B. Salinity Modeling Report for the Brine Outfall

Simulation of Salinity Patterns near an Offshore Brine Outfall for a Desalination Plant near Cambria

Prepared for:

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August 15, 1994

Mr. Dave Andres, General Manager
Cambria Community Services District
P.O. Box 65
Cambria, CA 93428

Dear Mr. Andres:

We are pleased to submit the enclosed report Simulation of Salinity Patterns near an Offshore Brine Outfall for a Desalination Plant near Cambria, which documents the assumptions and results of our recent modeling of the salinity distribution that would occur near the brine outfall for Cambria Community Services District's proposed seawater desalination facility. The evaluation of impacts on marine biology that Rick Ware prepared for the administrative draft Environmental Impact Report (EIR) for the project was partly based on this work. Accordingly, we are forwarding a reproducible copy of our report to Glenn LaJoie to include as an appendix to the draft EIR.

The simulation results indicate that even with conservative assumptions regarding outfall design and mixing parameters, the brine discharge would be diluted to a safe salinity level before reaching sensitive marine organisms in the nearby kelp beds. We agree with Rick's conclusion that biological impacts of the discharge would be less than significant. This report should adequately document the evidence and technical analysis supporting this conclusion for the draft and final EIRs and various permit applications. If questions arise during the environmental review and permit application processes, however, we would be happy to conduct additional simulations.

Thank you for giving us the opportunity to continue providing technical and environmental consulting services to Cambria Community Services District as the desalination project continues toward completion. Please contact Gus Yates if you have any questions regarding the report.

Sincerely,

Curtis E. Spencer, P.E.
President

CES:GY:bld
Enclosure

cc: Glenn LaJoie, Robert Bein, William Frost & Associates
Greg Luke, Greg Luke & Associates
Rick Ware, Coastal Resources Management

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INTRODUCTION

Purpose and Scope

This report describes the results of simulations of salinity patterns near a proposed brine outfall near Cambria, on the central California coast, 56 kilometers (35 miles) northwest of San Luis Obispo. The brine discharge would be generated by a proposed desalination plant designed to produce up to 1 million gallons per day of potable water to augment the existing municipal water supply.

The purpose of the simulations is to estimate the potential impact of the brine discharge on marine organisms in the vicinity of the outfall. The simulations indicated the areas that would be exposed to various salinity levels. This information is needed to support environmental impact analysis, obtain discharge permits, and develop an optimal design for the outfall.

The offshore, submerged, multiport outfall investigated in this report is one of several brine disposal alternatives evaluated at a reconnaissance level in a previous report (Jones & Stokes Associates 1994). This alternative was selected for further investigation based on cost and environmental considerations.

The U.S. Environmental Protection Agency's PLUMES model (Baumgartner et al. 1993) was used to simulate near-field mixing of the brine discharge within a few meters of the outfall, where mixing processes are dominated by the momentum of the brine as it exits the jet ports along the outfall. The Fisher model (Fisher et al. 1979) was used to simulate the far-field movement and dispersion of the brine caused by ocean currents and turbulence. Salinity levels up to 250 meters (820 feet) downgradient of the outfall were simulated.

The PLUMES model also calculates far-field movement and dispersion, but the output is less suitable for contouring. Some of the discharge parameters for the outfall were known, such as water depth and the flow rate and density of the discharge. Other parameters were either flexible depending on outfall design (e.g., jet velocity and angle) or were not precisely known at the outfall site (e.g., current direction, current velocity, and dispersion coefficient). Values for these parameters were estimated from standard design practice and from regional oceanographic information. A sensitivity analysis was done to test a range of alternative values for each of these parameters.

Salinity Standards

The desalination plant will require a National Pollutant Discharge Elimination System (NPDES) permit from the California Regional Water Quality Control Board (RWQCB). The RWQCB generally requires permit applicants to identify the zone of initial dilution (ZID), which is the area near the outfall where salinity levels would be high enough to adversely affect marine organisms. Benthic organisms that are unable to move away from the relatively dense brine plume face the greatest risk of adverse impacts.

Presently, no numerical standards exist for salinity of brine discharges from desalination plants. However, bioassays of selected marine organisms completed for other desalination projects on the central California coast found adverse effects on sea urchin embryos when salinity was as low as 36.5 parts per thousand (ppt), or 110% of ambient salinity (33 ppt) (ABA Consultants 1992, Aquatic Bioassay and Consulting Laboratories 1992, Water Engineering and Modeling 1993). The precise threshold at which elevated salinity produces adverse effects appears to be at, or slightly less than, 110% of ambient salinity. For this study, it is conservatively assumed that a salinity of 34.0 ppt (103% of ambient salinity) is safe for marine organisms, and this threshold is used to define the ZID.

The brine discharge would consist of concentrated seawater with a total dissolved solids concentration of approximately 60 ppt. To bring the salinity down to 103% of ambient salinity, a dilution factor of 26:1 (26 parts ambient seawater to 1 part brine) would be necessary.

DESCRIPTION OF OUTFALL

The desalination plant would be located near San Simeon Creek about 3 kilometers (2 miles) north of Cambria and 0.8 kilometer (0.5 mile) inland from the coast (Figure 1). The waste brine would be conveyed to the coast by pipeline. A buried pipeline would extend offshore approximately 300 meters (1,000) feet to a water depth of 8-9 meters (25-30 feet), as shown in Figure 1. From there, a diffuser pipe resting on the sea floor would extend perpendicular to shore for approximately 30 meters (100 feet), with six to 10 jet ports spaced uniformly along it. Simulation results indicated that this spacing would be sufficient to prevent individual jet plumes from coalescing before settling to the sea floor.

Each port would consist of a jet at the end of a riser pipe that would elevate the jet orifice about 1 meter (3.2 feet) above the sea floor to protect against burial by drifting sands. The jet direction would be perpendicular to the main diffuser pipe at an angle of about 45° above horizontal. Alternate jets would be directed toward the opposite side of the diffuser pipe.

In addition to a salinity of approximately 60 ppt, the brine would contain small amounts of biodegradable antiscalant compounds and possibly backwash from onshore filters for the raw seawater entering the plant. These additional compounds are nontoxic or would be diluted to nontoxic concentrations before discharge. They would have a negligible effect on the density of the brine and are not considered in the simulations.

