City and County of San Francisco 2030 Sewer System Master Plan

TASK 700 TECHNICAL MEMORANDUM NO. 705 DILUTION MODELING FOR THE SAN FRANCISCO SOUTHWEST OCEAN OUTFALL

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CITY AND COUNTY OF SAN FRANCISCO 2030 SEWER SYSTEM MASTER PLAN

TASK 700

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TABLE OF CONTENTS

		<u> </u>	Page No.
1.0	INTR	ODUCTION	705-1
2.0	OUTI	FALL DESCRIPTION	705-1
3.0	OCE/ 3.1 3.2 3.3	ANOGRAPHIC CONDITIONS	705-3 705-3
4.0	MATH 4.1 4.2 4.3 4.4	HEMATICAL MODELING APPROACH Introduction Master Plan Alternatives Diffuser Configurations Typical Results	705-6 705-6 705-7
5.0	RESU 5.1 5.2 5.3	JLTS Master Plan Alternatives Effects of Seasonal Variations Diffuser Configuration Alternatives	705-11 705-11
6.0	DISC	USSION	705-14
		LIST OF APPENDICES	
	_	raphic Data ry Background and Outfall Mixing Processes	
		<u>LIST OF FIGURES</u>	
Figure Figure Figure Figure Figure Figure Figure	2 S 3 P 4 F 5 D M 6 D	an Francisco Southwest Ocean Outfall	705-2 705-4 705-4 705-5

DILUTION MODELING FOR SAN FRANCISCO SOUTHWEST OCEAN OUTFALL

1.0 INTRODUCTION

The purpose of this Technical Memorandum is to present the results of mathematical dilution simulations for the San Francisco Southwest Ocean Outfall for various oceanographic conditions, flow rates, and diffuser configurations. The oceanographic data used are those collected during measurement campaigns in the late 1980s. The City of San Francisco is presently updating its Master Plan that considers various wastewater management options that result in different dry and wet weather (DW and WW) flows through the outfall. The outfall is presently operating with most of the ports on the diffuser closed, and changes to the number of ports open and/or their diameters would be needed to accommodate the higher wet weather flows contemplated. Check valves on the ports may be needed to accommodate the higher flows while preventing seawater intrusion at the lower flows. Dilution simulations are presented for various flow and port configurations.

In a previous report (Roberts, 2003) dilutions were simulated for the existing diffuser configuration using DW flow and oceanographic data for a limited period. It was argued that the dilution value of 76:1 used in a previous NPDES permit application was overly conservative and a better measure of the environmental impact of the discharge is the harmonic average dilution. It was recommended to use this value, which was about 250:1, for the NPDES permit. In this report, these simulations are updated to include more of the available oceanographic data.

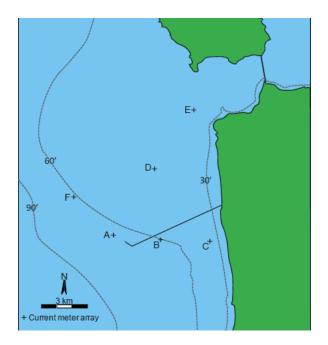
2.0 OUTFALL DESCRIPTION

The Southwest Ocean Outfall (SWOO) is shown in Figure 1. The outfall began discharging Richmond-Sunset plant wastewaters in September 1986. After completion of the Oceanside Water Pollution Control Plant (WPCP) in 1993, the Richmond- Sunset plant was abandoned and eventually razed. The outfall also carries stormwater runoff resulting in wide flow variations.

The outfall is 4.5 miles (7.2 km) long and carries the treated wastewater out to a diffuser system that begins approximately 3.8 miles (6.1 km) from shore and at a depth of 78 feet (23.8 m). The diffuser section is approximately 3024 ft (922 m) long, with an internal diameter that varies from 8 to 12 feet (2.4 to 3.7 m). Schematics of the outfall and diffuser are shown in Figure 2. The diffuser consists of 85 risers spaced 36 feet (11.0 m) apart. Each riser contains eight ports with nominal diameters of 4.3 inches (109 mm) from which the effluent is discharged. The hydraulic design capacity of the outfall is approximately 465 million gallons per day (mgd) (20.4 m₃/s), depending on tidal elevation. It was designed with this capacity in order to accept the dry and wet weather flows from the entire city. The

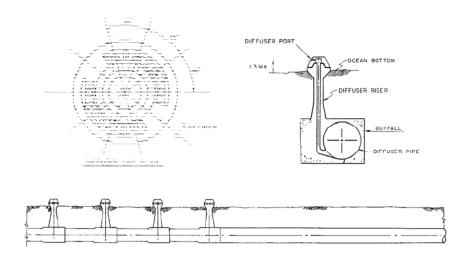
peak wet weather flow at present is about 175 mgd (7.7 m₃/s), however, and the average dry weather flow is only about 18 mgd (0.8 m₃/s), approximately 4 percent of capacity. Therefore, to maintain adequate port velocity to prevent seawater intrusion, only 21 out of the 85 risers are currently open. The 21 active risers begin from the offshore end and alternate, so the effective riser spacing is 72 feet (21.9 m). Inspections of the outfall imply that only 12 of these risers are actually discharging, however.

Figure 1 San Francisco Southwest Ocean Outfall



The discharge location is in federal waters since it is beyond the three-mile limit of the state's territorial sea. The implications of this for the discharge permit are discussed in Appendix B.

Figure 2 Schematics of San Francisco Southwest Ocean Outfall and Risers



3.0 OCEANOGRAPHIC CONDITIONS

3.1 Introduction

As part of bacterial compliance and wastefield transport studies carried out in 1987 and 1988 (CH2M Hill, 1989), extensive field measurements of currents, temperature, and conductivity were collected in the vicinity of the outfall over a period of thirteen months. InterOcean S4 Electromagnetic current meters were moored at up to three depths at the locations shown in Figure 1. In addition to currents, each meter was equipped with a temperature and conductivity sensor from which seawater salinity and density were computed. Details of the oceanographic program are given in Appendix A.

The array near the diffuser (Station A) consisted of three current meters. The instruments were A1, at 7.6 m depth (designated near-surface); A2, at 13.7 m depth (mid-depth); and A3, at 19.8 m (near-bottom). This array recorded continuously, with breaks for servicing, from June 19, 1987 to July 18, 1988. Due to intermittent failures of the temperature and conductivity sensors and calibration drift, however, the record of stratification during this period is incomplete. The current measurements are fairly complete for the study period.

