 23.1 °C with a salinity of 36.71 ppt. Over a 24 hour period the maximum temperature in the discharge channel is 21.0 °C. No area of seabed beyond the discharge

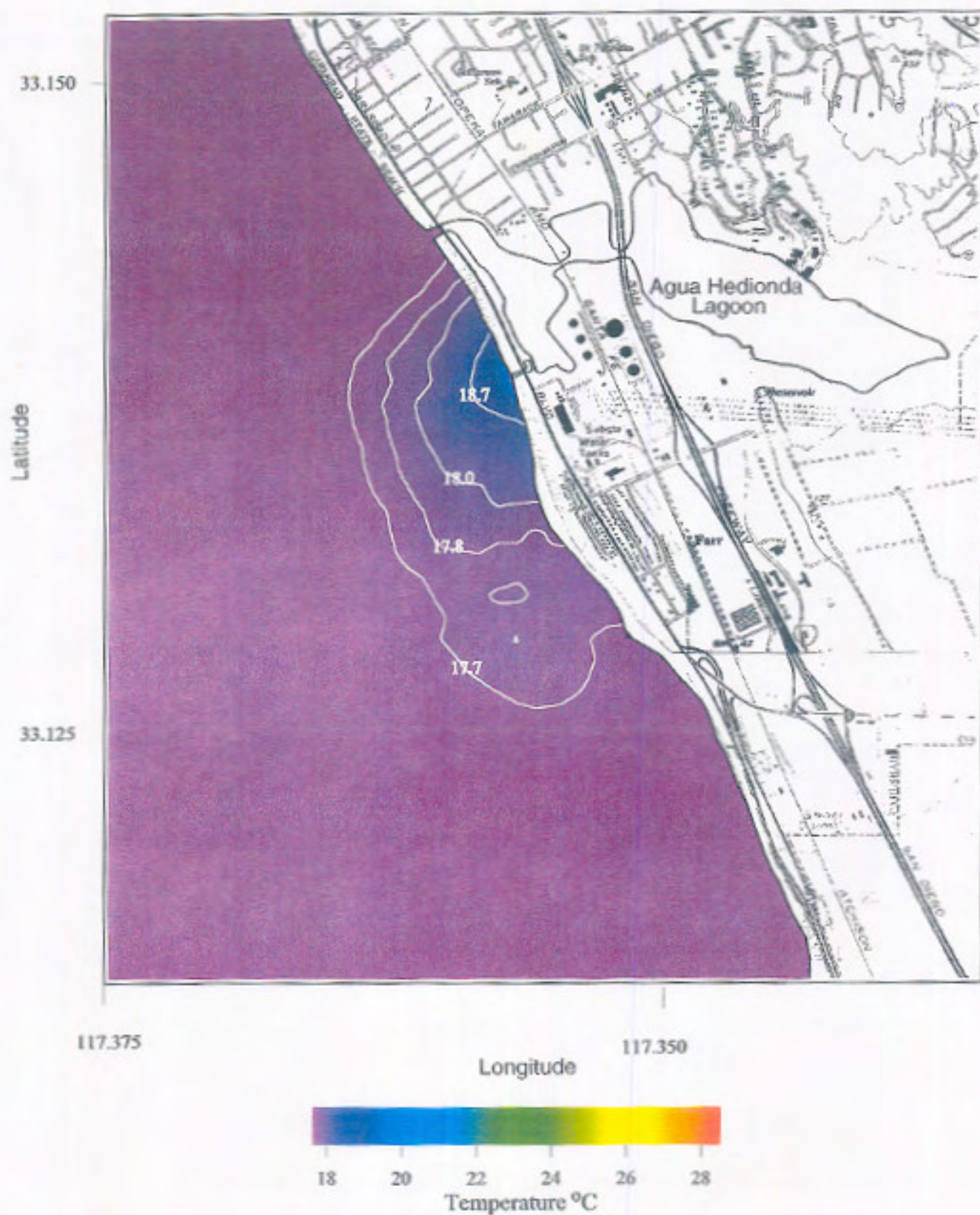


Figure 4.37. Daily average of the bottom temperature of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 576 mgd, combined discharge = 526 mgd, ambient ocean temperature = 17.6 °C, average day (23 May 1994).

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channel experiences a 4 °F (2.2 °C) increase in bottom temperature. Maximum seabed temperature is 19.3 immediately offshore of the discharge jetties. The maximum temperature 1000 ft (305 m) from the discharge channel in any direction is only 1.45 °F (0.8 °C) above ambient ocean temperatures.

The depth-averaged temperature field is plotted in Figure 4.38 for RO production at 50 mgd during average day conditions. Because the combined discharge is heavier than ambient seawater, elevated temperatures within the water column are less and the thermal footprint is much smaller than what was found on the seabed in Figure 4.37. Maximum depth-averaged temperatures reach 18.9 °C directly seaward of the mouth of the discharge channel. Comparing with Figure 4.37, it is apparent that the concentrated seawater under average day conditions has caused the maximum thermal footprint to move to the seafloor. The seabed footprint of the 2 °F temperature anomaly (18.7 °C contour) is 9 acres. This compares with 65 acres for the existing 2 °F maximum footprint found on the sea surface under average case conditions during the 1989 field measurements (see Section 3.5 and Appendix A).

If the RO production rate is increased to 100 mgd there is still no impingement of the 4 °F temperature anomaly on the seabed, (Figure 4.39). Maximum seabed temperatures beyond the discharge channel only reach 19.4 °C, despite the fact that maximum temperatures in the discharge channel increase to 21.1 °C. This is due to initial dilution in the discharge channel promoted by tidal variations of water level (high tide dilution). Because of these higher temperatures in the discharge channel (relative to 50 mgd), the depth-averaged temperatures in Figure 4.40 show an enlargement of the water column thermal footprint as compared to Figure 4.38. The bottom footprint of the 2 °F anomaly in Figure 4.39

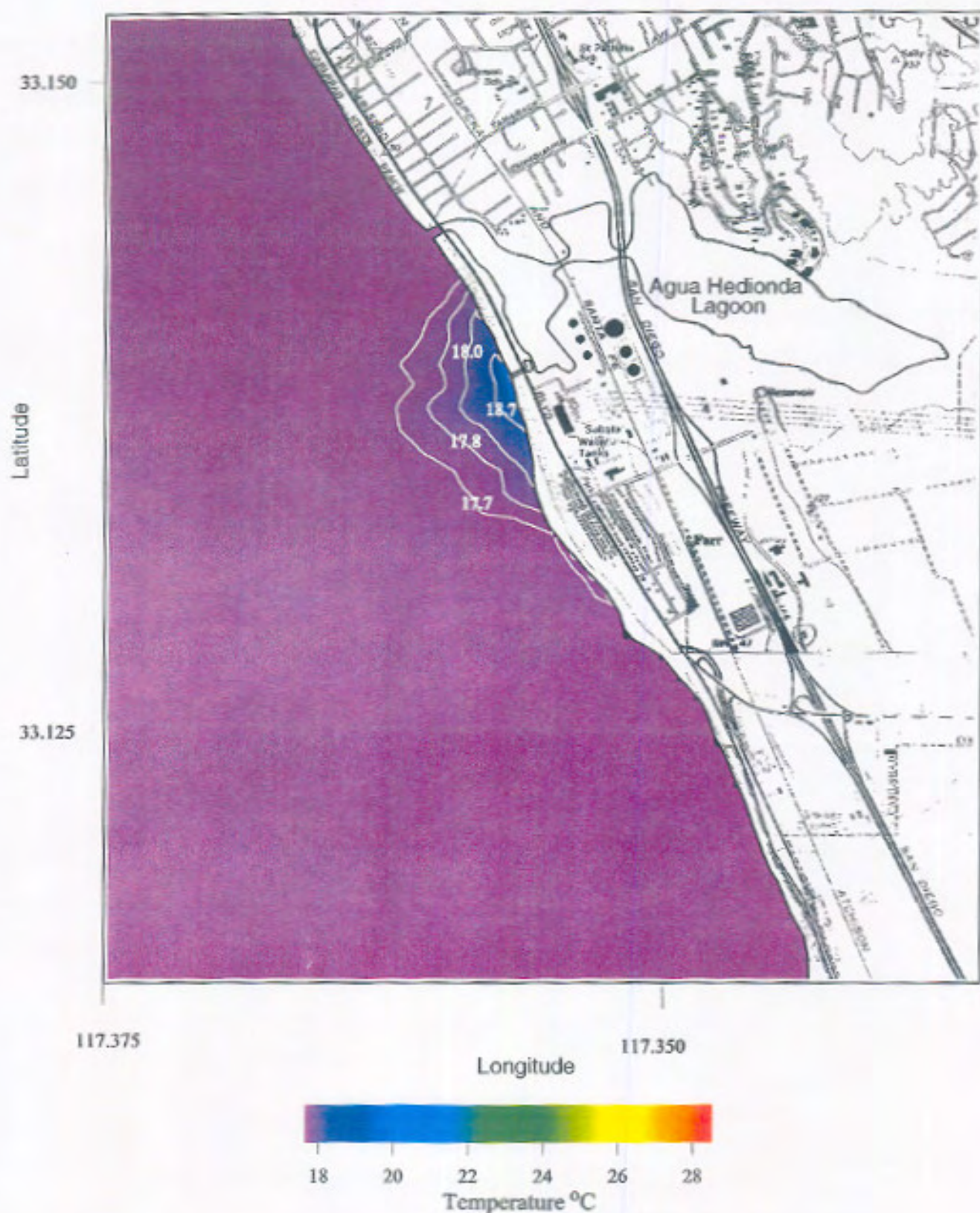


Figure 4.38. Daily average of the depth-averaged temperature of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 576 mgd, combined discharge = 526 mgd, ambient ocean temperature = 17.6 °C, average day (23 May 1994).