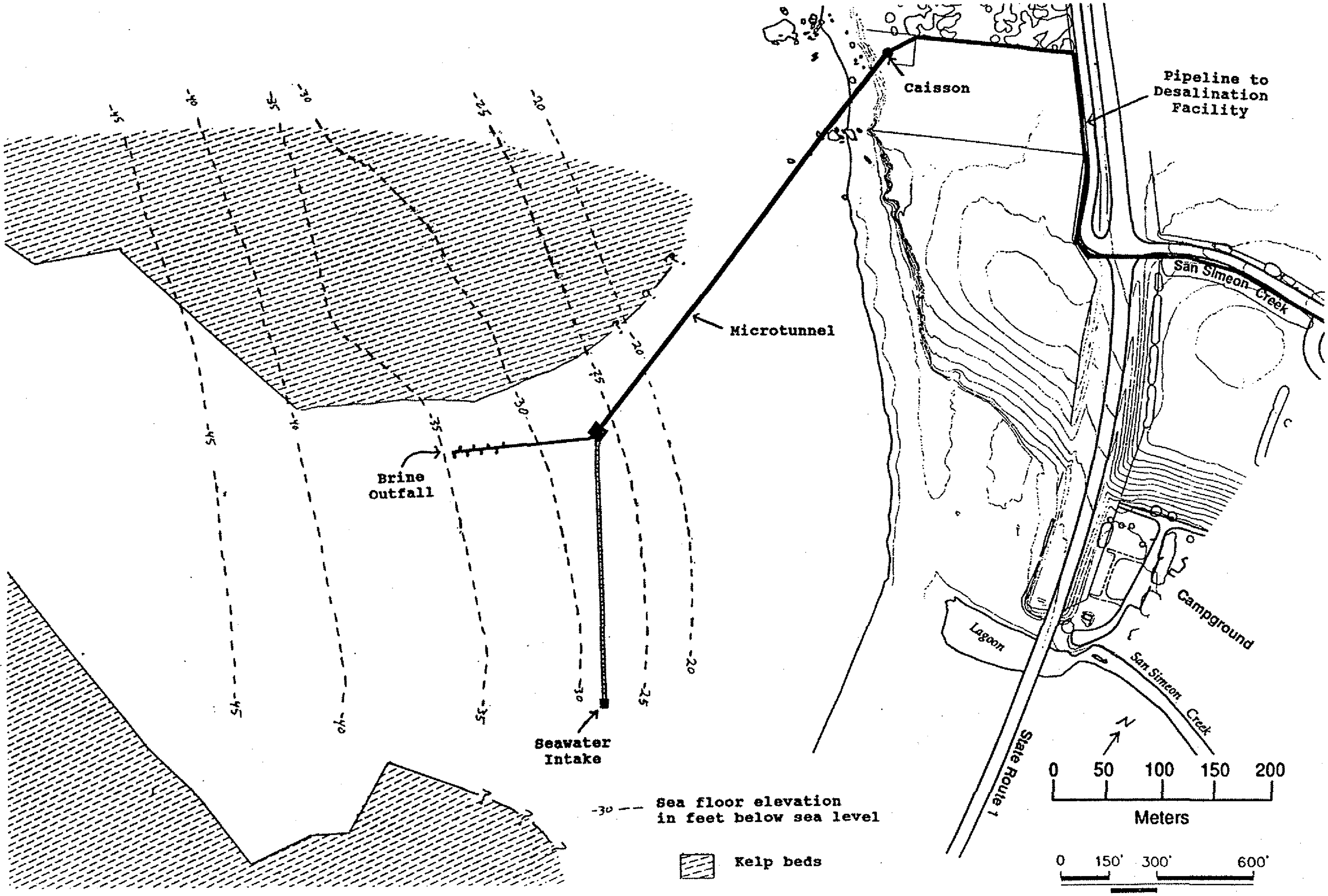

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Figure 1
Approximate Locations of Seawater Intake and Brine Outfall

NEAR-FIELD SIMULATIONS

Description of Model

The PLUMES model uses analytical equations to describe the trajectory and dispersion, or spread, of a plume exiting a jet port into a still water column. The principal variables in the model are the port angle and diameter, flow rate and velocity, and the densities of the discharge and ambient water column.

Results

The simulations indicate that a dilution factor of 22:1 can be achieved at the apogee (top) of the plume trajectory with reasonable design parameters. For example, this could be achieved using an outfall with 10 jet ports, a jet angle of 45° above horizontal, and a jet velocity of 3.3 meters per second (m/s) (11 feet per second [ft/s]). The apogee of the simulated plume was about 1.3 meters (4.3 feet) above and 2.1 meters (6.9 feet) away from the jet orifice. The plume diameter was about 1.2 meters (3.9 feet).

A dilution factor of 22:1 corresponds to a salinity of 34.2 ppt, or 104% of ambient salinity. Thus, with no further dilution, turbulent mixing within 3 meters (10 feet) of the outfall jets is sufficient to decrease salinity to a level that would, at worst, affect only very sensitive marine organisms.

The density of the plume at the apogee of its trajectory would be slightly greater than ambient seawater density, so the plume would slowly settle to the sea floor and spread out as the ambient current carries it away from the outfall. Additional mixing would occur as the plume settles, and the salinity might decrease to less than the target salinity (34.0 ppt or 103% of ambient salinity) by the time the plume reaches the sea floor. The PLUMES model cannot calculate this phase of mixing through use of the jet equations because the velocity of the plume at the apogee approaches zero. Instead, further mixing is simulated using the far-field transport equations described in the next section.

Although the outfall design parameters for this simulation are reasonable, cost and engineering considerations may make a different design more desirable, possibly including a design that achieves significantly less than the target dilution factor of 26:1 in the near-field area. For example, high jet velocities may result in corrosion of the jet, and a large number of small jets require a higher discharge pressure than a small number of large jets. Tradeoffs among design parameters and the resulting dilution factor were investigated by means of a sensitivity analysis of the model.

Sensitivity Analysis

The effect of varying the jet angle on the plume characteristics at the apogee of the trajectory is shown in Figure 2. These results are for a hypothetical outfall with only ports instead of the 10 ports assumed earlier. As the jet angle increases from 15° to 45° above horizontal, the dilution factor increases slightly, from about 11:1 to 15:1. Increasing the angle above 45° results in little additional dilution. The rise of the plume above the level of the jet increases from about 0.5 meter to 2.0 meters (1.6 to 6.5 feet) as the angle increases from 15° to 45° and continues to increase with higher jet angles. The diameter of the plume at the apogee is relatively insensitive to jet angle and is between 1 and 2 meters (3 and 6 feet) for all jet angles. Similarly, the horizontal distance at which the plume reaches its apogee is 2-3 meters (6-10 feet) for jet angles between 15° and 50°.

Little additional dilution is achieved by increasing the jet angle above 45°. With angles near vertical, the plumes could superimpose if the ambient current happened to be aligned with the main outfall axis for a period of time. Thus, the best overall jet angle is approximately 45°.

The jet velocity can be increased by decreasing the number of jet ports or by decreasing the diameter of each jet port and increasing the discharge pressure. Figure 3 shows that dilution is quite sensitive to jet velocity. The results shown in the graph are for a two-port outfall with varying jet diameter. The dilution factor at the apogee of the plume increases from 5:1 to 41:1 as the jet velocity increases from 1 to 8 m/s (3 to 26 ft/s). However, rapid corrosion of the jet orifice would probably occur with velocities greater than 4 m/s (13 ft/s). Velocities near 3 m/s (10 ft/s) are probably reasonable for achieving substantial mixing without causing corrosion problems.