Two "critical periods" were more extensively studied. These were the periods of expected minimum stratification (September to October 1987) and expected maximum stratification (May to June 1988). During these two periods, field dye studies to measure dilution were conducted, and current meters were deployed at all of the stations shown in Figure 1 for approximately one month. For a complete deployment history of the instruments and a summary of the data they collected, see Tables A-2 and A-3 in Appendix A.

As part of the present study, the data were reevaluated for use in the dilution simulations and new data files were prepared. The data preparation and the resulting files are summarized in Appendix A along with plots of the data used in the simulations.

The essential findings of the field studies relevant to this report are summarized below. For a more detailed discussion, see CH2M Hill (1989).

3.2 Currents

The major characteristics of the currents are illustrated by the October near-surface measurements in Figure 3. This shows polar scatter diagrams of the currents and the directions of their first principal axes; these are the directions which maximize the kinetic energy of the currents when projected onto them. The components of the currents along the first principal axes are the first principal components; the second principal components are the components in a direction orthogonal to the first. The principal axes are shown as PC1 and PC2 on Figure 3. A feather plot of the May A2 (middepth) data is shown in Figure 4.

Figure 3 Polar Scatter Diagrams of NearSurface Currents, October 1987

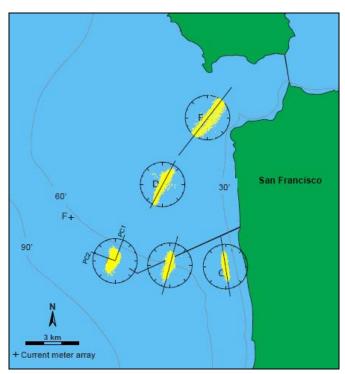
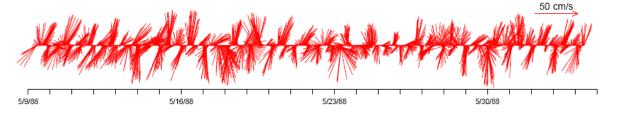


Figure 4 Feather Plot of May Currents at Mooring A2



The directions of the first principal components at all mooring locations generally point towards the Golden Gate. These components are strongly tidal, with an amplitude that increases closer to the Golden Gate. Peak speeds are around 30 cm/s near the diffuser (Station A), and 100 cm/s near the Golden Gate (Station E). Near shore, at Station C, the currents are very parallel to the coastline.

The current properties vary somewhat with depth. Peak current speeds generally decrease with depth although the mid-depth currents at Station A show about the same peak speeds as at the surface. The mid-depth peak flood currents near the Golden Gate (Station E) are also similar to those at the surface, but the current vector rotates clockwise on the ebb tide and flows in a more Westerly direction as the current speed increases. This effect was also observed in the bottom currents. Similar patterns are apparent for the May data (see

below), although the surface currents are more variable in direction. This scatter was more pronounced at the offshore mooring offshore (Station F), however, and the currents inshore at Station C were still very parallel to shore. The greater directional variability of the surface currents may be caused by the stronger winds during this period. The clockwise rotation of the deeper ebb currents near the Golden Gate was also evident in the May data.

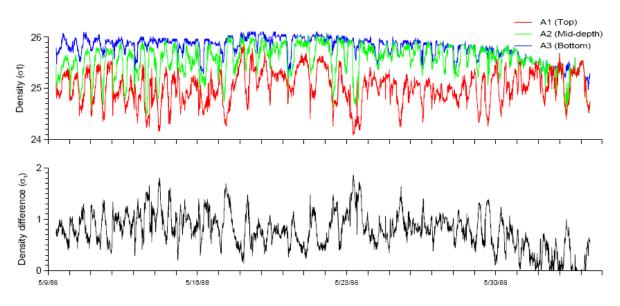
The net drifts at near-surface were generally offshore but become more onshore with depth. This is probably caused by density-induced circulations caused by the low salinity water flowing from the San Francisco Bay.

3.3 Density Stratification

The seawater density was computed from the temperature and salinity recorded by each instrument. The computed densities for the May data set at the three depths are shown in Figure 5; the lower plot shows the density difference between the near-surface and near-bottom instruments.

The density shows clear correlations with the tide. In general, measurements on an ebbing tide show warmer, less saline water, and on the flooding tide cooler and more saline water. This is due to movement of the waters from San Francisco Bay that are warmer and less saline than the deeper oceanic waters. In May, the surface temperature fluctuates by up to 3 deg C, and the salinity by about 1 PSU. This causes the surface density to fluctuate widely, by almost 2 σ_t . The magnitudes of the temperature and salinity fluctuations decrease with depth, so the variation in density of the bottom waters is less. This causes the density stratification to vary strongly with the tide with density differences over depth ranging from 0.1 to 1.9 σ_t , mostly due to variations of surface water properties.

Figure 5 Density and Density Difference Between the Top and Bottom Meters, May Data



Maximum stratification occurs on the ebbing tide, and minimum stratification occurs near the end of the flood tide. The density fluctuations during May were larger than in October, probably because of the stronger winds that were observed during May. The average density difference over the water column for the May data is about $0.8~\sigma_t$. The water column was occasionally homogeneous, or well-mixed, over the water column at the end of the May data period.

The Bay outflow appears to behave like a surface buoyant jet. In October, the ebb flows from the Golden Gate were often strong enough to mix the flow over depth, although the water re-stratified farther offshore. This causes the net drifts to be offshore at the surface and onshore (or towards the Golden Gate) at the bottom. Stronger winds during May appeared to cause more variability in the surface current direction and bottom salinity and temperature, but were not strong enough to overcome this density-induced circulation. In May, the density differences were usually too large to be mixed by the ebb currents and the waters were almost always stratified.

4.0 MATHEMATICAL MODELING APPROACH

4.1 Introduction

Simulations of dilution were made using the mathematical model NRFIELD, described in Roberts (1999, 2003). NRFIELD is also available as part of the U.S. EPA plume modeling package Visual Plumes (Frick et al., 2001). NRFIELD (formerly called RSB) can use long time series of oceanographic data as input. The model predicts the plume characteristics at the end of the near field, which is the region where mixing and dilution is due to turbulence and other processes associated with the discharge. The program was modified to output the dilution at a fixed distance equal to the Federal regulatory mixing zone distance of 100 m (see Appendix B). If the near field length was less than 100 m, the dilution at 100 m was assumed to be equal to the near field dilution, i.e. further dilution due to oceanic turbulence was neglected.

The model was run with various oceanographic data and flow and diffuser configurations to produce time series of predicted plume characteristics. This is similar to the procedure used in modeling the Mamala Bay, Hawaii, outfalls (Roberts, 1999) and in previous studies for San Francisco (Roberts, 2003). The results are discussed below.