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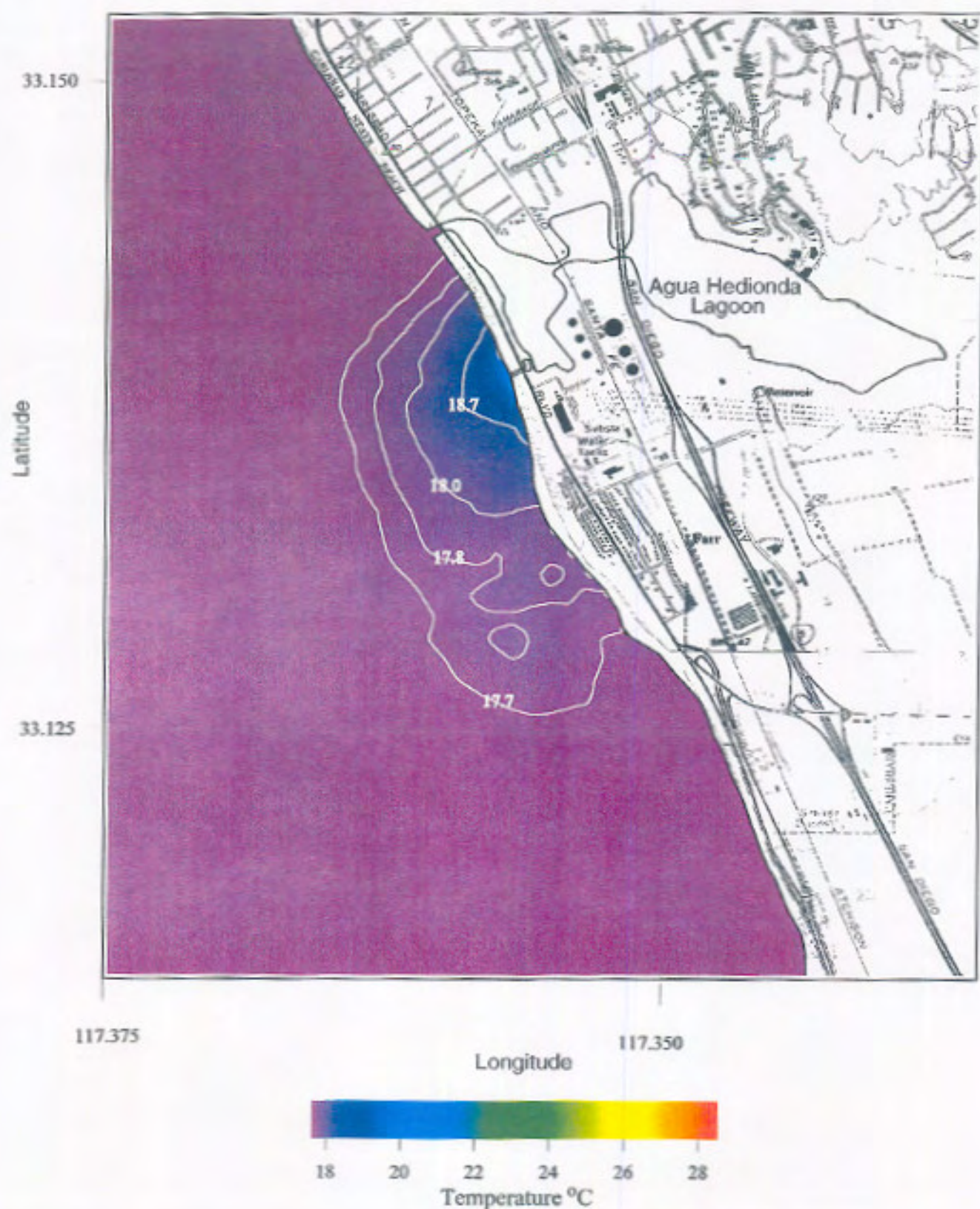


Figure 4.39. Daily average of the bottom temperature of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 576 mgd, combined discharge = 476 mgd, ambient ocean temperature = 17.6 °C, average day (23 May 1994).

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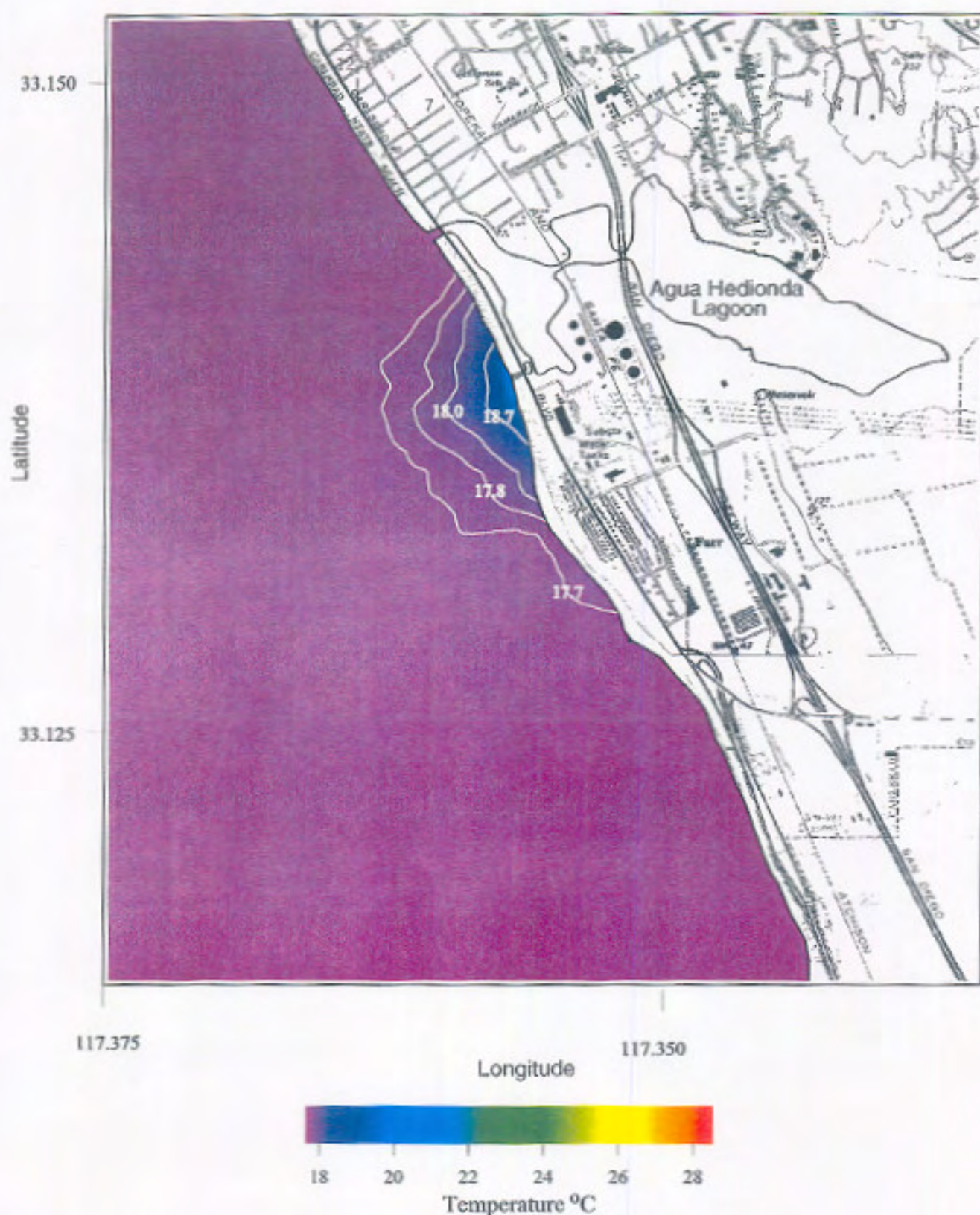


Figure 4.40. Daily average of the depth-averaged temperature of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 576 mgd, combined discharge = 476 mgd, ambient ocean temperature = 17.6 °C, average day (23 May 1994).
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is similarly enlarged by the retarded mixing of the heavier, more saline discharge at 100 mgd of RO production. The 2 °F bottom temperature anomaly, (18.7 °C contour in Figure 4.39) envelopes 14.6 acres, which is significantly less than the 65 acres of thermal footprint under average case existing conditions. The maximum temperature increase found anywhere in the water column at a distance of 1000 ft (305 m) in any direction from the discharge jetty is 2 °F (1.1 °C). The results of the thermal field modeling under average day conditions in Figures 4.37 - 4.40 indicate that all the Water Quality Objectives under the Thermal Plan are satisfied, regardless of the proposed levels of RO production by the desalination plant. In addition, more efficient and rapid dissipation of the waste heat is achieved when concentrated seawater by-product from desalination is added to the power plant's thermal effluent. As a result, the maximum size of the thermal footprint is reduced on an average day by 86% when the RO production rate is 50 mgd, and by 78% with production rates at 100 mgd.

C) Worst Month

The model simulation of the 30 day average of the temperature field on the seabed is plotted in Figure 4.41 during the worst month conditions for an RO production rate of 50 mgd and a plant flow rate of 703 mgd. Contours of temperature are in degrees Celsius (°C), where the ambient background ocean temperature is 22.7 °C. The "end of the pipe" discharge temperature is 28.2 °C with a salinity of 36.05 ppt. Over a 30 day period the maximum temperature in the discharge channel is 25.3 °C. No portion of the seabed beyond the discharge channel experiences a 4 °F (2.2 °C) increase in bottom temperature. The maximum temperature on the seabed beyond the discharge jetties is 24.2 °C, within restrictions of Water Quality Objective 3B(4). The maximum seabed temperature

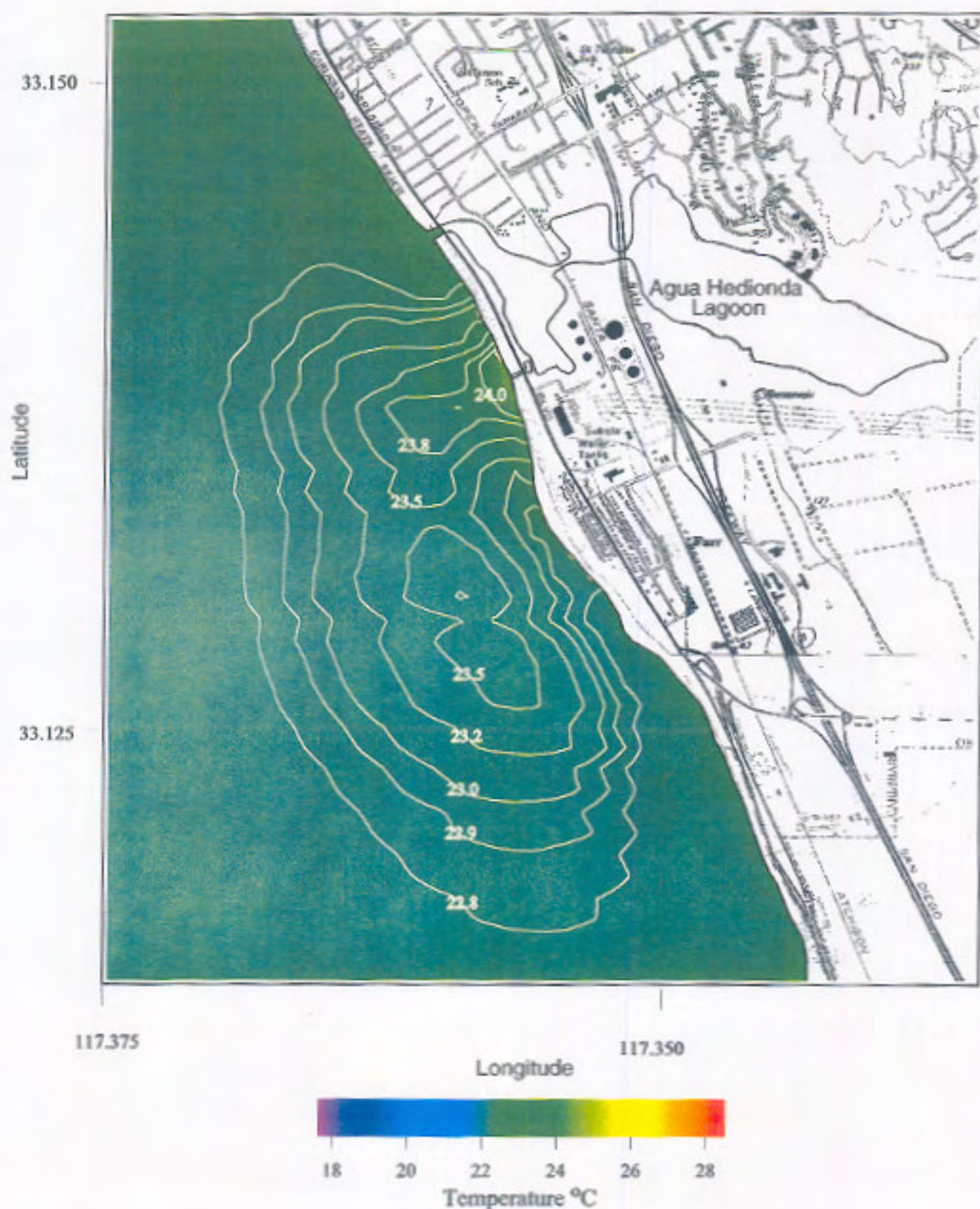


Figure 4.41. 30 day average of the bottom temperature of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 703 mgd, combined discharge = 653 mgd, ambient ocean temperature = 22.7 °C, worst month (August 1992).