Increasing the number of jet ports increases the amount of dilution if the jet velocity is held constant. Figure 4 shows the effect of increasing the number of ports while simultaneously decreasing the port diameter to maintain a jet velocity of 4 m/s (13 ft/s). The dilution factor in this case increases from about 16:1 for one jet port to 28:1 for eight jet ports. Increasing the number of jet ports would entail higher construction and operating costs, however, because a larger number of ports would need to be installed and maintained and a higher discharge pressure would be required.

The amount of mixing in the near-field area is only slightly affected by the temperature of the discharge. The temperature of the brine discharge could be 2-3° C warmer than the ambient ocean temperature if natural gas is used to power the pumps at the desalination plant and the desalination recovery efficiency is enhanced by prewarming the incoming seawater. Figure 5 shows that dilution at the plume apogee is barely affected by temperatures up to 10° C greater than the ambient seawater temperature. These results confirm that near-field mixing is driven by the energy and momentum of the jet and that these forces are much larger than the small forces created by temperature and density differences.

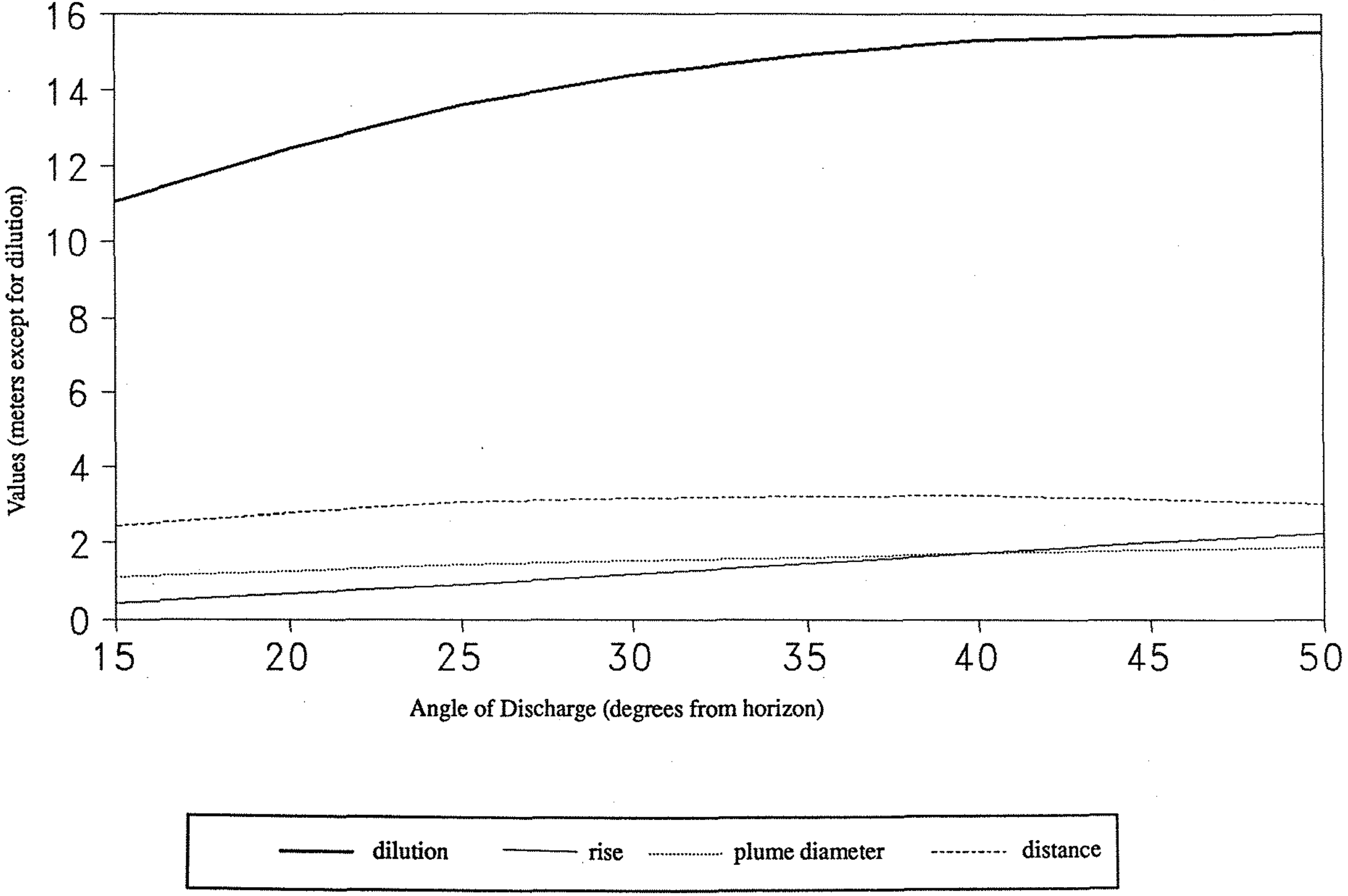

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Figure 2
Effect of Jet Angle on Plume Characteristics at the Apogee