4.2 Master Plan Alternatives

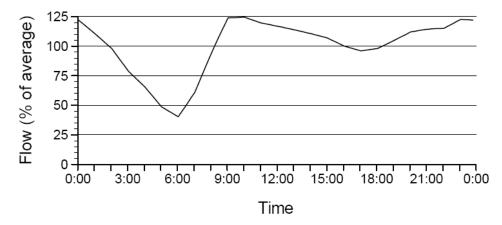
The San Francisco Public Utilities Commission (SFPUC) Wastewater Enterprise is involved in a Sewer System Master Planning process that includes four alternatives with various average dry weather flow (ADWF) and peak wet weather flow (PWWF) scenarios through the SWOO. The alternatives are summarized in Table 1. Alternatives 1 and 4 include no change to the existing average dry weather flow conditions, but increase wet weather flow

with the reduction of near shore discharges; alternatives 2 and 3 include additional volumes of dry weather flow and maximized wet weather flow through the SWOO.

Table 1 Sewer System Master Plan Alternatives and SWOO Flows 2030 Sewer System Master Plan City and County of San Francisco												
PWWF (mgd) ADWF Reduced Near-Si												
Alternative	Description	(mgd)	Base Case	Reduced Near-Shore Discharges								
1	Improve existing system	15.3	175	300								
2	Decentralize Bayside treatment with Cayuga Flow to OSP	25.3	590	590								
3	Treat all day-weather flows on Westside	94.7	590	590								
4	Relocated SEP to new Bayside site	15.3	175	300								

For dry weather flows, a diurnal flow variation was used as shown in Figure 6. This was obtained by interpolating hourly average diurnal flows measured at the treatment plant to 15 minute intervals. The flow is shown as a percentage of the ADWF. The same variation was assumed for all dry weather flows for the average values shown in Table 1. It was assumed that this diurnal variation repeated through the simulation periods. For wet weather flows, the flow rate was taken as constant through the simulation period.

Figure 6 DW Diurnal Flow Variations Used in Simulations



4.3 Diffuser Configurations

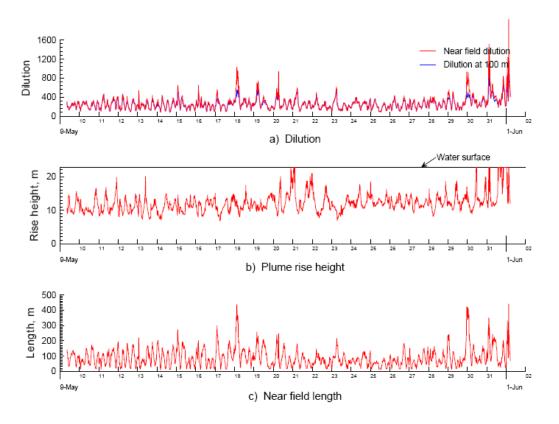
At present, SWOO is operating with 21 active risers spaced 72 feet apart. This would give an effective diffuser length of 1440 feet (439 m). It appears, however, that only 12 are actually discharging, the 11 farthest offshore and that closest inshore. The more conservative assumption was made, therefore, that the present configuration consists of 12 adjacent active risers with a diffuser length of 792 feet (241 m).

Modifications to this diffuser configuration would be needed to discharge the maximum contemplated WWF without excessive headloss. Two main alternatives were simulated. The first maintained the existing port openings (assumed to be 96 ports) but increased their diameters if necessary so that the jet exit velocity was always less than 20 feet/s. The second consisted of opening all of the existing 680 ports at their present nominal diameter of 4.33 inches (109 mm). In order to prevent seawater intrusion, the port densimetric Froude number should be greater than about one. It was assumed that this would be accomplished at the lower flow rates by the use of check valves that increase the jet velocity as the flow deceases. A summary of the diffuser configurations tested for the various Master Plan alternatives is given in Table 2 along with computations of jet velocity and Froude number at the various flows.

4.4 Typical Results

Each simulation results in time series of dilutions and plume rise heights. Typical results are shown in Figure 7 for Alternative 1, ADWF = 15.3 mgd, May oceanographic conditions (Figures 4 and 5), and the existing diffuser (D1). The mid-depth currents (A2) were used. Figure 7 shows time-series of near field and 100 m dilution, plume rise height, and the length of the near field.

Figure 7 Typical NRFIELD Simulation Results (May Data)



Diffuser Configurations Assumed for Dilution Simulations 2030 Sewer System Master Plans City and County of San Francisco Table 2

Alt.	ID	Comment	No. of Risers	Ports per Riser	Total No.	Port Diam.	Diffuser	Flow	Jet velocity (ft/s)	Froude Number
1	D1	Existing diffuser	12	8	96	(m) 4.33	Length (ft) 791	(mgd) 15.3	2.4	4.5
1 & 4	D1	Existing diffuser	12	8	96	4.33	791	175.0	27.6	51.2
1 & 4	D1	Existing diffuser	12	8	96	4.33	791	300.0	47.2	87.7
1 & 4	D1b	Existing + valves	12	8	96	5.12	791	175.0	19.7	33.7
1 & 4	D1c	Existing + valves	12	8	96	6.65	791	300.0	20.0	30.0
2 & 3	D1d	Existing + valves	12	8	96	9.33	791	590.0	20.0	25.3
2 & 3	DAO	All ports open	85	8	680	4.33	3,024	590.0	13.1	24.3
2 & 3	CD1	Tee-riser with check valves	85	2	170	8.66	922	590.0	13.1	17.2

Because of the widely varying flow, current speed and direction, and density stratification, the plume properties vary widely. Near field dilution varies from about 90 to 2,500, with a mean value of 290. The lowest dilutions occur when high flowrate, strong stratification, and weak currents occur simultaneously. Conversely, the highest dilutions occur when low flow, high current speed, and weak stratification coincide. Low dilutions are infrequent; dilutions below 100:1 occur less than 1 percent of the time.

The plume is almost always submerged, with rise heights varying from 3.4 m to 22.8 m (surfacing) with a mean value of 8.9 m. Overall, the plume is submerged for 94 percent of the time, and when the plume surfaced its dilution exceeded 210.

The length of the near field is similarly variable. It ranges from less than 10 m to about 600 m. It is less than 100 m more than 99 percent of the time, so the dilutions at 100 m are very similar to the near field results. Dilutions at 100 m range from about 90:1 to 1200:1 with an average value of 270:1.

The lowest, mean, and highest dilution values have little statistical significance. A better measure of the range of dilutions is the 5 and 95 percentile values. For this case, the 5 percentile value of the near field dilution is 125, and the 95 percentile value is 582. The median near field dilution is 244.