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increase at a distance of 1000 ft (305 m) in any direction from the discharge channel is 2.2 °F (1.2 °C).

The depth-averaged temperature field is plotted in Figure 4.42 for RO production at 50 mgd during the worst month conditions. Because the combined discharge is heavier than ambient seawater, elevated temperatures within the water column are much less and the thermal footprint is much smaller than what was found on the seabed in Figure 4.41. Maximum depth-averaged temperatures reach 23.5 °C directly seaward of the mouth of the discharge channel. Comparing with Figure 4.41, it is apparent that the concentrated seawater under worst month conditions has caused the maximum thermal footprint to move to the sea floor. The seabed footprint of the 2 °F temperature anomaly (23.8 °C contour) is 35 acres. This compares favorably to the existing 2 °F maximum footprint found on the sea surface that was estimated to be 113 acres under worst case conditions during the 1989 field measurements (see Section 3.5 and Appendix A).

If the RO production rate is increased to 100 mgd, there is still no impingement of the 4 °F anomaly on the sea floor under worst month conditions (see Figure 4.43). Maximum seabed temperatures outside the discharge channel reach 24.6 °C, within compliance standards of Water Quality Objective 3B(4). Maximum temperatures in the discharge channel increase to 25.9 °C, which is subsequently reduced by initial dilution along the length of the discharge channel due to tidal variation over a 30 day period. However, because of these initially higher temperatures in the discharge channel, the depth-averaged temperatures in Figure 4.44 show an enlargement of the thermal footprint relative to lower RO production in Figure 4.42. Maximum temperatures increases anywhere in the water column at 1000 ft from the discharge are 2.54 °F (1.4 °C). The bottom footprint of



Figure 4.42. 30 day average of the depth-averaged temperature of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 703 mgd, combined discharge = 653 mgd, ambient ocean temperature = 22.7 °C, worst month (August 1992).

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Figure 4.43. 30 day average of the bottom temperature of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 703 mgd, combined discharge = 603 mgd, ambient ocean temperature = 22.7 °C, worst month (August 1992).

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the 2 °F anomaly in Figure 4.43 is similarly enlarged by the retarded mixing of the heavier, more saline discharge at 100 mgd RO production. The 2 °F bottom temperature anomaly, (23.8 °C contour in Figure 4.43) encircles 53 acres, which is still less than the 113 acres of thermal footprint under worst case existing conditions.

D) Average Month

The model simulation of the 30 day average of the temperature field on the seabed is plotted in Figure 4.45 during the average month conditions for an RO production rate of 50 mgd and a plant flow rate of 527 mgd. Contours of temperature are in degrees Celsius (°C), where the ambient background ocean temperature is 17.81 °C. The "end of the pipe" discharge temperature is 23.31 °C with a salinity of 37.00 ppt. Over a 30 day period the maximum temperature in the discharge channel is 21.0 °C. No portion of seabed beyond the discharge channel experiences a 4 °F (2.2 °C) increase in bottom temperature. The maximum temperature on the seabed beyond the discharge jetties is 19.6 °C, within restrictions of Water Quality Objective 3B(4). The maximum seabed temperature increase at a distance of 1000 ft (305 m) in any direction from the discharge channel is 1.45 °F (0.8 °C).

The depth-averaged temperature field is plotted in Figure 4.46 for RO production at 50 mgd during the average month conditions. Because the combined discharge is heavier than ambient seawater, elevated temperatures within the water column are much less and the thermal footprint is much smaller than what was found on the seabed in Figure 4.45. Maximum depth-averaged temperatures reach 18.8 °C directly seaward of the mouth of the discharge channel. Comparing with Figure 4.45, it is apparent that the concentrated seawater under average month

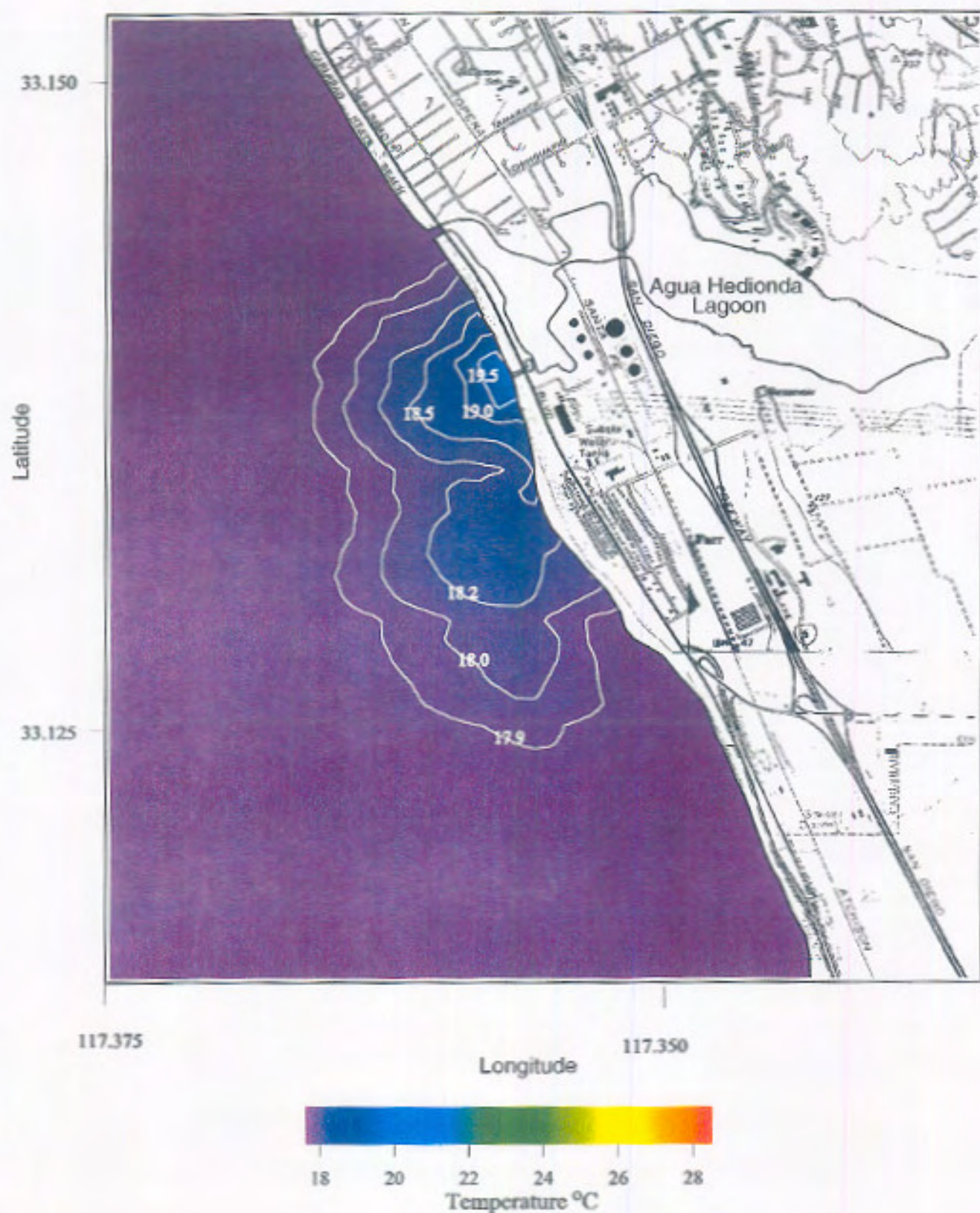


Figure 4.45. 30 day average of the bottom temperature of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 527 mgd, combined discharge = 477 mgd, ambient ocean temperature = 17.81 °C, 30 day period (May - June 1994).
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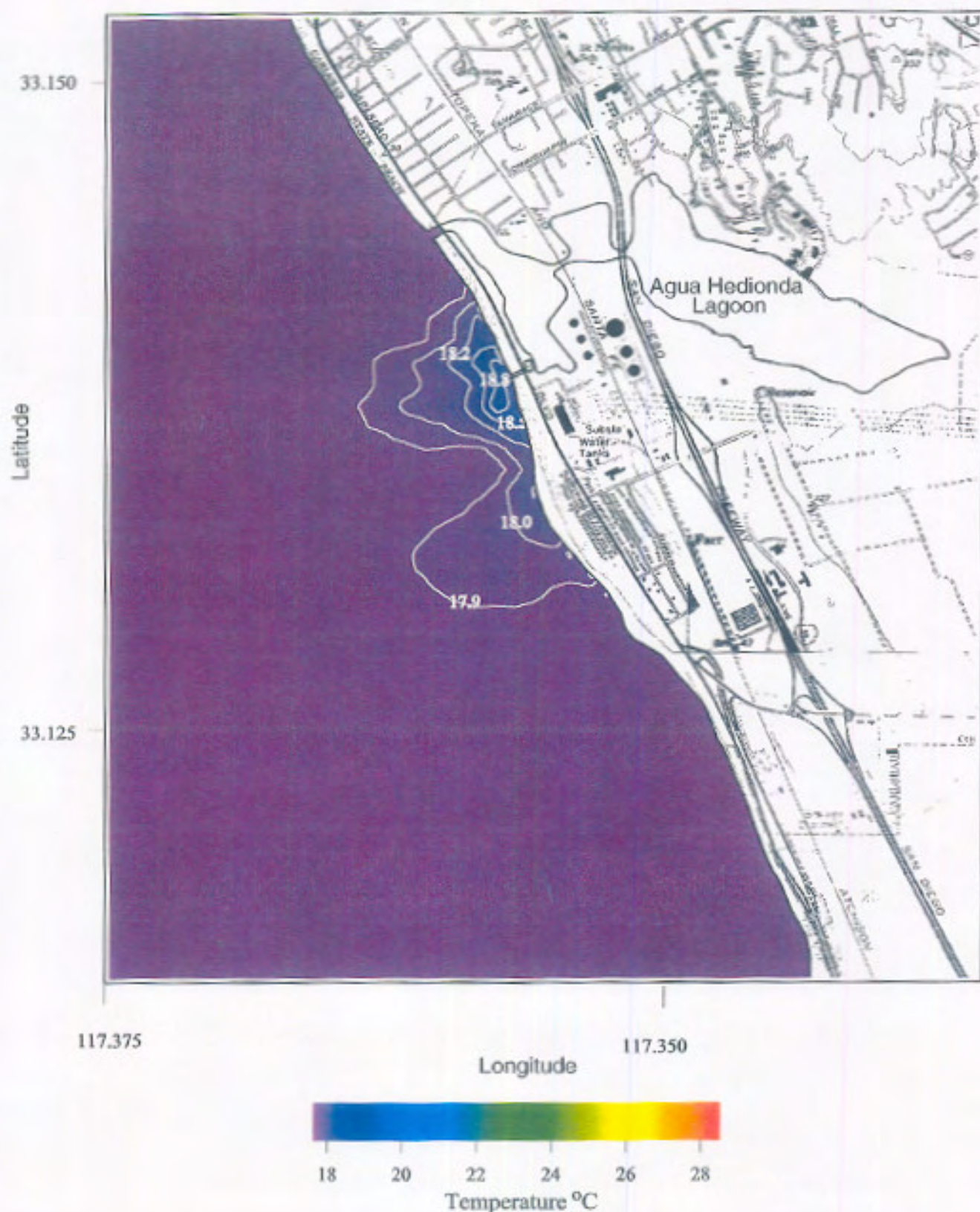


Figure 4.46. 30 day average of the depth-averaged temperature of concentrated seawater for R.O. = 50 mgd, plant inflow rate = 527 mgd, combined discharge = 477 mgd, ambient ocean temperature = 17.81 °C, 30 day period (May - June 1994).