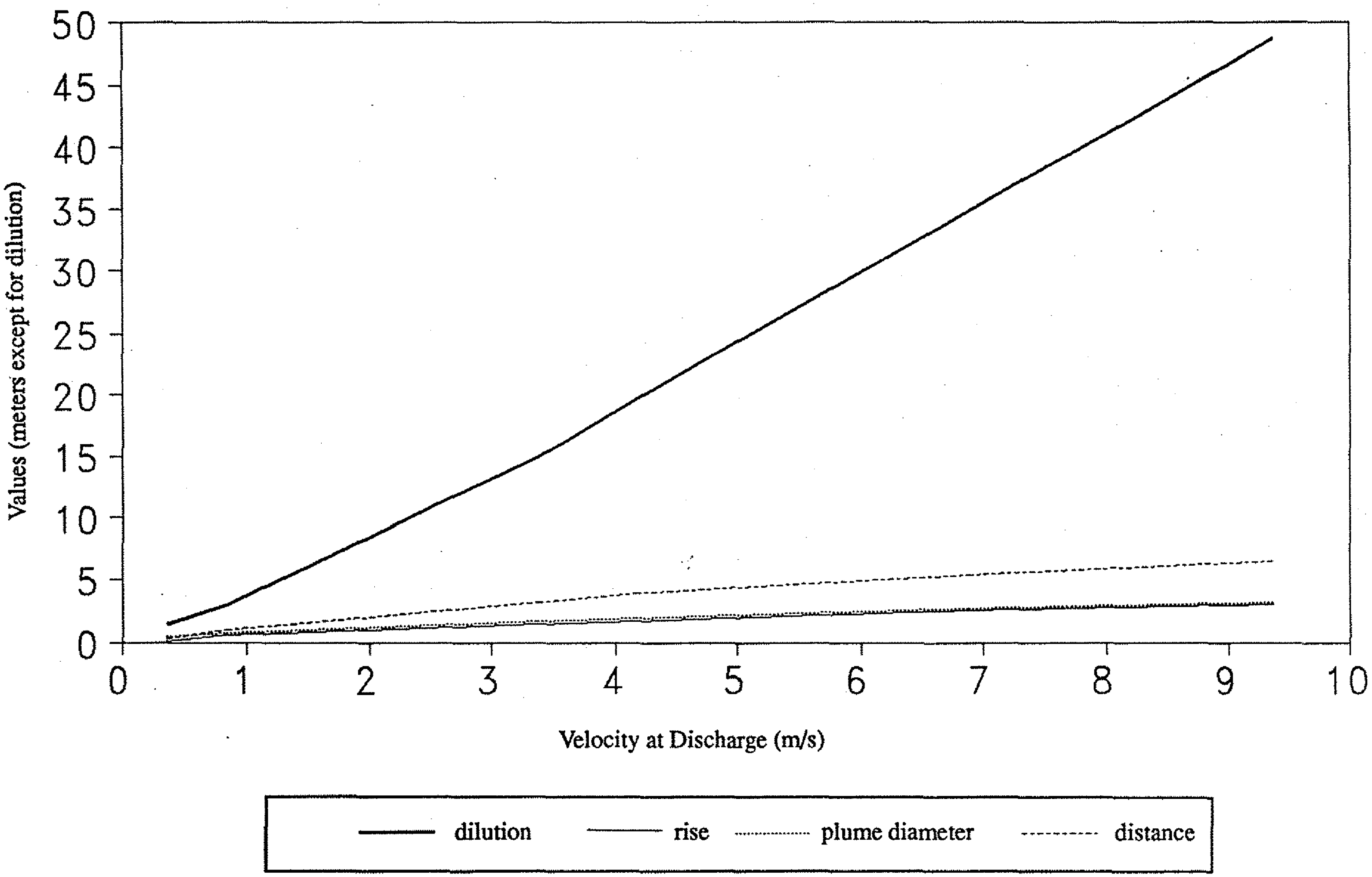

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Figure 3
Effect of Jet Velocity on Plume Characteristics at the Apogee

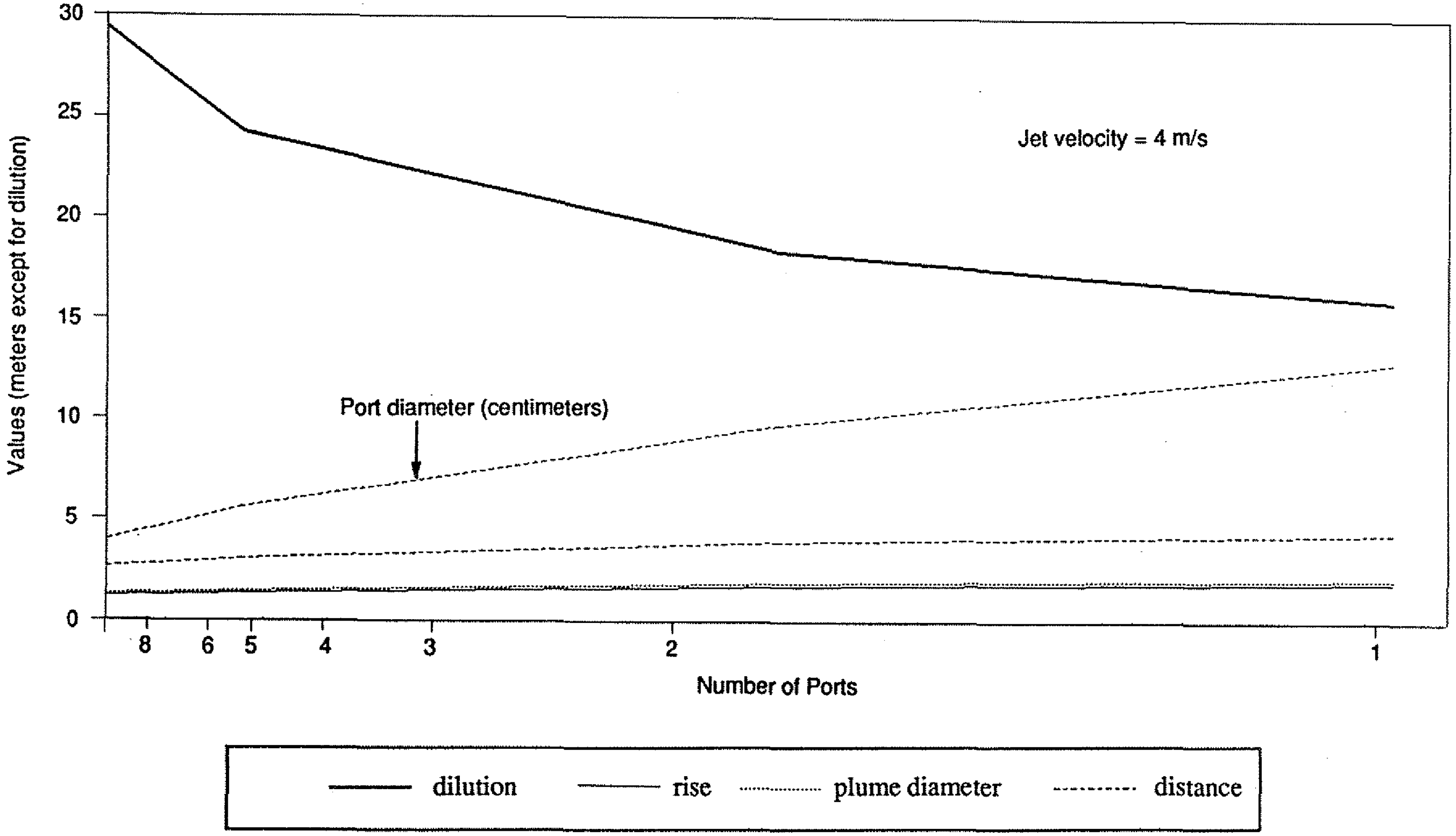

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Figure 4
Effect of Increasing the Number of Ports on Plume Characteristics at the Apogee