Lowest dilutions are also not a significant measure of the environmental impact of the discharge, although they have been used in NPDES permit applications. It was argued in Roberts (2003) that a more meaningful number is the harmonic average dilution:

$$\overline{S} = \frac{1}{\frac{1}{n} \sum_{i=1}^{n} \frac{1}{S}}$$

where S is the dilution at time n. The significance of the harmonic average dilution is that it can be used to compute the time-average concentration of a contaminant after dilution as the concentration in the effluent divided by the harmonic average dilution. This average concentration cannot be directly computed from the simple mean value of dilution. The harmonic average is therefore, in keeping with the spirit of the CCC (Appendix B), a more useful measure of dilution and it is recommended that it be used in the NPDES permit application. The harmonic average dilution computed in this way for the case above is 226:1 at 100 m.

5.0 RESULTS

5.1 Master Plan Alternatives

NRFIELD was run in a similar way to that above for Master Plan Alternatives 1, 2, and 3 in Table 1 (Alternative 4 has the same flow rates) using the May oceanographic data. In order to summarize the large volume of results that were generated, they are presented in Table 3 as the and 5 and 95 percentile and median values of near field dilution, the harmonic average dilution at 100 m, and the frequency of plume submergence.

Dilution and the frequency of plume submergence decrease as the flow rate increases for otherwise fixed conditions. For the DW flow alternatives with the present port openings (increased for Alternative 3), as the flow increases from 15.3 to 94.7 mgd, the harmonic average dilution reduces from 226 to 100 and the frequency of submergence decreases from 94 to 63 percent.

Similar results are seen for the WW flow alternatives and the present port openings (with their diameters increased to accommodate the higher flows as shown in Table 2). As the WW flow increases from 175 to 590 mgd, the dilution decreases from 75 to 33, and the submergence from 43 percent to less than 1 percent.

The WW dilutions and submergence frequency increase as more ports are opened thereby increasing the diffuser length. Consider the results for all ports open (diffuser DAO). At 175 mgd, dilution increases from 75 to 145 and submergence increases from 43 percent to 86 percent. At 590 mgd, dilution increases from 33 to 79 and submergence increases from less than 1 percent to 63 percent.

The two port configurations simulated above, present port openings and all ports open, result in lower and upper bounds for dilution. Other options, such as paired ports on each riser, or four ports per riser would result in dilution values between these bounds. Similarly, these other options would result in higher dilutions than the DWF simulations summarized above.

5.2 Effects of Seasonal Variations

The second question to be addressed by this report is the effect of seasonal variations in oceanographic conditions on the outfall dilution.

In order to answer this question, NRFIELD was run for fixed diffuser configurations and flow rates for the various oceanographic conditions measured during the 1987 and 1988 campaigns. It was initially hoped to use the whole 13-month data set in order to obtain 30-day, 6-month and 13-month averages. Unfortunately, due to the lack of continuous data through the 13-month period and other problems with the data this was not possible.

Table 3 **Alternatives with May Oceanographic Data** 2030 Sewer System Master Plans City and County of San Francisco

Run ID	Comment	Master Plan Alternative	Diffuser	Flow (mgd)	5%	Median	95%	Harm. ave. at 100 m	% Submergence
11	ADWF	1	D1	15.3	125	248	582	226	93.8
13	PWWF; existing diffuser + check valves	1	D1b	175	51	76	143	75	43.1
14	PWWF; all ports open	1	DAO	175	80	157	321	145	85.6
15	PWWF; existing diffuser + check valves	1	D1c	300	44	53	98	55	13.9
16	PWWF; all ports open	1	DAO	300	67	117	225	112	68.2
21	ADWF	2	D1	25.3	102	194	416	179	90.6
22	PWWF; existing diffuser + check valves	2	D1d	590	28	30	54	33	0.3
23	PWWF; all ports open	2	DAO	590	53	80	152	79	38.3
31	ADWF	3	D1	94.7	62	107	212	100	63.0

All of the oceanographic data were examined, as discussed in Appendix A. As summarized in Table A-2, some of the data files had bad temperature or conductivity sensors, and some of the data were obviously incorrect. For example, computed seawater densities at mid depth were not intermediate between the top and bottom sensors. In those cases, only the top and bottom density values were used. The data files were edited to have common starting and end times for the density and current values and manually edited to remove obviously wrong values. The only data files that were salvageable and usable were Jul and Dec of 1987, and Jan, Feb, Mar, and May of 1988. The actual data files used are plotted in Appendix A.

NRFIELD was run for these months for similar conditions to those in Roberts (2003): present port openings (diffuser D1 in Table 2) and an ADWF of 17 mgd. The results are summarized in Table 4. Note that the results are slightly different from those presented in Roberts (2003). This is because NRFIELD has been updated to include the results of more recent experimental data obtained with three-dimensional laser-induced fluorescence (3DLIF). These experiments are described in a series of four papers, two for unstratified receiving waters (Tian et al. 2004ab), and two for stratified receiving waters (Tian et al. 2006, and Daviero and Roberts, 2006). This update resulted in a lowering of predicted dilution values by about 10 percent; the previous predicted value of 248 is now 222.

Table 4	Table 4 Summary of NRFIELD Simulated Dilutions for Various Seasonal Conditions 2030 Sewer System Master Plan City and County of San Francisco												
	Dilution												
Run ID	Period	5%	Median	95%	Harm. ave. at 100 m	% Submergence							
43	May	123	244	564	222	93.6							
44	Jul	188	356	1,112	328	61.9							
45	Dec	123	222	336	203	100.0							
46	Jan	124	231	376	209	100.0							
47	Feb	104	191	327	175	100.0							
48	Mar	104	183	285	169	100.0							

Because the currents are strongly tidal, their influence on dilution does not vary significantly through the year. The density stratification, and its effect on dilution, does vary significantly, however. The weakest stratification occurred in Jul 1987. For this month, the dilution was 328, and the plume was submerged about 62 percent of the time. The strongest stratification occurred in winter, particularly Mar when the dilution was 169 with 100 percent submergence. It had previously been assumed in Roberts (2003) that the May data was the most strongly stratified, as this was the critical period

chosen to obtain the most strongly stratified data. Inspection of the data shows, however, that the winter months are more strongly stratified, presumably due to increased freshwater runoff during this period.

Caution is needed in interpreting these results, however. Only the May data had three operating density sensors, at near-surface, mid-depth, and near-bottom, and the data from all three sensors were used in the dilution simulations. For all the other data sets, only two sensors were operational, at near-surface and near-bottom, and these two were used in the simulations. The sensors are subject to drift and calibration errors, and errors in either sensor would result in systematic over or under estimation of the density stratification. The results are very sensitive to the density stratifications. For more reliability it is recommended that future measurements be obtained with thermistor and conductivity probe strings to obtain extended records of density stratification and used in further dilution simulations.