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conditions has caused the maximum thermal footprint to move to the sea floor. The seabed footprint of the 2 °F temperature anomaly (18.9 °C contour) is 17 acres. This compares favorably to the existing 2 °F maximum footprint found on the sea surface that was estimated to be 65 acres under average case conditions during the 1989 field measurements (see Section 3.5 and Appendix A).

If the RO production rate is increased to 100 mgd, there is still no impingement of the 4 °F anomaly on the sea floor under average month conditions (see Figure 4.47). Maximum seabed temperatures outside the discharge channel reach 19.8 °C, within compliance standards of Water Quality Objective 3B(4), even though maximum temperatures in the discharge channel reach 21.1 °C. Because of these slightly higher temperatures in the discharge channel, the depth-averaged temperatures in Figure 4.48 show a bit of enlargement of the thermal footprint relative to lower RO production in Figure 4.46. Maximum temperatures increases anywhere in the water column at 1000 ft from the discharge are 2.0 °F (1.1 °C). The bottom footprint of the 2 °F anomaly in Figure 4.47 is similarly enlarged by the heavier, more saline discharge at 100 mgd RO production. The 2 °F bottom temperature anomaly, (18.9 °C contour in Figure 4.47) contains 22 acres, which is still less than the 65 acres of thermal footprint under average case existing conditions.

The results of the thermal field modeling during average month conditions in Figures 4.45 - 4.48 indicate that all the Water Quality Objectives under the Thermal Plan are satisfied, regardless of the proposed levels of RO production by the desalination plant. In addition, more efficient and rapid dissipation of the waste heat is achieved when concentrated seawater by-product from desalination is added to the power plant's thermal effluent. Consequently, the maximum size of the

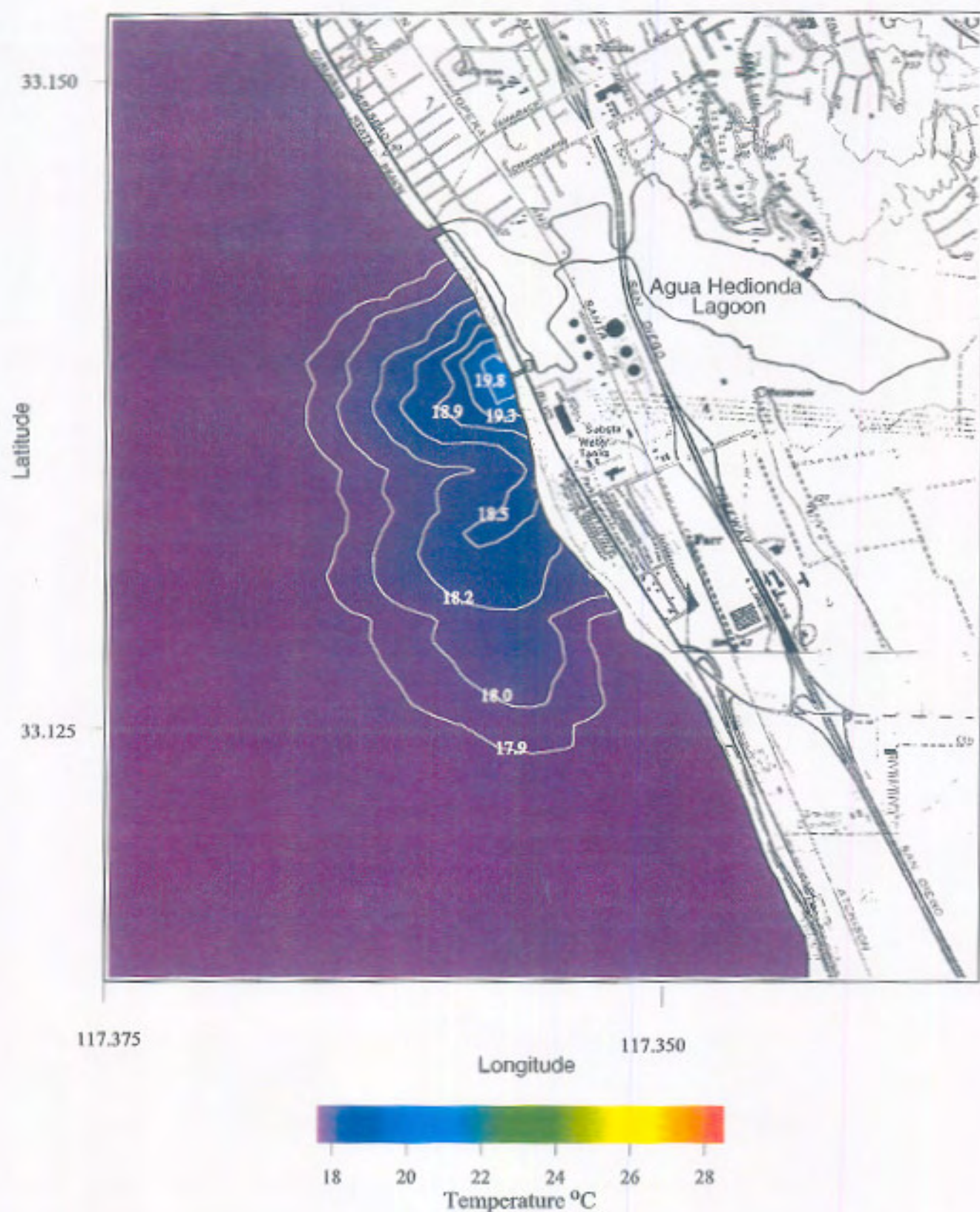


Figure 4.47. 30 day average of the bottom temperature of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 527 mgd, combined discharge = 427 mgd, ambient ocean temperature = 17.81 °C, 30 day period (May - June 1994).

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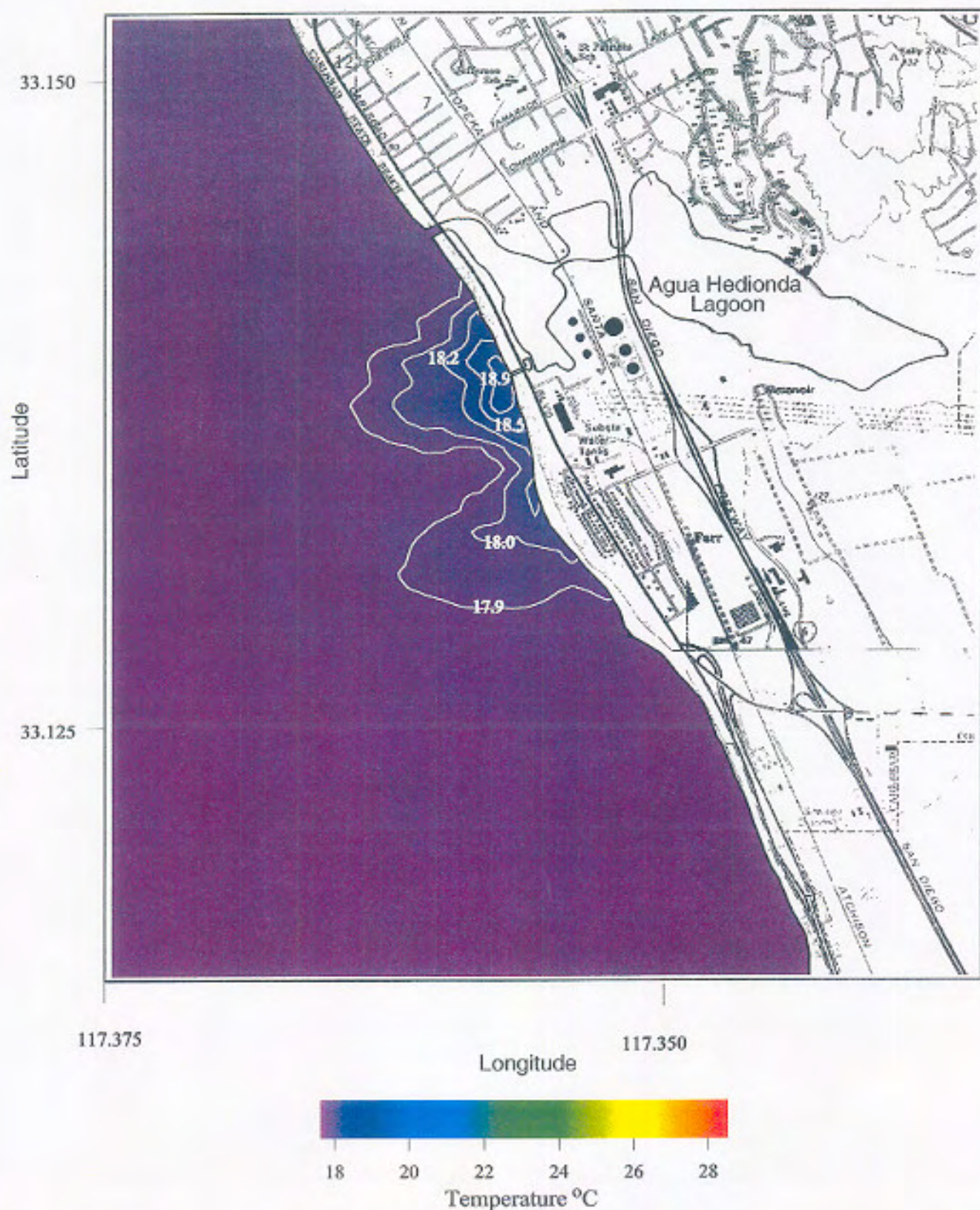


Figure 4.48. 30 day average of the depth-averaged temperature of concentrated seawater for R.O. = 100 mgd, plant inflow rate = 527 mgd, combined discharge = 427 mgd, ambient ocean temperature = 17.81 °C, 30 day period (May - June 1994).

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thermal footprint is reduced during an average month by 74% when the RO production rate is 50 mgd, and by 66% with production rates at 100 mgd.

4.3) Recirculation of concentrated Seawater

The tidal hydraulics model, TIDE_FEM, for Agua Hedionda Lagoon (Figure 3.2) was run concurrently with the SEDXPORT ocean dispersion model for the worst day and average day boundary conditions and forcing functions to determine the degree of potential recirculation of concentrated seawater by-product back into the lagoon. The modeling was performed with the existing inlet jetty system and with a proposed 200 ft extension to the North Jetty (see red contour line in Figures 4.49 - 4.56). The North Jetty extension was found to produce a slight increase in recirculation. Only the results for the North Jetty extension will be presented here as an upper limit surrogate of recirculation potential. In either case, recirculation was found to be negligible.

A) Worst Day

Figure 4.49 presents the model simulation of the 24 hour average of the bottom salinity distribution of Agua Hedionda Lagoon for the worst day conditions with RO production rates at 50 mgd and power plant inflow rates at 725.8 mgd. Because of the minute gradients in the salinity field, the bottom salinity is contoured in 0.01 ppt intervals. The ambient ocean salinity is 33.51 ppt and the maximum salinity found anywhere in the lagoon is in the inlet channel near the Highway 101 bridge. Here the bottom salinity reaches 33.66 ppt. This represents an increase of at most 0.4% above ambient ocean levels. The bottom salinity anomaly rapidly declines from the inlet channel into the deeper waters of the West Basin of the lagoon where local depths reach -20 ft NGVD (Figure 3.3).