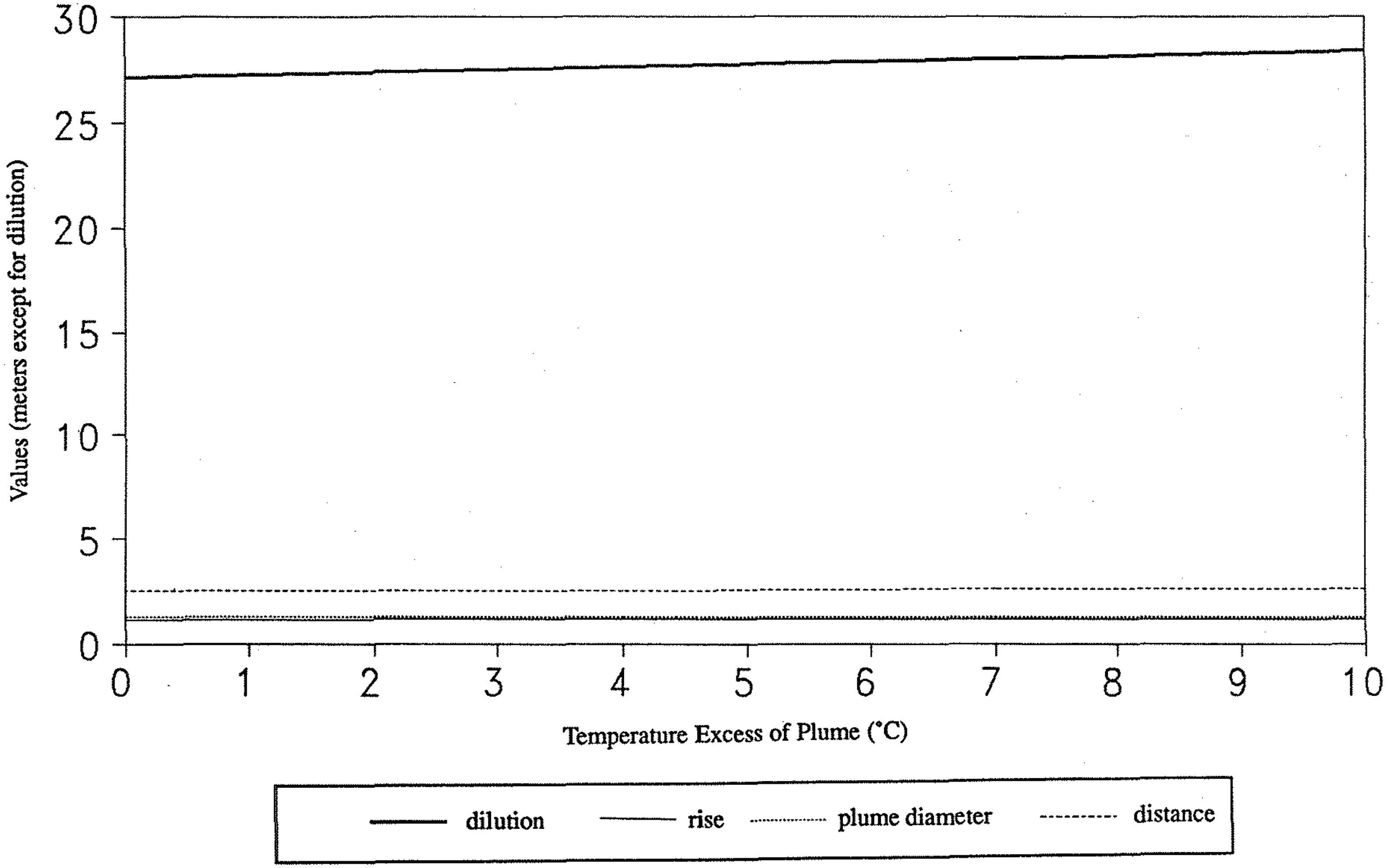

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Figure 5

Effect of Discharge Temperature on Plume Characteristics at the Apogee

FAR-FIELD SIMULATIONS

Description of Model

After the jet plumes from the outfall have settled to the sea floor and coalesced into a layer of slightly hypersaline water, additional dilution occurs as this water is slowly moved away from the outfall by ocean currents. The Fisher model simulates this second stage of mixing using an advection-dispersion equation. The advection term in the equation describes the downgradient translation of the plume as it moves with the current, and the dispersion term describes the mixing and lateral spreading that occurs at the same time. The plume is assumed to be symmetrical about its centerline in the downgradient direction. The model results show the salinity distribution for half of the plume, on one side of the centerline. The salinity distribution on the opposite side is a mirror image of that distribution.

The model is two-dimensional and shows a plan view, or map, of the salinity distribution as the brine plume spreads out in a layer across the sea floor. The layer is assumed to have a fixed thickness, and mixing is assumed to be complete throughout the vertical thickness of this layer. For this analysis, the brine layer was conservatively assumed to be only 1 meter (3.2 feet) thick. Larger thicknesses result in greater dilution and lower salinity. The initial thickness of the layer near the outfall would probably be approximately 1 meter (3 feet) which is the diameter of the jet plume before it settles to the sea floor. Some vertical mixing will occur as the current carries the brine away from the outfall, and the brine layer will tend to become thicker and more diluted with distance. However, the amount of vertical mixing might be fairly limited under low-current conditions because the tendency toward density stratification could outweigh the turbulent forces that create vertical dispersion. A conservative estimate of 1 meter was assumed for the constant thickness of the brine layer.

The salinity distribution downgradient of the outfall is affected by current speed. Conceptually, the minimum amount of mixing would occur with no current at all, but in practice this never happens except for brief periods when tidal currents are reversing direction. A study of currents in Estero Bay north of Morro Bay (25 kilometers [15 miles] south of the project site) found average current speeds ranging from 0.03 to 0.05 m/s (0.06 to 0.10 knot) (ECOMAR 1978). These were averages over 3- to 10-week periods during the 14-month study. The lowest average velocities were generally during July and August. These averages indicate only net long-term movement and do not reveal the short-term variations in current speed and direction that contribute substantially to mixing. Instantaneous current speeds ranged from 0 to 1.2 m/s (0 to 2.4 knot). Although some of the transient current movements are oscillatory, they create a substantial amount of mixing and are a better indicator of brine plume dispersion than are the long-term average current speeds. Also, even under low-current conditions, waves contribute a fairly constant, background level of mixing. For this model, a reasonably low current speed of 0.1 m/s (0.2

knots) was assumed, which reflects the occurrence of transient current fluctuations. Along open coast lines, occurrences of currents less than 0.1 m/s are generally very brief.

The principal current direction was assumed to be from north to south, parallel to the shoreline. Occasionally, the current direction may reverse because of tidal oscillations, but it is unlikely that a large current would persist for any appreciable length of time perpendicular to the shoreline. In Estero Bay, local currents were dominated by the California Current, which flows from north to south at an average speed of 0.25 m/s (0.5 knots). Deep ocean upwelling and the Davidson countercurrent occasionally created variable current speeds and directions, but the predominant movements were parallel to the shoreline. Currents are even more likely to remain parallel to the shoreline near Cambria because the coastline is relatively straight for 15 kilometers (10 miles) to the north and south. For this study, the current was assumed to be parallel to the shoreline and perpendicular to the outfall pipe.

The lateral spread of the plume downgradient of the outfall is also affected by a model parameter called diffusivity, which represents the combined effects of various sources of small-scale water movement and turbulence. These sources include orbital wave motion, daily tidal oscillations, thermally driven convective mixing, and eddies created as ocean currents flow past irregularities in the coastline and sea floor. Diffusivity is difficult to measure directly. Instead, it is estimated empirically through calibration of models to observed dispersion patterns. Values of diffusivity used in calibrated models typically range between 0.05 and 0.5 meter squared per second (m^2/s). No measured plume dispersion data are available for the proposed outfall site, so the model could not be calibrated to measured data. Instead, a conservatively low estimate of 0.05 m2/s was assumed to occur only under very calm wave conditions. This value is particularly conservative for the assumed low-current conditions, because the forces that create lateral spread of the brine plume are somewhat independent of current velocity, and diffusivity consequently tends to be relatively large under low-current conditions. Larger values were tested during sensitivity analysis of the model.