The long-term averages of dilution, such as 6-month, cannot be computed due to the lack of continuous data through the year. The most that can be concluded from these data is that the long-term dilution averages lie somewhere between the lowest value of 170 that occurred with the Mar data set and the highest of 330 that occurred with the Jul data set.

5.3 Diffuser Configuration Alternatives

Check valves can be used to minimize headloss at the peak wet weather flows contemplated while preventing seawater intrusion at low flows. It is desirable to minimize the number of ports to minimize the costs of the valves and reduce maintenance requirements. In this section, the effect of port configurations on dilution is considered.

6.0 DISCUSSION

Oceanographic instrumentation has advanced considerably in the twenty years since the data that were used here were obtained. In particular, Acoustic Doppler Current profilers (ADCPs) are now commonly used to measure the variation of current speed and direction through the water column. And density stratification can be measured by moored strings of thermistors and conductivity sensors. It is recommended that future measurements be made with these types of instruments to allow for improved reliability of the dilution simulations of wastefield behavior.

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APPENDIX A – OCEANOGRAPHIC DATA

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Extensive oceanographic data were obtained in the area around SWOO in 1987 and 1988. Field data collections involved extensive current, temperature and conductivity measurements from recording current meters, wind measurements, outfall dye injection and tracing studies, receiving water monitoring of bacteria, and surveys of shoreline beneficial uses. This appendix provides descriptions of the procedures used in gathering the current meter and seawater density data.

Currents and Density Stratification – Continuous Array

Thirteen months of continuous measurements of currents, temperature, and conductivity were collected near the Southwest Ocean Outfall diffuser. Three InterOcean electromagnetic S4 current meters were deployed at various depths on one array cable for the entire study period. In addition, current meters were deployed at two or three depths on five other moorings during for two "critical periods."

The continuous array was deployed at Station A, 500 meters northwest of the diffuser end gate, from June 19, 1987 to July 18, 1988 (Figure 1). This station was deployed at the same depth contour as the outfall diffuser (24 meters, 78 feet). The array location was selected to provide physical data representative of the receiving waters at the outfall diffuser, but sufficiently distant to avoid distortion of conductivity values by mixing processes.

The array at Station A consisted of three current meters designated AI (near-surface) at 8 meters (25 feet) depth, A2 (mid-depth) at 14 meters (45 feet), and A3 (near bottom) at 20 meters (65 feet). The array deployment depth and the current meter depths are relative to Mean Lower Low Water (MLLW). The Station A array design, shown in Figure 2-2, consisted of a steel sub-surface buoy with 250 pounds of buoyancy at 6 meters (18 feet) depth, connected to the cable with three S4 meters, and then connected to 1,500 pounds of anchor weight. Two soldier spar buoys were deployed at 100 foot distances northwest and southeast of the main array (along the same contour) to provide additional marking for vessel traffic to avoid the array. The deployment history of the array is provided in Table A-2. The data retrieval history of each current meter is shown in Figure A-3.

The current meters were equipped to record physical parameters including current speed and direction, conductivity, and temperature. In addition, meter AI was equipped with a tilt sensor and meter A3 was equipped with a high-resolution depth sensor.

Current speed was measured with a 2-axis electromagnetic sensor with a range of zero to 350 cm/sec, a resolution of 0.2 cm/sec, and an accuracy of 2 percent (1 cm/sec). When equipped with a tilt meter the current speed is internally corrected. Current direction is

measured with a flux-gate compass with a resolution of 0.5 degree and an accuracy of 2 degrees. The compass can operate at this accuracy for tilts of up to 25 degrees.

Temperature and conductivity sensor specifications for the probes employed were: 1) standard temperature sensors had a resolution and accuracy of 0.05 degrees C and 0.2 degrees C, respectively, with a range of -5 to 45 degrees C; and 2) the standard conductivity sensor had a resolution of 0.1 mS/cm, an accuracy of 0.2 mS/cm, and a range of 5 to 70 mS/cm.

All instruments were set to switch "ON" for 3 minutes for every 15-minute interval. During the switch "ON" time the instrument takes 360 readings (one every 0.5 second) for each of the preset parameters. It then records the average for this 3-minute period. Thus, in any given 24-hour period there are 96 sets of records based on a total of 34,560 readings for each variable recorded.

Data were stored in the instrument until recovered. The data files contain a header with a format in the form shown in Table A-1. Data information is recorded in a binary format with each record occupying 2 bytes.

Table A-1 S4 Current Meter Data Files Header 2030 Sewer System Master Plan City and County of San Francisco										
InterOcean Systems, Inc. Model S4 Current Meter Serial Number: 04911013										
Header	SFO-CURRENTS-A3									
Cycle	On for 0 days, 0 hr, 3 min Every 0 days, 0 hr, 15 min									
Average Count	360									
Channels at Average	1 2 3 4 5 6									
SRB Count	24									
Channels in SRB	1									
Sensitivities	X = 239 Y = 235									
Offsets	X = 1,745 Y = 1,763									
Battery Type	L									
Date Installed	06/15/87									
Half Second Count	33502									
Bytes Written Count	2034									
Date of Data Block	06/18/87									
Time of Data Block	10:04									

Special record blocks (SRBs), created for better data management, are contained within the file. SRBs include a record of month, date, year, hour, minute, and other user-selectable variables. All data recovered were archived in the above format. The S4 applications software program (APPIBM) was used to set up the meters for deployment, retrieve data from the meters in the field, and output data.