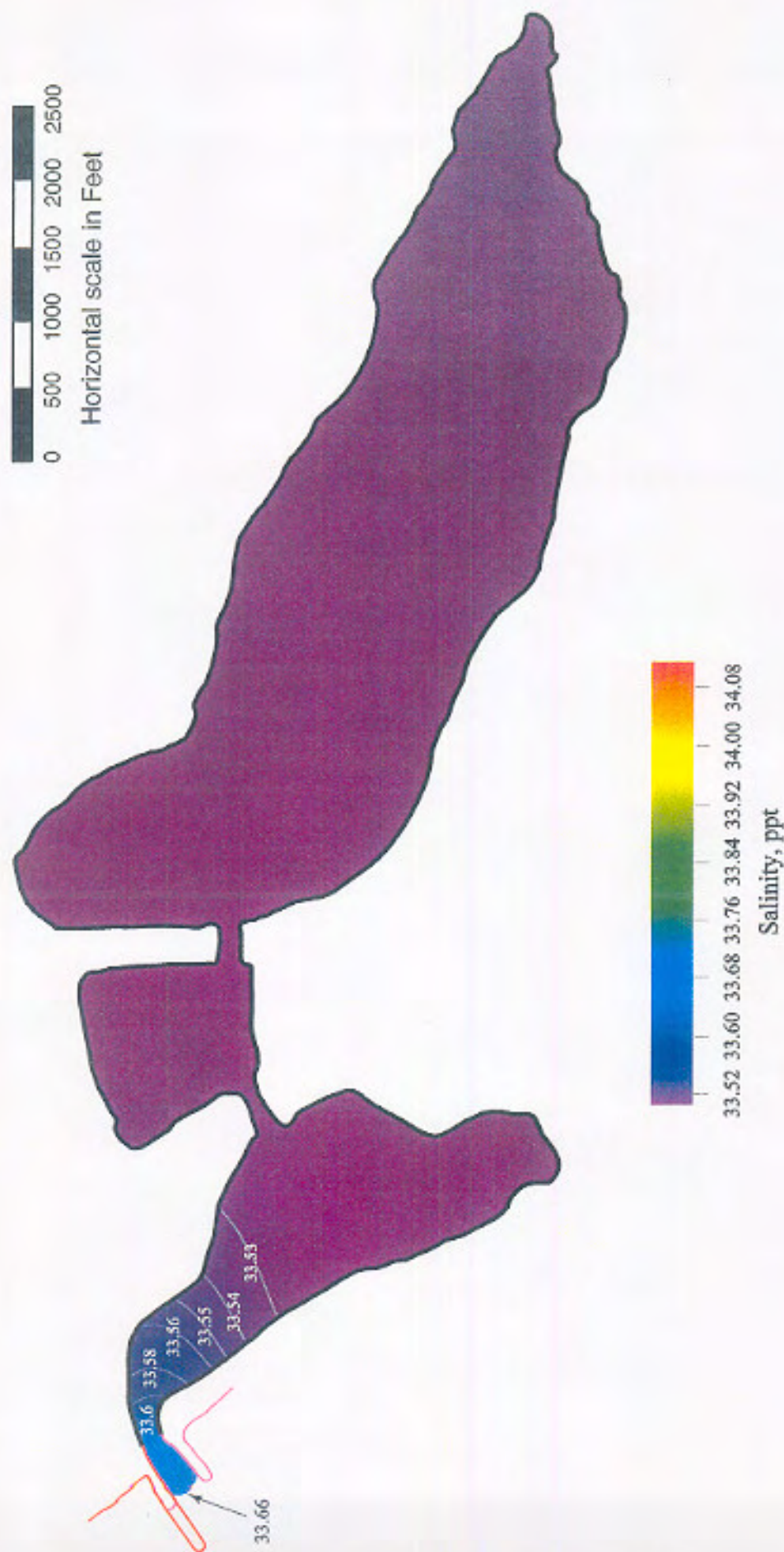


Figure 4.49. Lagoon bottom salinity of concentrated sea water for R.O. = 50 mgd, plant inflow rate = 725.8 mgd, combined discharge = 675.8 mgd, ambient ocean salinity = 33.51 ppt, worst case day (17 Aug 92).

Figure 4.50 gives dilution contours of the concentrated seawater over the lagoon bottom on a log-10 scale for the worst day at 50 mgd RO production rates. The dilution at the power plant intake screen (southwest corner of the West Basin) is 170,000 to 1. Consequently recirculation is not a factor of concern for RO production system design. The dilutions of concentrated seawater also progressively decline into the shallower Middle and East Basins of the lagoon, reaching 316,000 to 1 in the middle of the East Basin.

When RO production is increased to 100 mgd during worst day conditions, bottom salinities at the lagoon inlet reach 34.00 ppt, or about 1.2% over ambient ocean salinities, (Figure 4.51). This salinity anomaly effects about 1.1 acres of rocky bottom inlet channel beneath and immediately west of the Highway 101 bridge. The corresponding dilution field of the concentrated seawater over the bottom of the lagoon is plotted in Figure 4.52. Dilution factors at the cooling water intake to Encina Power Plant are 160,000 to 1. Therefore, increasing RO production to 100 mgd results in a negligible degree of recirculation of the concentrated seawater by-product for worst day conditions. At either 50 mgd or 100 mgd production rates, dilutions of concentrated seawater remain so large that there is a negligible effect on Agua Hedionda water properties that would be below quantifiable detection limits.

A) Average Day

Figure 4.53 presents the model simulation of the 24 hour average of the bottom salinity distribution of Agua Hedionda Lagoon for average day conditions with RO production rates at 50 mgd and power plant inflow rates at 725.8 mgd. The ambient ocean salinity is 33.52 ppt and the maximum salinity found anywhere in the lagoon is in the inlet channel near the Highway 101 bridge. Here the bottom

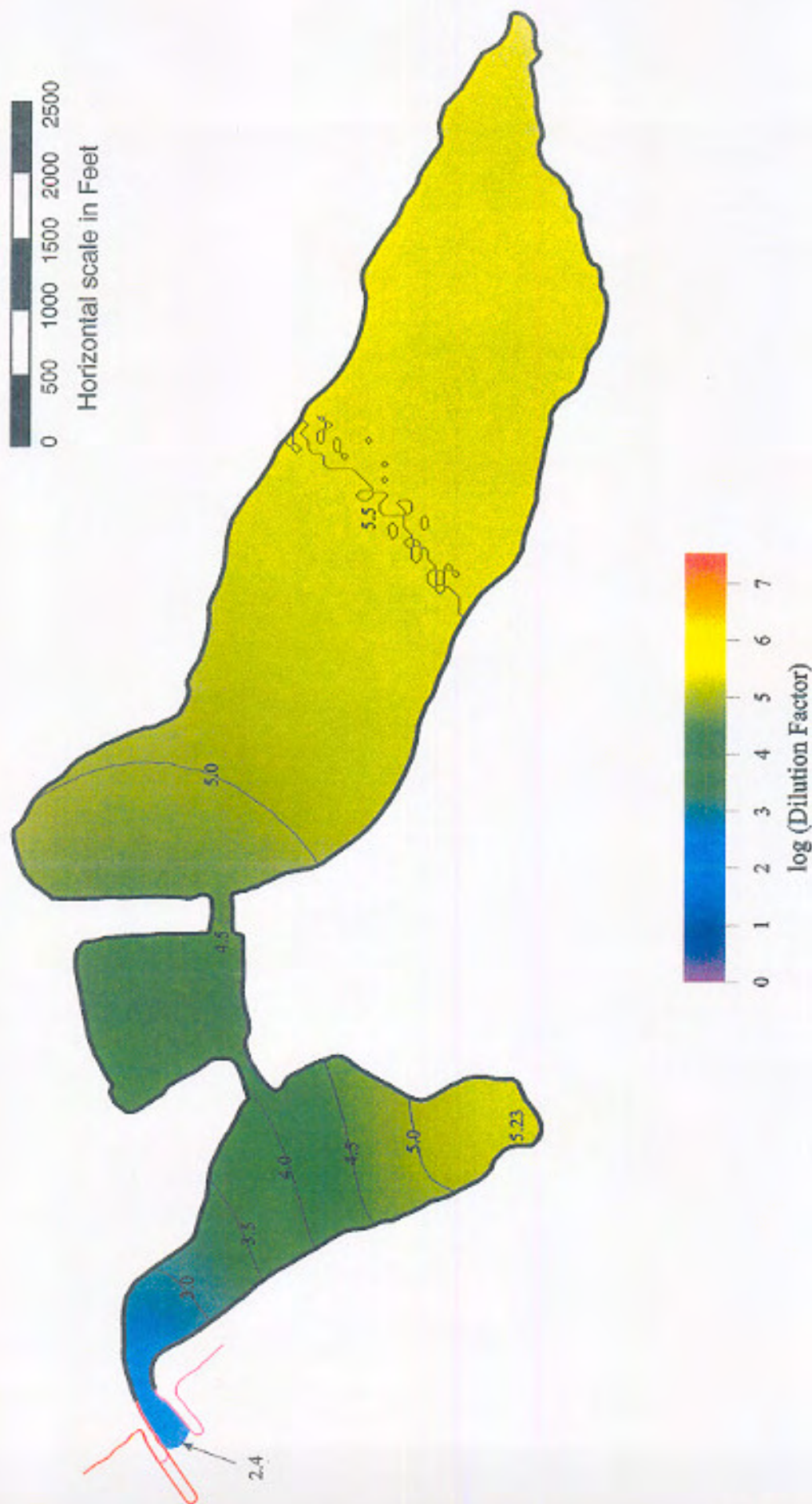


Figure 4.50. Lagoon bottom dilution of concentrated sea water for R.O. = 50 mgd, plant inflow rate = 725.8 mgd, combined discharge = 675.8 mgd, ambient ocean salinity = 33.51 ppt, worst case day (17 Aug 1992).