Results

The simulated salinity distribution on the sea floor downgradient of the outfall is shown in Figure 6. The figure is a contour map of salinity concentrations on one side of the plume centerline, which coincides with the bottom horizontal axis of the graph. The current direction is from left to right. The plotting scale in the transverse direction (vertical axis) is expanded five times relative to the horizontal axis, to better show the salinity contours in the transverse direction. The results indicate that salinities greater than the target value of 34.0 ppt would be present only in a triangular area extending a maximum of about 85 meters (280 feet) downgradient of the outfall. This triangular area represents the ZID and has a total area of approximately 950 square meters (m^2) (0.23 acre).

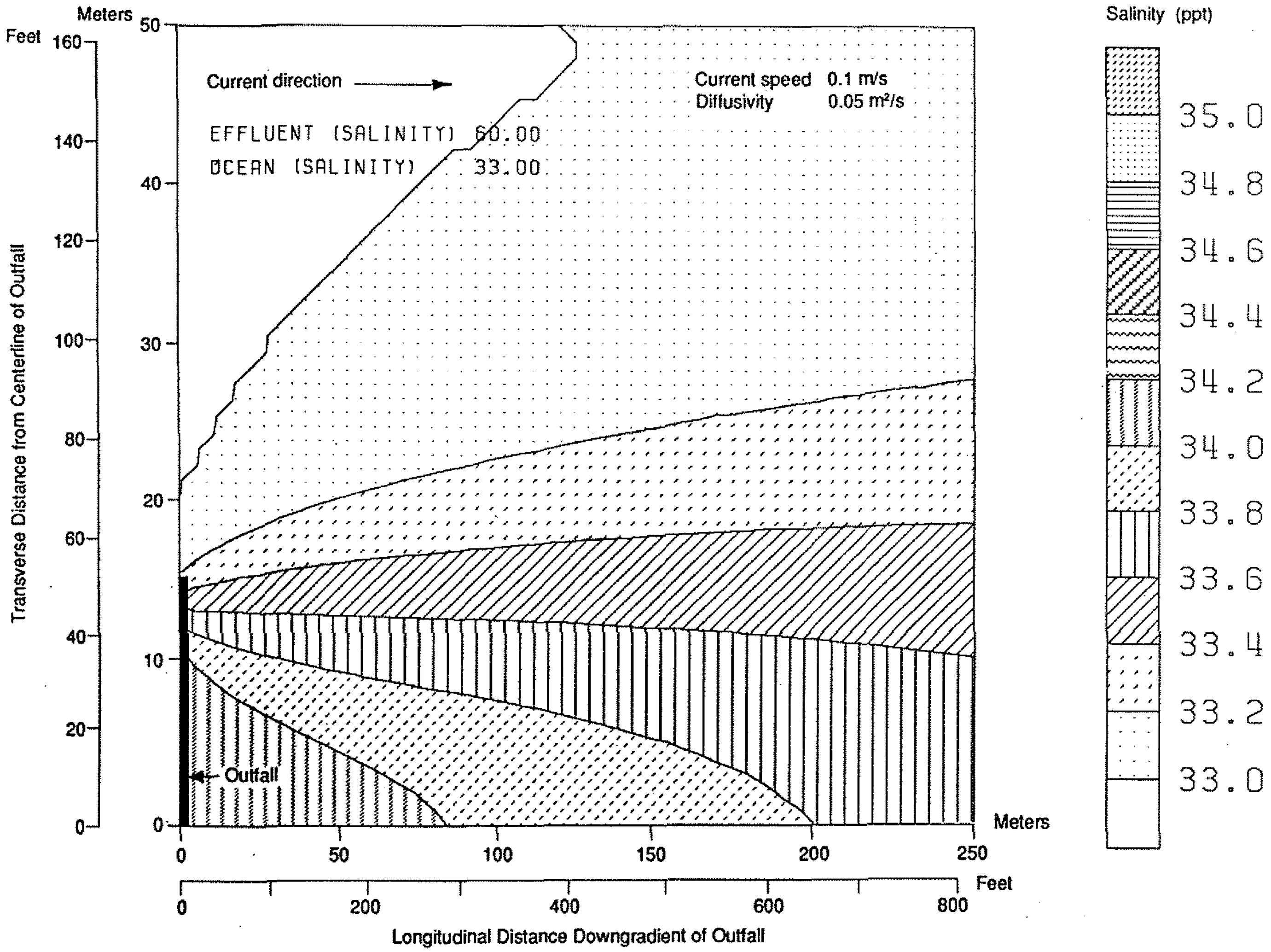

Figure 6

Map of Salinity Contours Downgradient of the Outfall with Low Current Speed and Low Diffusivity

These results indicate that even under low-current conditions, the area of the sea floor in which benthic organisms might potentially be adversely affected by elevated salinity would be confined to the sandy area between the kelp beds north and south of San Simeon Creek (see Figure 1). The distance from the outfall to the downgradient kelp bed would be 150-250 meters (500-800 feet), depending on whether the outfall is located in the center of the sandy area or shifted to the north (as shown in Figure 1). The kelp beds, which are most likely to be sensitive to elevated salinity, would not be adversely affected by the plume.

The transit time from the outfall to the downgradient kelp bed under these low-current conditions would be 25-42 minutes. Low-current conditions are most likely to occur when tidal currents are reversing direction and would not persist for more than about 1 hour before current speeds increased again.

Sensitivity Analysis

Higher current speeds increase the rate of dilution of the brine plume because total mixing is affected by both current speed and diffusivity. Figure 7 shows the salinity distribution for a current speed of 0.3 m/s (0.6 knot). Salinities are less than 33.4 ppt (101% of ambient salinity) throughout the plume.

If a relatively high diffusivity of 0.50 m^2/s is assumed, lateral spreading of the plume increases substantially, as shown in Figure 8. Dilution is also more rapid. The ZID has a total area of only 150 m^2 (0.04 acre). This higher diffusivity value would be reasonable estimate for moderate to large waves in summer.

A slightly larger ZID could occur if the current direction were aligned with the axis of the outfall pipe, as shown in Figure 9. In this case, the plumes from individual ports would be superimposed, and the ZID would extend 150 m (500 feet) downgradient from the outfall. The total ZID area would be 1,800 m^2 (0.45 acre). It is unlikely that the current would flow in this direction (perpendicular to shore) for an extended period of time. Even if it did, the plume would not affect the kelp beds because it would not be flowing toward them.

SUMMARY AND CONCLUSIONS

The simulation results demonstrate that near-field and far-field mixing processes are capable of diluting the brine discharge to less than 34.0 ppt (103% of ambient salinity) before the discharge plume reaches sensitive marine organisms in the kelp beds near the outfall site.