Table A-2	Table A-2 Deployment History For Station A Current Meter Arrays (June 1987 to July 1988) 2030 Sewer System Master Plan												
		•		n Francisc	0								
Station	Date	Start				End		Total	File	Comments			
		Time	No.	Date	Time	No.	Data	Readings	Name				
		(PST)			(PST)		Channels						
A 1	06/19/87	0924	93	07/20/87	0954	3071	5	14895	Jul-A1	A2 densities higher than			
A 2	06/19/87	0929	92	07/20/87	0959	3070	4	11916	Jul-A2	bottom			
A 3	06/19/87	0922	94	07/20/87	0952	3072	5	14895	Jul-A3	densities, only A1 and A3 usable.			
A 1	07/20/87	1608	3	08/02/87	0908	1222	5	6100	Aug-A1	A2 temperature sensor failed			
A 2	07/20/87	1617	10	07/27/87	0102	621	4	2448	Aug-A2	after a few days			
A 3	07/20/87	1607	9	07/26/87	0237	531	5	2615	Aug-A3	arter a rew days			
A 1	08/17/87	1123	9	08/19/87	0823	189	5	905	Sep-A1	A1 and A3 failed after a few			
A 2	08/17/87	1123	7	08/19/87	0823	187	4	724	Sep-A2	days			
A 3	08/17/87	1121	5	08/19/87	0821	185	5	905	Sep-A3	udys			
A 1	-	-	-	-	-	-	5	-	Aug2-A1				
A 2	08/19/87	1029	5	09/09/87	0919	1673	4	6676	Aug2-A2	?			
A 3	-	-	-	-	-	-	5	-	Aug2-A3				
A 1	09/25/87	1600	7	10/30/87	0900	3339	5	16665	Oct-A1	First critical period. A3 failed			
A 2	09/24/87	1712	4	10/30/87	0912	3442	4	13756	Oct-A2	after a few days.			
A 3	09/24/87	1704	3	10/30/87	1904	659	5	3285	Oct-A3				
A 1	10/30/87	1247	4	11/18/87	1003	1817	5	9070	Nov-A1	A2 failed after a few days.			
A 2	10/30/87	1259	10	11/06/87	1514	691	4	2728	Nov-A2	Bottom densities lower than			
A 3	10/30/87	1249	5	11/18/87	1004	1818	5	9070	Nov-A3	surface densities.			
A 1	11/18/87	1314	4	12/18/87	0944	2870	5	14335	Dec-A1	A2 densities higher than			
A 2	11/18/87	1314	6	12/18/87	0944	2872	4	11468	Dec-A2	bottom densities, only A1 and			
A 3	11/18/87	1314	5	12/18/87	0944	2871	5	14335	Dec-A3	A3 usable.			
A 1	12/18/87	1457	4	1/22/88	1312	3557	5	16770	Jan-A1	A2 densities higher than			
A 2	12/18/87	1448	4	1/22/88	1319	3358	4	13420	Jan-A2	bottom			
A 3	12/18/87	1447	5	1/22/88	1317	3359	5	16775	Jan-A3	densities, only A1 and A3 usable.			
A 1	01/22/88	1654	7	2/22/88	1139	2957	5	14755	Feb-A1	A2 densities higher than			
A 2	01/22/88	1651	4	2/22/88	1836	2955	4	11808	Feb-A2	bottom			
A 3	01/22/88	1655	8	2/22/88	1040	2959	5	14760	Feb-A3	densities, only A1 and A3 usable.			

Table A-2	2030 Sewer System Master Plan														
	City and County of San Francisco														
	-	_	Start			End									
A 1	02/22/88	1359	6	3/17/88	1044	2297	5	11460	Mar-A1	A2 densities higher than					
A 2	02/22/88	1346	6	3/17/88	1031	2297	4	9168	Mar-A2	bottom					
A 3	02/22/88	1353	5	3/17/88	1038	2297	5	11465	Mar-A3	densities, only A1 and A3 usable.					
A 1	03/17/88	1445	7	4/21/88	0900	3344	5	16690	Apr-A1	Intermittent temperature.					
A 2	03/17/88	1434	5	4/21/88	0904	3343	4	13356	Apr-A2						
A 3	03/17/88	1440	6	4/21/88	0910	3344	5	16695	Apr-A3						
A 1	05/9/88	0848	682	6/03/88	1003	3087	5	12030	May-A1	Second critical period. Usable					
A 2	05/9/88	0848	682	6/03/88	1003	3087	4	9624	May-A2	data.					
A 3	05/9/88	0848	682	6/03/88	1003	3087	5	12030	May-A3						
A 1	06/03/88	1318	4	7/18/88	0833	4305	5	21510	Jun-A1	A2 and A3 sensors bad.					
A 2	06/03/88	1318	3	7/18/88	0833	4305	4	17212	Jun-A2						
A 3	06/03/88	1318	3	7/18/88	0833	4305	5	21515	Jun-A3						

Table A-3 **Critical Period Deployments of Current Meters** 2030 Sewer System Master Plan City and County of San Francisco

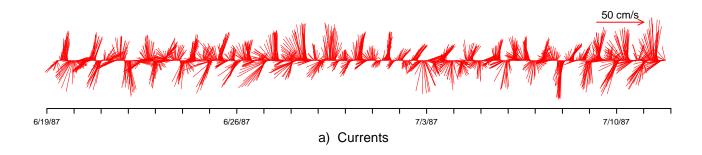
			Start			End		Data	Total	
Station	Depth m (ft)	Date	Time ⁽¹⁾	No.	Date	Time ⁽¹⁾	No.	Channels	Readings	File Name
Septembe	er to October 1987									•
A1	7.6 (25)	09/25/87	1600	7	10/30/87	0900	3339	5	16665	Oct-A1
A2	13.7 (45)	09/24/87	1712	4	10/30/87	0912	3432	4	13716	Oct-A2
А3	19.8 (65)	09/24/87	1704	3	10/01/87	1904	659	5	3285	Oct-A3
B1	7.6 (25)	09/26/87	0933	167	10/28/87	1448	3260	4	12376	Oct-B1
B2	13.7 (45)	-	-	-	-	-	-	4	-	Oct-B2
C1	7.6 (25)	09/26/87	0903	165	10/28/87	1533	3262	4	12392	Oct-C2
D1	7.6 (25)	09/25/87	1848	108	10/28/87	1133	3247	4	12560	Oct-D1
E1	7.6 (25)	09/25/87	1248	84	10/28/87	1048	3244	4	12644	Oct-E1
E2	13.7 (45)	09/25/87	1248	84	10/28/87	1048	3244	4	12644	Oct-E2
E3	19.8 (65)	09/25/87	1248	84	10/28/87	1048	3244	4	12644	Oct-E3
F1	7.6 (25)	-	-	-	_	-	-	4	-	-
F2	13.7 (45)	-	-	-	-	-	-	4	-	-
May to Ju						l	L			1
A1	7.6 (25)	05/09/88	0848	682	06/03/88	1003	3087	5	12030	May-A1
A2	13.7 (45)	05/09/88	0848	682	06/03/88	1003	3087	4	9624	May-A2
A3	19.8 (65)	05/09/88	0848	682	06/03/88	1003	3087	5	12030	May-A3
B1	7.6 (25)	04/27/88	1003	15	06/03/88	1048	3570	4	14224	May-B1
B2	13.7 (45)	04/27/88	1003	16	06/03/88	1048	3571	4	14224	May-B2
C1	7.6 (25)	04/27/88	1018	16	06/03/88	2003	3223	4	12832	May-C1
D1	7.6 (25)	04/27/88	0933	77	06/03/88	1348	3645	4	14276	May-D1
E1	7.6 (25)	04/26/88	1517	8	06/04/88	1047	3733	4	14904	May-E1
E2	13.7 (45)	04/26/88	1520	9	06/04/88	1050	3734	4	14904	May-E2
E3	19.8 (65)	04/26/88	1518	9	06/04/88	1048	3734	4	14904	May-E3
F1	7.6 (25)	04/26/88	1619	11	06/03/88	1434	3652	4	14568	May-F1
F2	13.7 (45)	04/26/88	1618	11	06/03/88	1433	3652	4	14568	May-F2
Note:		3 23. 30	.0.0	•••	30,00,00	1 1100		•	1	a, . =