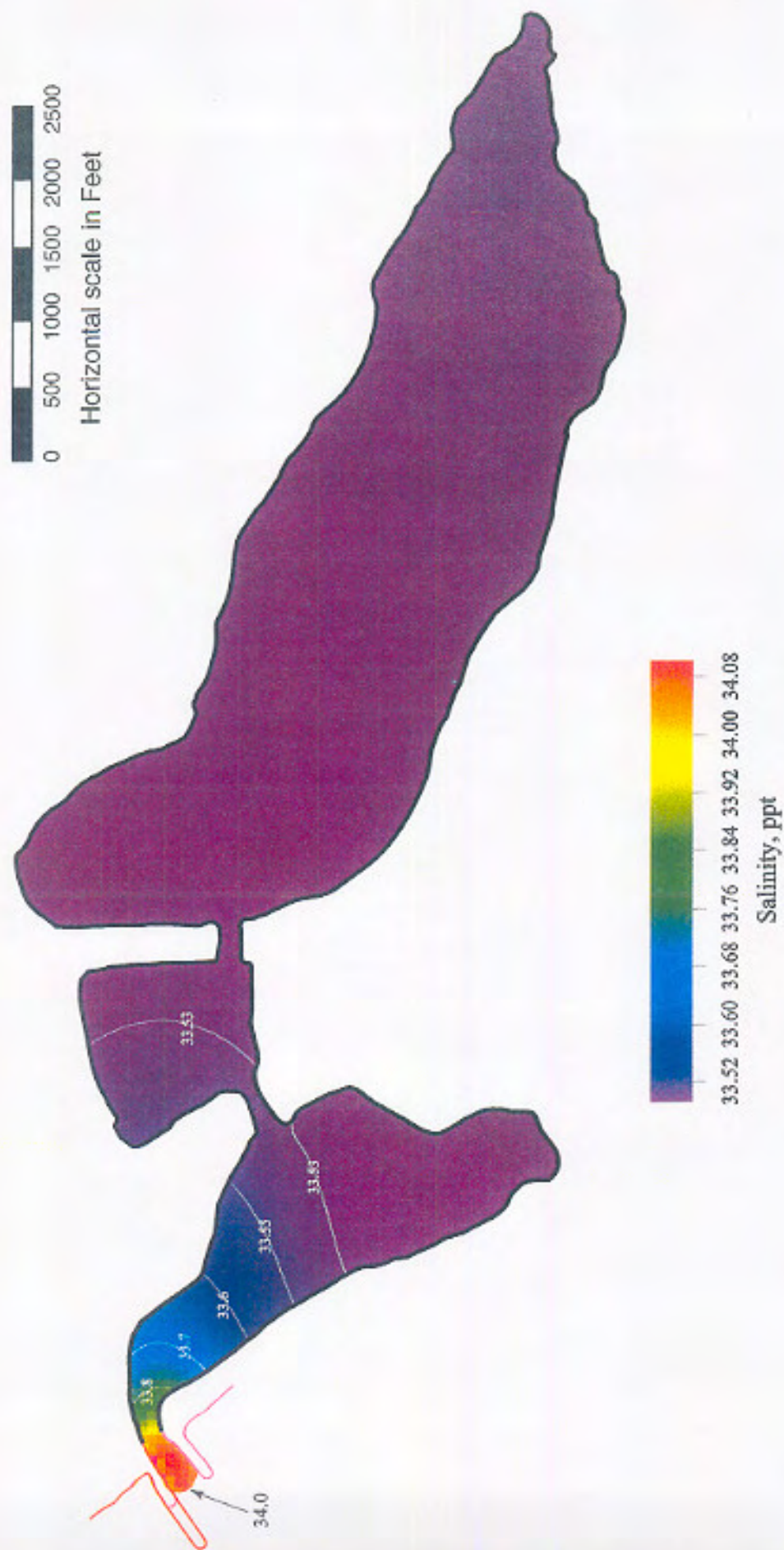


Figure 4.51. Lagoon bottom salinity of concentrated sea water for R.O. = 100 mgd, plant inflow rate = 725.8 mgd, combined discharge = 625.8 mgd, ambient ocean salinity = 33.51 ppt, worst case day (17 Aug 92).

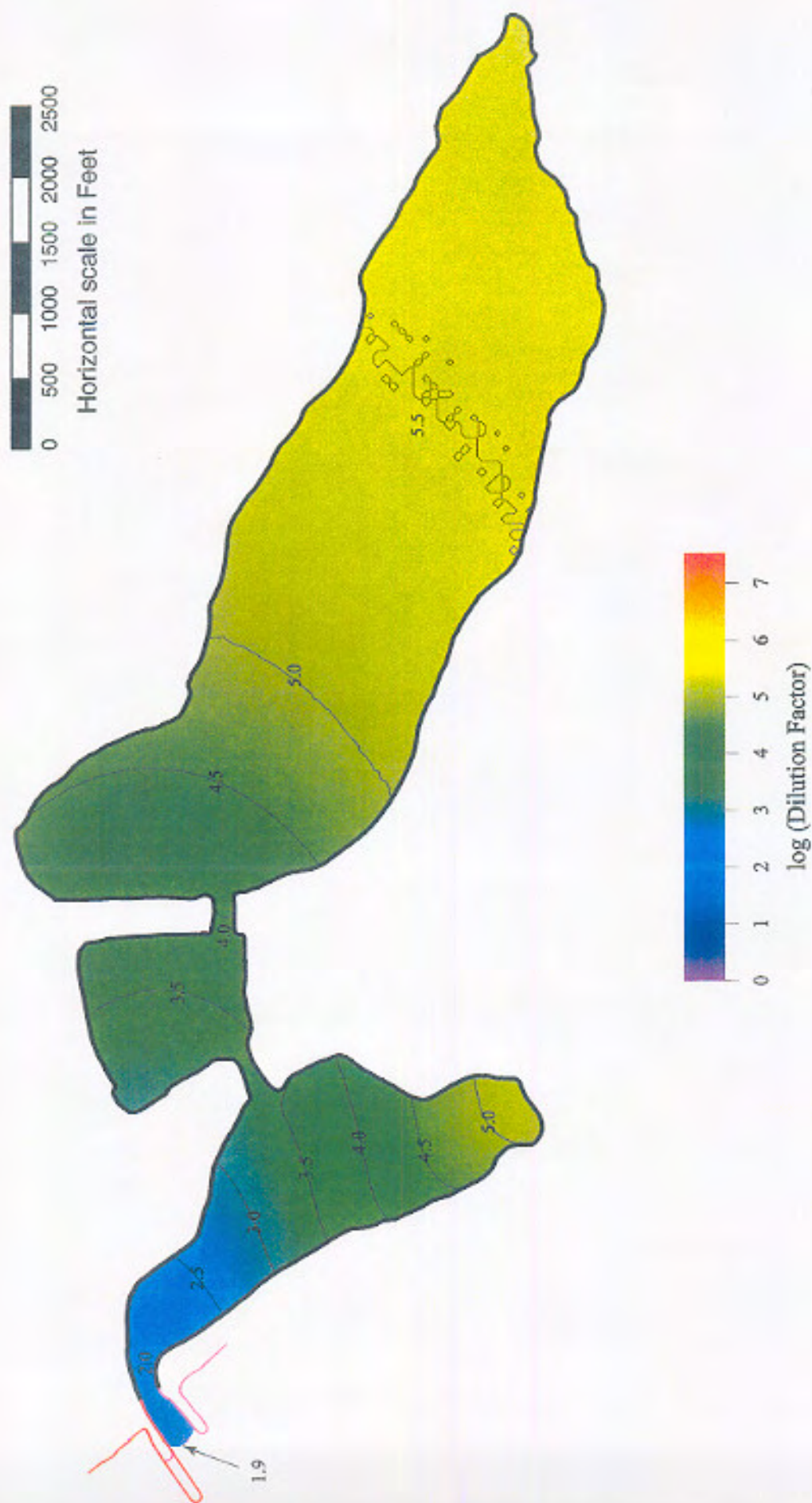


Figure 4.52. Lagoon bottom dilution of concentrated sea water for R.O. = 100 mgd, plant inflow rate = 725.8 mgd, combined discharge = 625.8 mgd, ambient ocean salinity = 33.51 ppt, worst case day (17 Aug 92).

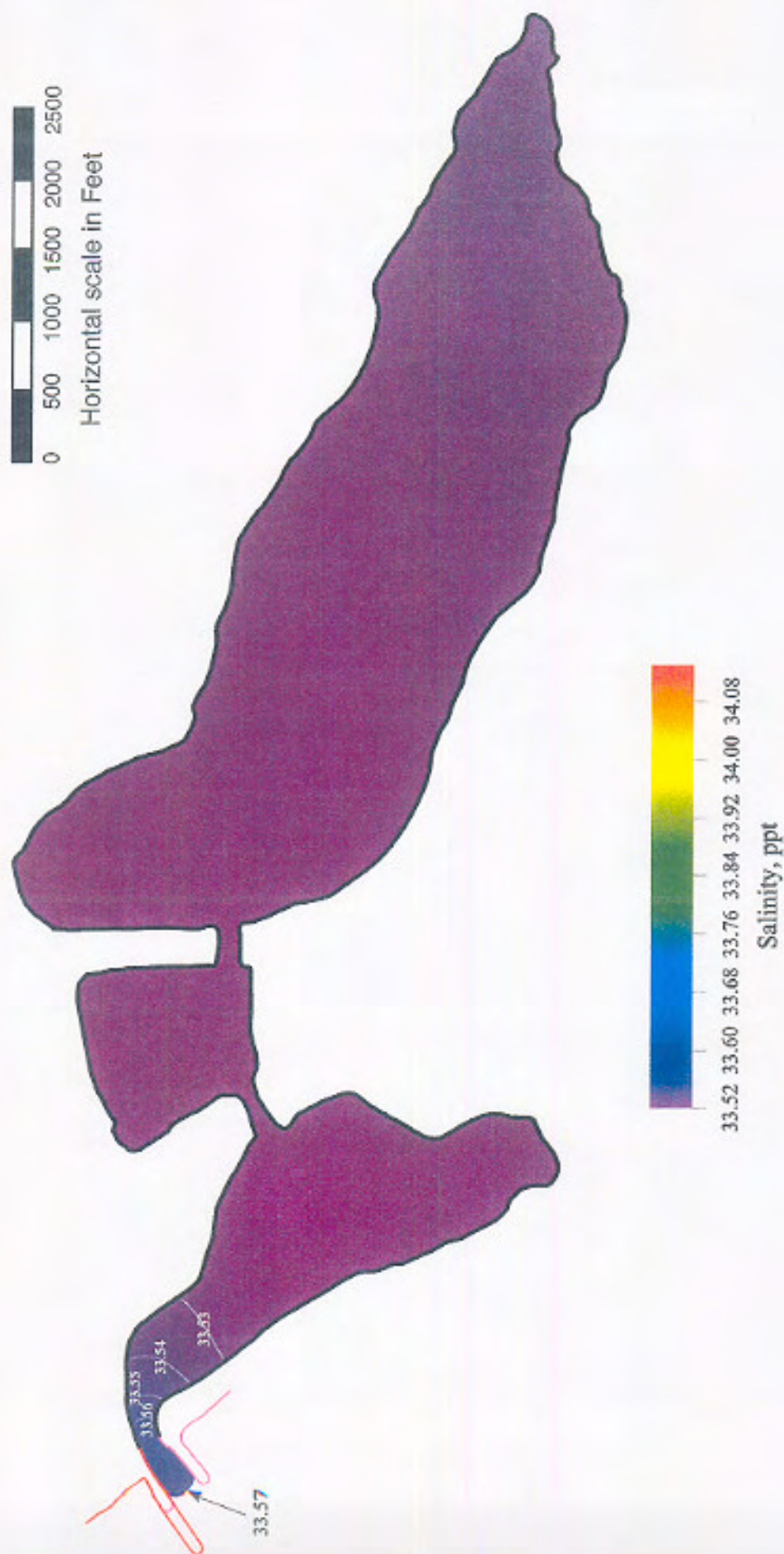


Figure 4.53. Lagoon bottom salinity of concentrated sea water for R.O. = 50 mgd, plant inflow rate = 576 mgd, combined discharge = 526 mgd, ambient ocean salinity = 33.52 ppt, average day (23 May 94).

salinity reaches 33.57 ppt. This represents an increase of at most 0.1% above ambient ocean levels. The bottom salinity anomaly rapidly declines from the inlet channel into the deeper waters of the West Basin where local depths reach -20 ft NGVD.

Figure 4.54 gives dilution contours of the concentrated seawater over the lagoon bottom on a log-10 scale for the average day at 50 mgd RO production rates. The dilution at the power plant intake screen (southwest corner of the West Basin) is 316,000 to 1. Consequently recirculation is not a factor of concern for RO production system design. The dilutions of concentrated seawater also progressively decline into the shallower Middle and East Basins of the lagoon, reaching 320,000 to 1 in the middle of the East Basin.

When RO production is increased to 100 mgd during average day conditions, bottom salinities at the lagoon inlet reach 33.61 ppt, or about 0.2% over ambient ocean salinities, (Figure 4.55). The corresponding dilution field of the concentrated seawater over the bottom of the lagoon is plotted in Figure 4.56. Dilution factors at the water intake to Encina Power Plant are 251,000 to 1. Therefore, increasing RO production to 100 mgd results in a negligible degree of recirculation of the concentrated seawater by-product for average day conditions. At either 50 mgd or 100 mgd production rates, dilutions of concentrated seawater remain so large that there is a negligible effect on Agua Hedionda water properties that would be below quantifiable detection limits.