An outfall diffuser consisting of 10 jet ports spaced uniformly along a 30-meter (100-foot) outfall pipe, each pointed upward at a 45° angle and discharging with a jet velocity of

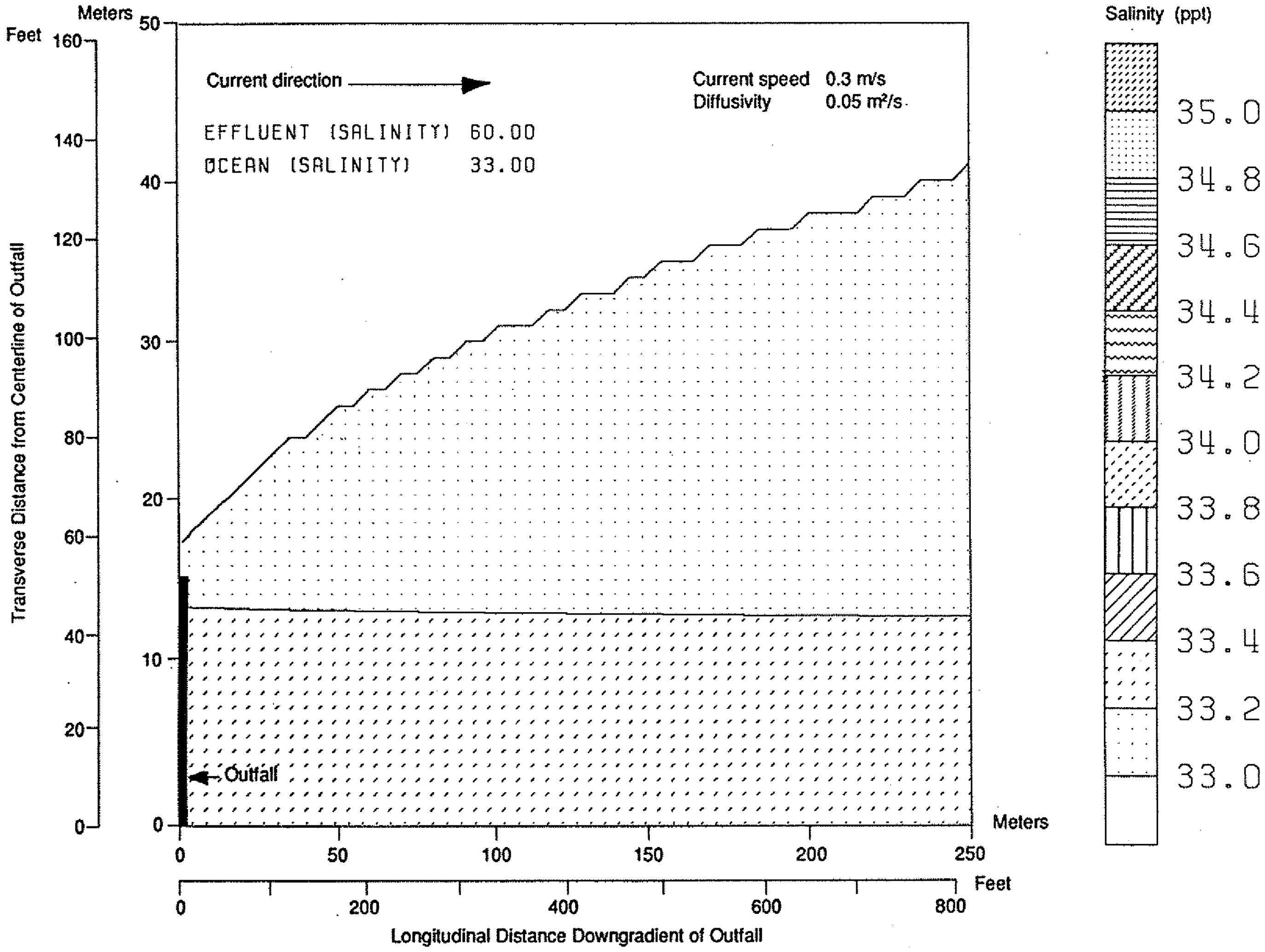

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Figure 7
Map of Salinity Contours Downgradient of the Outfall with High Current Speed and Low Diffusivity

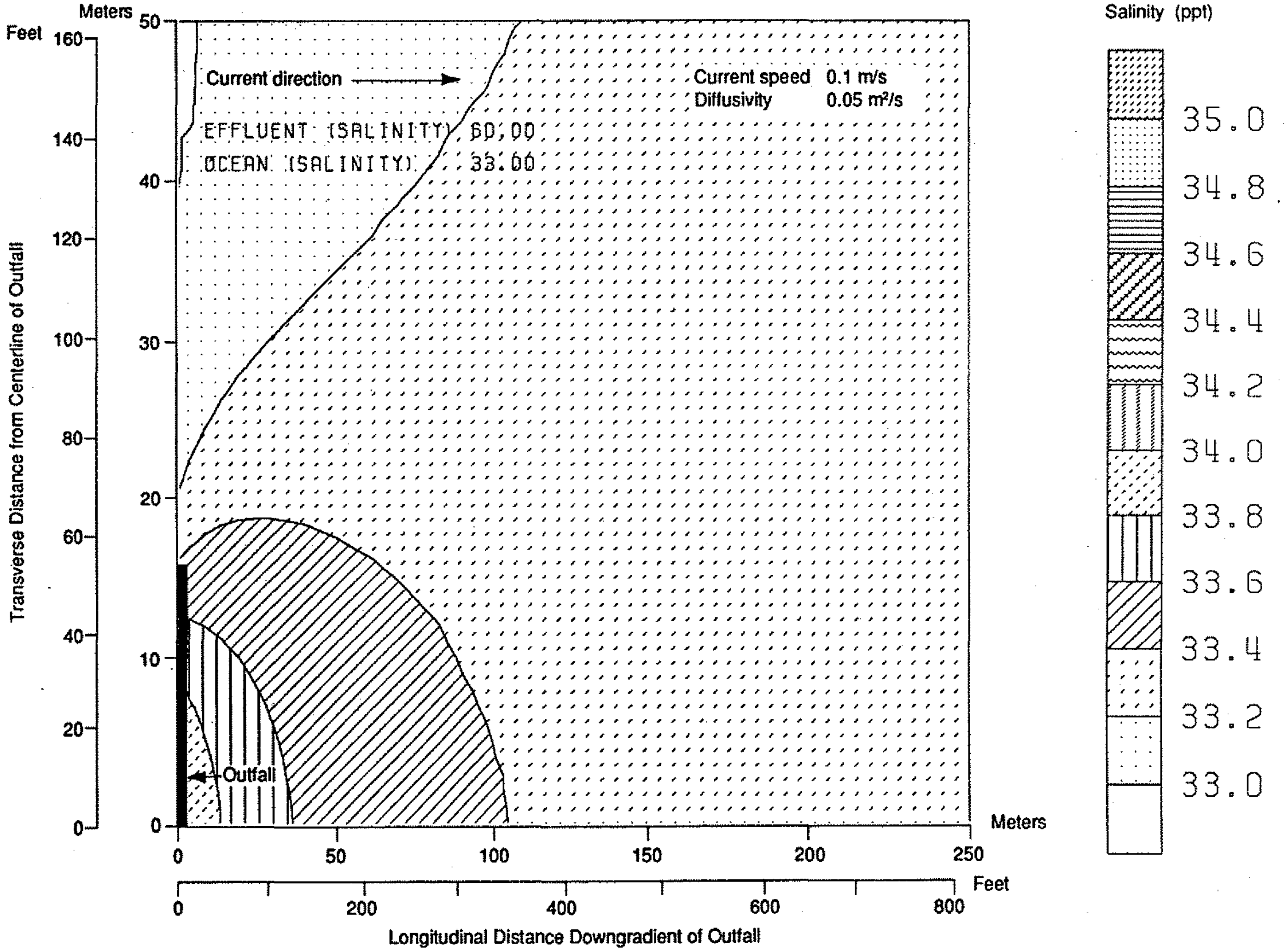

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Figure 8

Map of Salinity Contours Downgradient of the Outfall with Low Current Speed and High Diffusivity