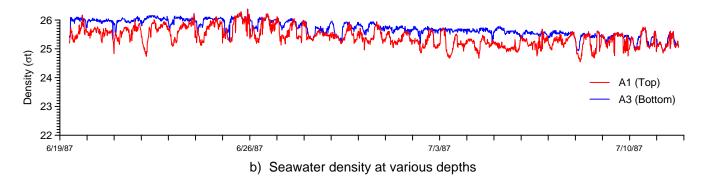
Note:

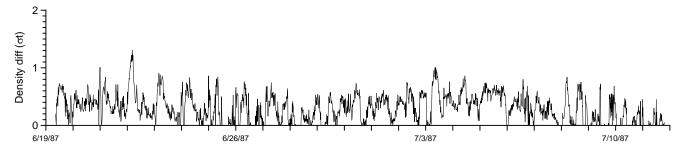
Pacific Standard Time

Data Processing

Further manipulations of the data files at mooring A were done as part of the present modeling project. First, the binary data files (e.g. JUL-A1.s4b) were converted to ACIII files (e.g. JUL-A1.txt) by the supplied program AS4NEW. The ASCII files were then rewritten into a more convenient format with dates and times of each measurement (e.g. JUL-A1x.txt) by a Fortran program, ReadS4Text. The three data files were then combined into an Excel workbook (e.g. JUL.xls) containing worksheets for each depth, and manually edited to remove spikes, etc, to have common start and end date and times for the current, temperature, and salinity data. Finally, the worksheets were exported into text files of currents and density stratification (e.g. JUL-Currents.prn and JULDensity. prn) for use in Nrfield. The files which had usable data were Jul and Dec (1987) and Jan, Feb, Mar, and May (1988). The actual data are plotted in the following figures.

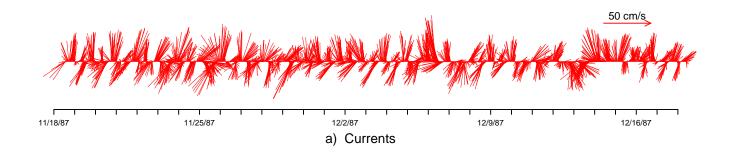


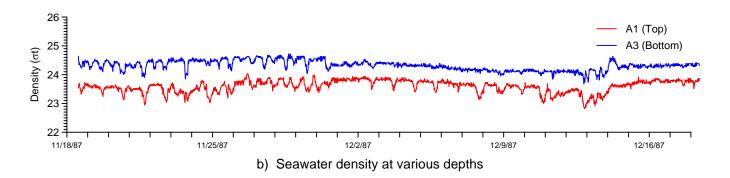


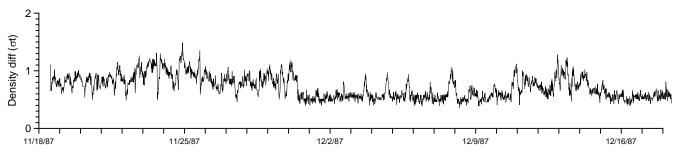


c) Density difference between top and bottom sensors

Jul Data Files Used in Nrfield Simulations

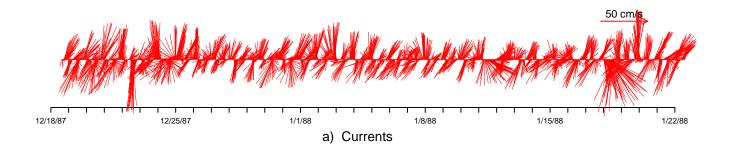


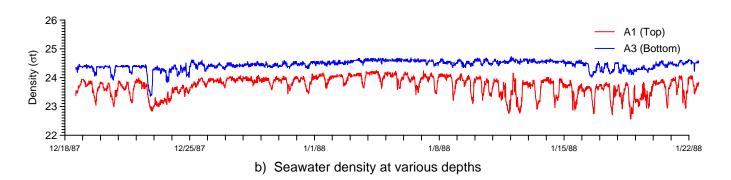


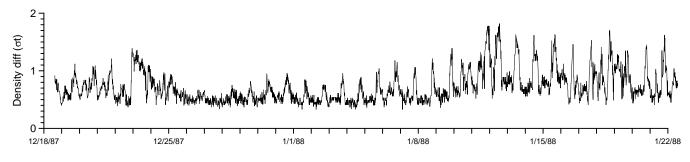


c) Density difference between top and bottom sensors

Dec Data Files Used in Nrfield Simulations

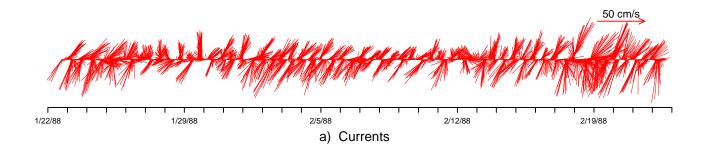


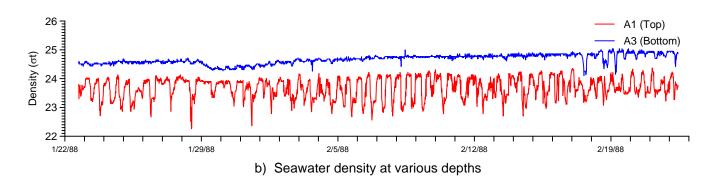


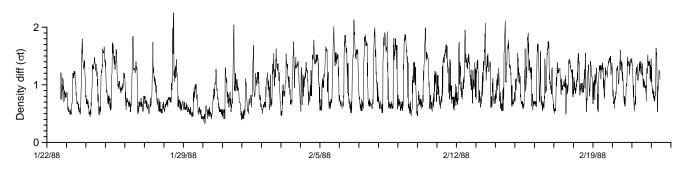


c) Density difference between top and bottom sensors

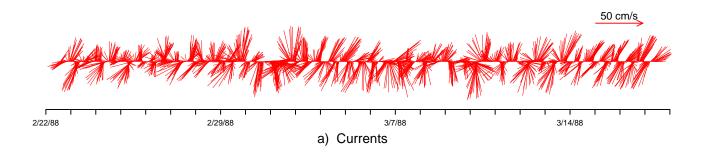
Jan Data Files Used in Nrfield Simulations