4.4) Summary of Results

A tabular summary of dispersion modeling results are contained in Table 3 for RO production at 50 mgd and in Table 4 for production at 100 mgd.

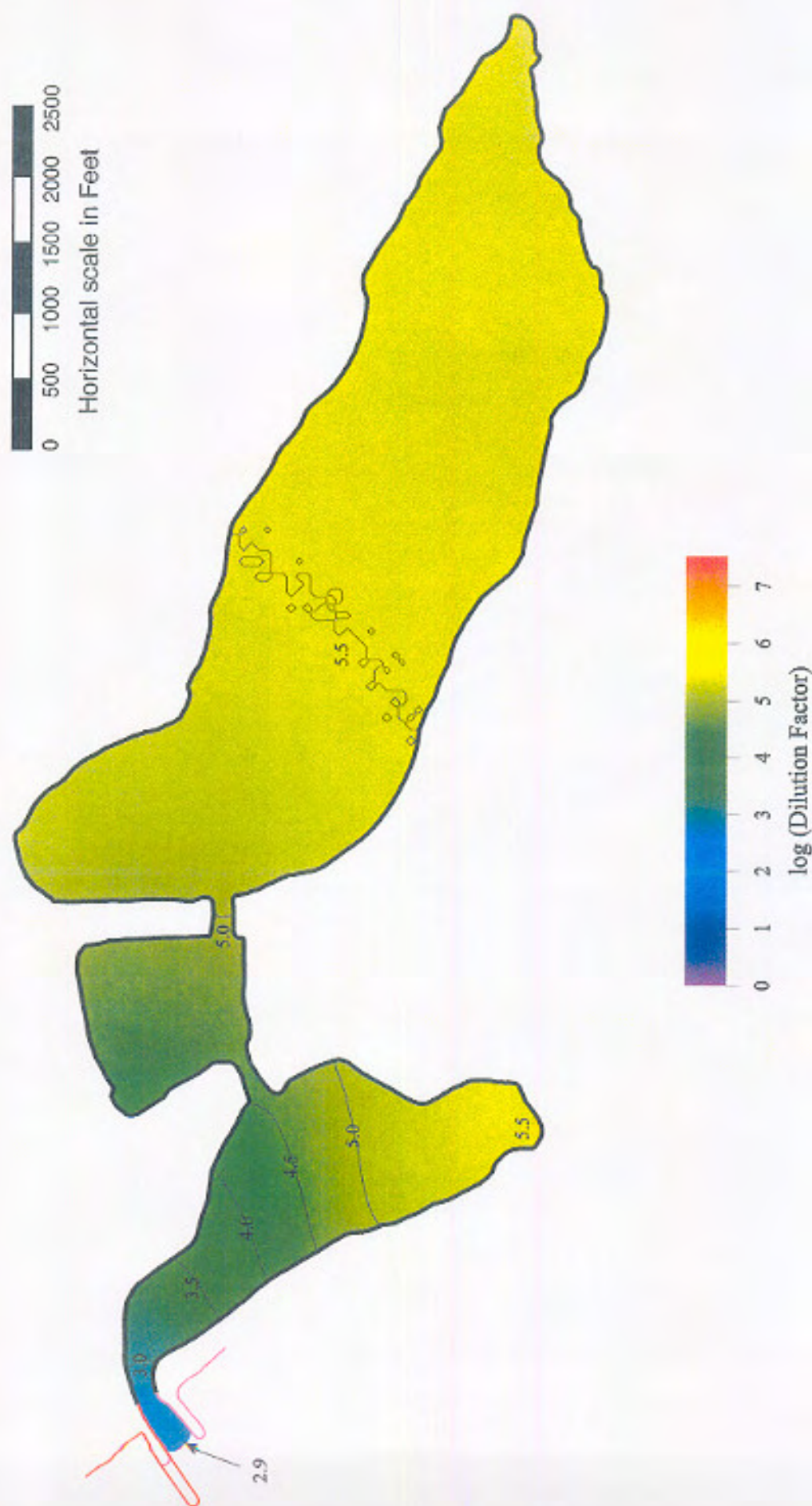


Figure 4.54. Lagoon bottom dilution of concentrated sea water for R.O. = 50 mgd, plant inflow rate = 576 mgd, combined discharge = 526 mgd, ambient ocean salinity = 33.52 ppt, average day (23 May 92).

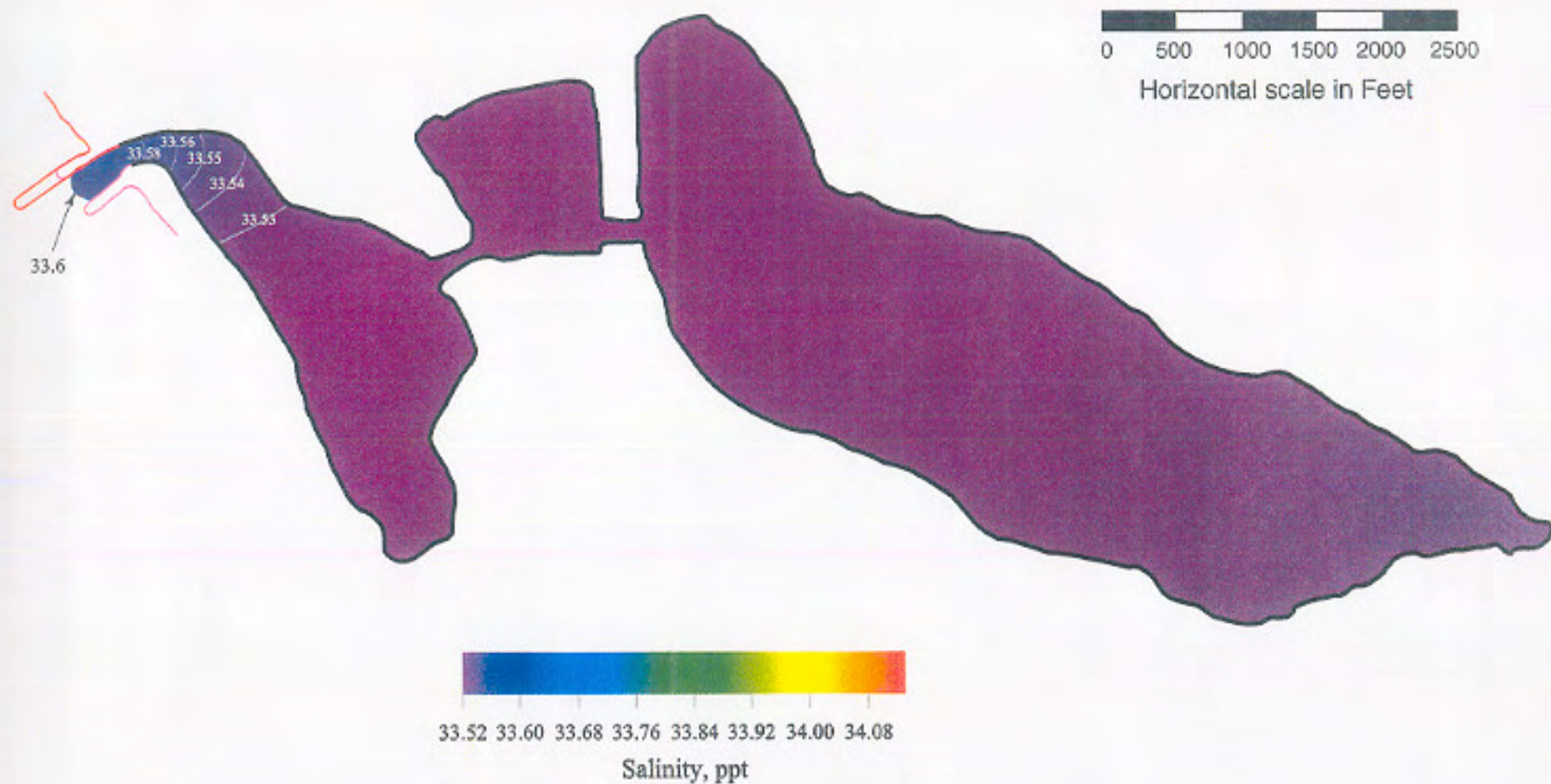


Figure 4.55. Lagoon bottom salinity of concentrated sea water for R.O. = 100 mgd, plant inflow rate = 576 mgd, combined discharge = 476 mgd, ambient ocean salinity = 33.52 ppt, average day (23 May 94).

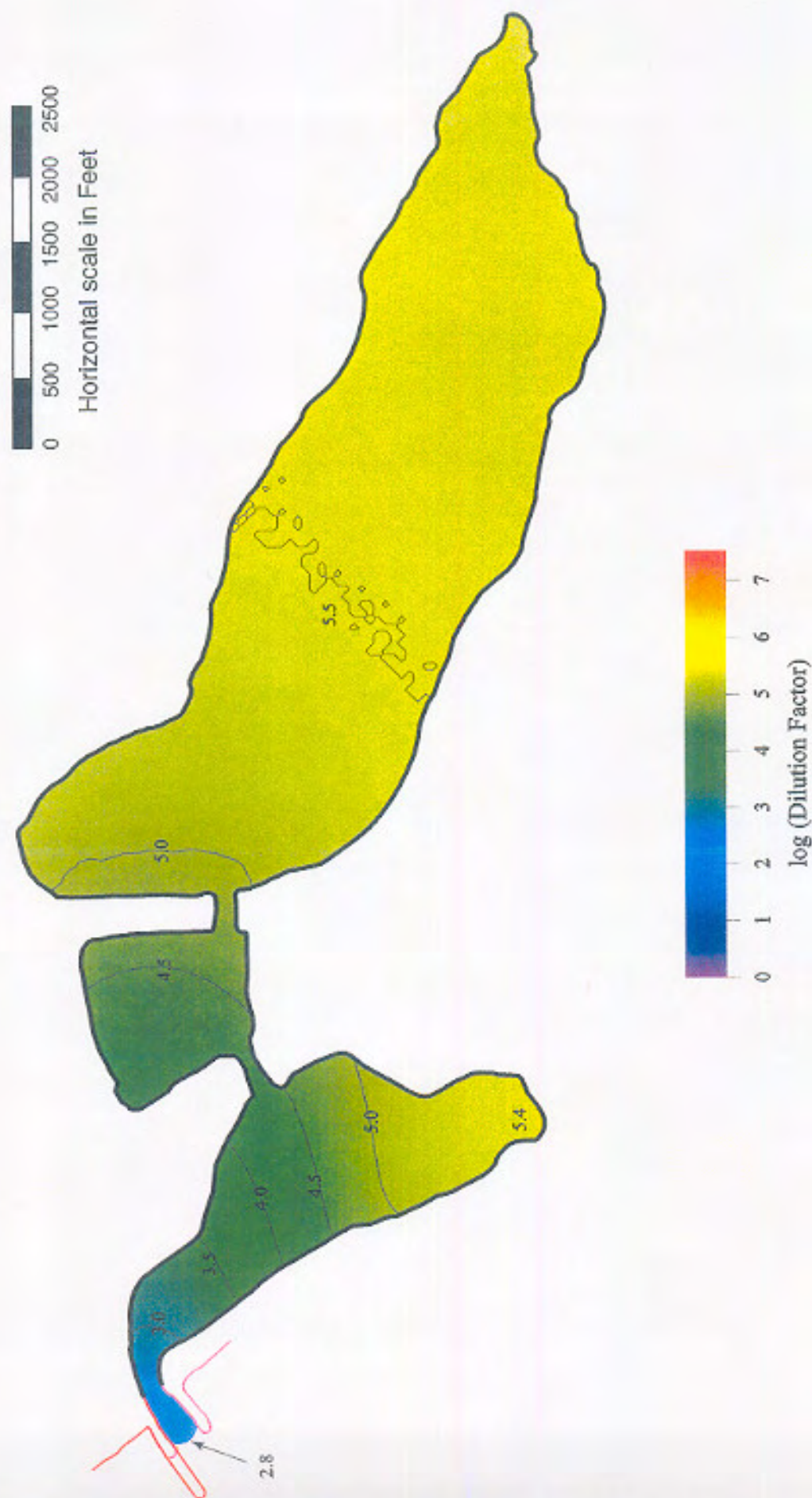


Figure 4.56. Lagoon bottom dilution of concentrated sea water for R.O. = 100 mgd, plant inflow rate = 576 mgd, combined discharge = 476 mgd, ambient ocean salinity = 33.52 ppt, average day (23 May 92).