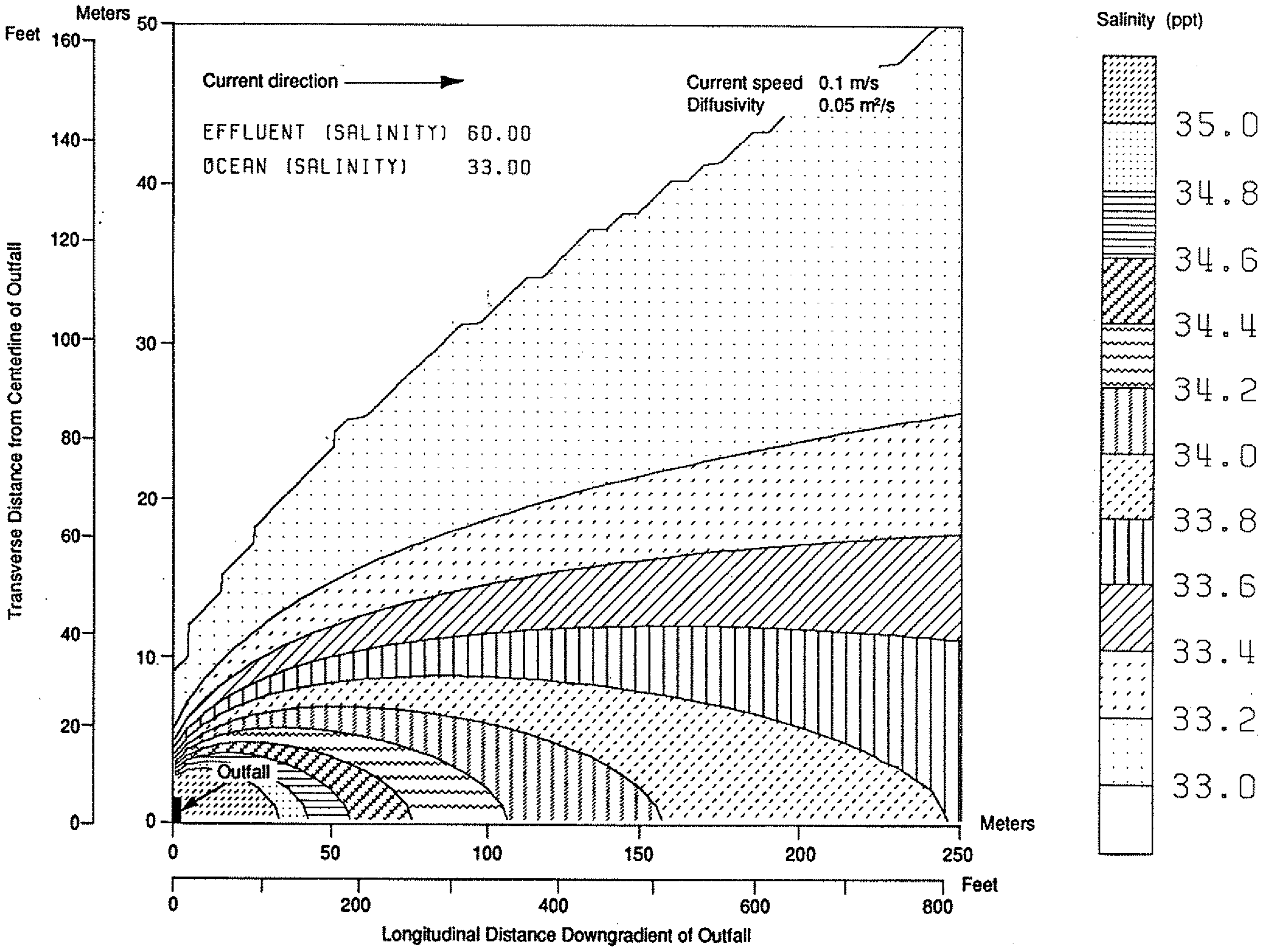

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Figure 9

Map of Salinity Contours Downgradient of the Outfall with Low Current Speed, Low Diffusivity, and Current Direction Parallel to Outfall Pipe

3.3 m/s (11 ft/s), can achieve a dilution factor of 22:1. This represents a reasonable outfall design, and it almost provides the total amount of dilution required to completely avoid impacts on marine organisms.

Additional dilution occurs when the brine plumes from the jets slowly drift away from the outfall and are dispersed by tidal currents and wave motion. Even if very conservative assumptions are made regarding vertical mixing, diffusivity, and current speed and direction, far-field dispersion is sufficient to decrease the salinity of the discharge to harmless levels within 85 meters (280 feet) of the outfall.

PRINTED REFERENCES

ABA Consultants. 1992. Effects of hyper-saline water on survival of Olivella pycna and Dendraster excentricus. November. Capitola, CA. Prepared for EIP Associates and Monterey Peninsula Water Management District, Pasadena and Monterey, CA.

Aquatic Bioassay and Consulting Laboratories. 1992. Bioassay reports for samples of Santa Barbara desalination plant and El Estero effluent. Ventura, CA. Prepared for Ionics, Inc., Santa Barbara, CA.

Baumgartner, D. J., W. E., Frick, and P. J. W. Roberts. 1993. Dilution models for effluent discharges 2nd edition. (EPA/600/R-93/139.) U.S. Environmental Protection Agency, Pacific Ecosystems Branch. Newport, OR.

ECOMAR, Inc. 1978. Predesigned oceanographic study for the Morro Bay - Cayucos Sanitary District. May. Santa Barbara, CA. Prepared for Morro Bay - Cayucos Sanitary District, Morrow Bay, CA.

Fisher, H. B., List, E. J., Koh, R. C. Y., Imberger, J., and Brooks, N. 1979. Mixing in inland and coastal waters. Academic Press. New York.

Jones & Stokes Associates. 1994. Brine discharge alternatives for Cambria Community Services District's seawater desalination facility, preliminary draft report. April 5, 1994. Sacramento, CA. Prepared for Cambria Community Services District, Cambria, CA.

Water Engineering and Modeling. 1993. Initial dilution study of Santa Barbara desalination plant brine discharge. Santa Ana, CA. Prepared for EIP Associates, San Francisco, CA.