Table 3. Carlsbad Desalinization Project: Summary of Dispersion Results for RO Production at 50 mgd.

Model Conditions	Worst ^a Day	Average Day	Worst Month	Average Month
Recurrence Probability	0.013%	50.0%	0.398%	50.0%
Maximum Seabed Salinity	35.4 ppt	36.0 ppt	35.0 ppt	36.1 ppt
Maximum Water Column Salinity	34.6 ppt	34.4 ppt	34.0 ppt	34.4 ppt
Benthic Area of 10% Saline Anomaly	0.0 acres	0.0 acres	0.0 acres	0.0 acres
Pelagic Area of 10% Saline Anomaly	0.0 acres	0.0 acres	0.0 acres	0.0 acres
Benthic Area of 1% Saline Anomaly	273 acres	111 acres	465 acres	239 acres
Pelagic Area of 1% Saline Anomaly	42 acres	37 acres	56 acres	24 acres
Minimum Saline Dilution 305 m from Discharge Jetties	20 to 1	32 to 1	25 to 1	35 to 1
Maximum Saline Anomaly in Lagoon	0.4%	0.1%	< 0.1%	< 0.1%
Dilution of Concentrated Seawater at Plant Infall	170,000 to 1	316,000 to 1	> 600,000 to 1	> 600,000 to 1
Maximum Temperature in Discharge Channel	29.0 °C	21.0 °C	25.3 °C	21.0 °C
Maximum Temperature Anomaly at 305 m from Discharge Jetties	1.7 °C	0.8 °C	1.2 °C	0.8 °C
Seabed Footprint of 4 °F Temperature Anomaly	0.8 acres	0.0 acres	0.0 acres	0.0 acres
Seabed Footprint of 2 °F Temperature Anomaly	57 acres	9 acres	35 acres	17 acres
% Reduction in Maximum Footprint of 2 °F Temperature Anomaly ^b	50%	86%	69%	74%

^a Lower Recurrence Probability than the acute toxicity threshold criteria (4 hours every 3 years)

^b Based on existing conditions field measurements of 2 °F footprint, giving: 113 acres for worst case and 65 acres for average case, [from Jenkins, et al., 1989].

Table 4. Carlsbad Desalinization Project: Summary of Dispersion Results for RO Production at 100 mgd.

Model Conditions	Worst ^a Day	Average Day	Worst Month	Average Month
Recurrence Probability	0.013%	50.0%	0.398%	50.0%
Maximum Seabed Salinity	38.2 ppt	39.3 ppt	38.0 ppt	39.4 ppt
Maximum Water Column Salinity	36.0 ppt	36.8 ppt	35.1 ppt	35.5 ppt
Benthic Area of 10% Saline Anomaly	24.4 acres	7.4 acres	14.8 acres	11.6 acres
Pelagic Area of 10% Saline Anomaly	0.0 acres	0.0 acres	0.0 acres	0.0 acres
Benthic Area of 1% Saline Anomaly	415 acres	241 acres	855 acres	414 acres
Pelagic Area of 1% Saline Anomaly	94.7 acres	54 acres	200 acres	64 acres
Minimum Saline Dilution 305 m from Discharge Jetties	10 to 1	22 to 1	14 to 1	12 to 1
Maximum Saline Anomaly in Lagoon	1.2%	0.2%	0.1%	< 0.1%
Dilution of Concentrated Seawater at Plant Infall	160,000 to 1	251,000 to 1	> 500,000 to 1	> 500,000 to 1
Maximum Temperature in Discharge Channel	29.4 °C	21.1 °C	25.9 °C	21.1 °C
Maximum Temperature Anomaly at 305 m from Discharge Jetties	1.9 °C	1.1 °C	1.4 °C	1.1 °C
Seabed Footprint of 4 °F Temperature Anomaly	8 acres	0.0 acres	0.0 acres	0.0 acres
Seabed Footprint of 2 °F Temperature Anomaly	73 acres	14.6 acres	53 acres	22 acres
% Reduction in Maximum Footprint of 2 °F Temperature Anomaly ^b	36%	78%	53%	66%

^a Lower Recurrence Probability than the acute toxicity threshold criteria (4 hours every 3 years)

^b Based on existing conditions field measurements of 2 °F footprint, giving: 113 acres for worst case and 65 acres for average case, [from Jenkins, et al., 1989].

SECTION 5: CONCLUSIONS

5) Conclusions

Hydrodynamic modeling of water mass dilution and dispersion was performed in a nearshore domain surrounding the Encina Power Plant including the Agua Hedionda Lagoon. The model was initialized for four sets of average and extreme environmental conditions: 1) a worst case day, 2) an average day, 3) a worst case month, 4) an average month. For each of these worst case and average case conditions, the model analysis studied dispersion and dilution of concentrated seawater byproduct at two levels of RO production, 50 mgd and 100 mgd.

The concepts of worst and average case apply to the simultaneous occurrence of 7 boundary condition and forcing function variables that in combination control acute and chronic toxicity tendencies for the combined RO and power plant discharge. These 7 variables include: ocean temperatures and salinities, ocean water levels, power plant flow rates, wind, waves, and currents. These variables control the dose levels and persistence of elevated salinities and temperatures associated with the combined discharge. Historical combinations of these variables that minimize mixing and ventilation in nearshore waters while maximizing absolute salinity and temperature lead to worst case scenarios, while combinations having the highest historic occurrence lead to average case scenarios. Twenty and one half year long records of these 7 variables were reconstructed and subjected to computerized recurrence and probability analyses to find the historic surrogate for each scenario. This analysis determined that these historic surrogates were: 1) 17 August 1992 for worst case day, 2) 23 May 1994 for average day, 3) August 1992 for worst month, and a consecutive 30 day period in May and June for worst month.

The probability of recurrence of the conditions of the worst day was 0.01% and 0.4% for the worst month.

Based on these representative historic data. The investigation provided a reasonable estimate of the likely worst case and average effects which the Carlsbad Desalination Project might have on the local and nearshore and lagoonal physical environment.

Salinity Effects:

The historic data indicates that nearshore ocean and lagoon salinities can vary by as much as 10% in response to El Niño events and climate cycles.

* The model analysis of concentrated seawater dispersion and dilution indicates that project effects are in all cases less than natural variability when the RO production rates are 50 mgd and less. Even for the worst case day, no benthic area experiences a 10% increase in bottom salinity, and the maximum salinity anomaly found anywhere in the lagoon (at the mouth) is only 0.4%. Benthic area in the nearshore experiencing a 1% increase in salinity varies from 465 acres for the worst case month to 111 acres for an average day. The minimum dilutions of concentrated seawater at 1000 feet in any direction from the discharge channel range from 20 to 1 for worst case day and 35 to 1 for an average month. At the power plant in-fall (inside the lagoon) dilution factors vary between 170,000 to 1 for a worst case day and more than 600,000 to 1 for an average month. Consequently, recirculation of concentrated seawater into the RO unit is a negligible.

** If RO production is raised to 100 mgd then small areas of seabed in the immediate neighborhood of the mouth of the discharge channel will be subjected to salinity increases of 10% or more (as large as 17.6%). Benthic area subject to 10% elevations in salinity range from 24.4 acres for a worst case day to 7.4 acres for an average day. The maximum salinity in any case reaches 39.4 ppt on 11.6 acres of seabed inside the surfzone directly offshore of the discharge channel. Benthic areas subjected to a 1% salinity increase ranges from 855 acres for a worst case month to 241 acres for an average day. The maximum salinity anomaly found anywhere in the lagoon is 1.2% for the worst case day and is confined to only 1.1 acres in the jettied inlet. The minimum dilution of concentrated seawater found 1000 feet from the discharge channel is between 10 to 1 for a worst case day and 22 to 1 for an average day. Dilutions of concentrated seawater at the power plant in fall vary between 100,000 to 1 for a worst case day and more than 500,000 to 1 for an average month.

Thermal Effects:

California's thermal plan incorporates provisions of Section 316(A) of the Federal Water Pollution Control Act of 1972 and defines the relevant regulatory requirements for power plant cooling water discharge at Encina. The applicable regulatory requirements are found in those sections of California's Thermal Plan dealing with Specific Water Quality Objectives, General Water Quality Provisions, as well as provisions within the Implementation Section. The most restrictive of these provisions with respect to the problem at hand is Water Quality Objective 3B(4) "The discharge of elevated temperature wastes should not result in increases

in the natural water temperature exceeding 4 °F at the: (a) shoreline, (b) surface of any ocean substrate, or c) ocean surface beyond 305 m (1000 ft) from the discharge system. The surface temperature limitation shall be maintained at least 50% of the duration of any complete tidal cycle.”

The model analysis finds that the addition of concentrated seawater to the thermal waste stream of the power plant renders the combined discharge heavier than ambient seawater at all levels of power plant and RO operating conditions. By causing the thermal plume to sink into the water column rather than float on the sea surface, we find that the addition of the RO byproduct provides for more efficient and rapid dissipation of heat into the receiving waters. The following findings were made specific to Water Quality Objective 3B(4).

* At an RO production level of 50 mgd during the worst case day, 0.8 acres of seabed within the surfzone directly offshore of the discharge channel experience a 4 °F (2.2 °C) temperature increase. However, due to active littoral sand transport in this effected area no hard bottom ocean substrate is effected by this thermal impingement. For all other environmental scenarios studied, there is no finding of impingement of the 4 °F temperature anomaly on the seabed. The maximum temperature increase found at any depth at a distance of 1000 ft from the discharge channel range from 3.1 °F (1.7 °C) for the worst case day to 1.5 °F (0.8 °C) for an average month. The thermal footprint of the 2 °F temperature anomaly varied between 57 acres for a worst case day and 9 acres for an average day. This represents a reduction of between 50% and 86% in the thermal footprint relative to existing conditions.

****** At an RO production level of 100 mgd during the worst case day, 8 acres of seabed within the surfzone containing no hard bottom substrate will experience a 4 °F (2.2 °C) temperature increase. For all other environmental scenarios studied, there is no finding of impingement of the 4 °F temperature anomaly on the seabed. The maximum temperature increase found at any depth at a distance of 1000 ft from the discharge channel range from 3.5 °F (1.9 °C) for the worst case day to 2.0 °F (1.1 °C) for an average month. The thermal footprint of the 2 °F temperature anomaly varied between 73 acres for a worst case day and 14.7 acres for an average day. This represents a reduction of between 36% and 78% in the thermal footprint relative to existing conditions.

Based on these findings we conclude that the proposed Carsbad Desalination Project when operated at a production level of 50 mgd would produce saline and thermal effects which are within the range of natural variability and compliant with Water Quality Objectives under California's Thermal Plan. When operated at 100 mgd production rates the project remains compliant with Water Quality Objectives, but results in saline effects outside the range of natural variability in a limited area immediately offshore of the discharge channel. No significant effects were found on Agua Hedionda Lagoon water properties.

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