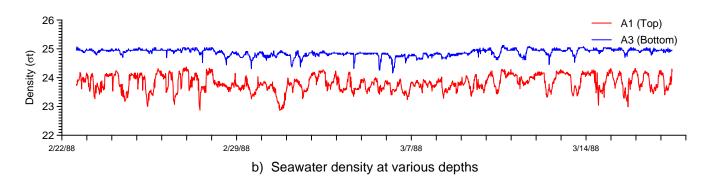


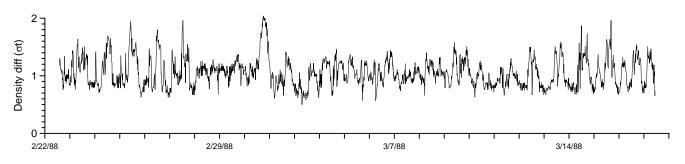




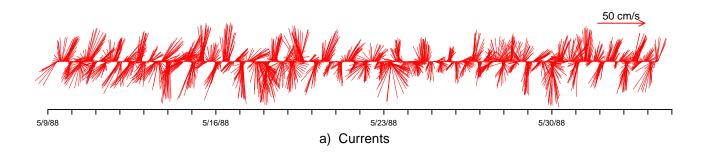
c) Density difference between top and bottom sensors

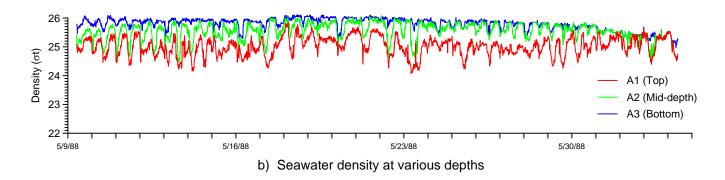


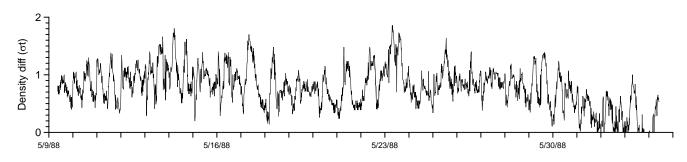




c) Density difference between top and bottom sensors







c) Density difference between top and bottom sensors

APPENDIX B - REGULATORY BACKGROUND AND OUTFALL MIXING PROCESSES

APPENDIX B – REGULATORY BACKGROUND AND OUTFALL MIXING PROCESSES

Because SWOO is beyond the three-mile limit, it is subject to federal water quality regulations as set forth in *Ocean Discharge Criteria at 40 CFR 125.121(c)*. These regulations specify a mixing zone, a limited area where initial dilution takes place and where numeric water quality criteria can be exceeded but acutely toxic conditions are prevented. The dilution factor must be met at the edge of the mixing zone, and so depends on the dimensions of the mixing zone. The *Ocean Discharge Criteria* defines the mixing zone for federal waters as:

"The zone extending from the sea's surface to seabed and extending laterally to a distance of 100 meters in all directions from the discharge point(s) or to the boundary of the zone of initial dilution as calculated by a plume model approved by the director, whichever is greater..."

The federal regulations do not specify how the dilution calculations are to be done, so judgment is necessary to decide which oceanographic conditions, density stratification, flow rates, and averaging times are used.

The U.S. EPA maintains two water quality criteria for toxic substances (U.S. EPA, 1991). The CMC (Criteria Maximum Concentration) is for protection of the aquatic ecosystem from acute or lethal effects; the CCC (Criteria Continuous Concentration) is for protection from chronic effects. The CCC is like a regular water quality standard and must be met at the edge of the mixing zone. It is "...intended to be the highest concentration that could be maintained indefinitely in a receiving water without causing an unacceptable effect on the aquatic community or its uses". The CCC limits may be sometimes exceeded, as organisms can tolerate higher concentrations for short periods so long as peak concentrations are limited. In other words, the CCC relates to average concentrations, which are in turn related to time-averaged dilutions. It is assumed that the CCC are the appropriate water quality criteria to apply to the outfall to protect the aquatic ecosystem from chronic effects.

The terminology used for mixing processes and regulatory purposes are not consistent and require further explanation. The processes governing effluent mixing are complex, and are described in many papers, for example Roberts (1996) and Wood et al. (1993).

Because the density of domestic sewage is close to fresh water (around 998 kg/m₃), it is very buoyant in seawater, whose densities are typically around 1025 kg/m₃. The effluent therefore begins rising after release from the diffuser as a turbulent plume that entrains seawater that rapidly dilutes the wastewater. The individual plumes may also merge. If the density stratification in the receiving water column is weak, the plumes will reach the

surface, but if the stratification is strong, the plumes may be trapped below the water surface. In either case, the turbulence induced by the discharge ultimately decays and the rate of mixing slows considerably. This typically occurs within distances of tens to hundreds of meters from the diffuser. Dilutions achieved within this region are typically of the order of hundreds to even thousands to one. The region in which these processes occur is often referred to as the near field. This is defined as the region where dilution is effected by turbulence generated by the discharge itself and other processes that are associated with the discharge, such as internal hydraulic jumps. It is thus distinct from the "far field" where dilution is due to ambient (oceanic) turbulence and where mixing proceeds at a much slower rate than in the near field. Because the near field is defined by physical processes, it is referred to as a hydrodynamic mixing zone, as opposed to a regulatory mixing zone, which is defined by some arbitrarily specified distance.

The *Ocean Discharge Criteria*, and also the EPA 301(h) regulations (U.S. EPA, 1994) refer to initial dilution. In the 301(h) regulations the *Zone of Initial Dilution (ZID)* extends to a fixed distance (equal to the water depth) from the diffuser. It is therefore a regulatory mixing zone. The *Ocean Discharge Criteria*, however, refer to "...the boundary of the zone of initial dilution *as calculated by a plume model*" implying that it is a hydrodynamic mixing zone.

Further difficulties are caused by differing definitions of dilution. Dilution is sometimes computed as a flux-averaged value. This apparently follows from the wording in the California Ocean Plan (SWRCB, 1997), which specifies "...the lowest average initial dilution..." which is usually assumed to refer to a flux-averaged value. The flux average is difficult to measure in the field or laboratory, however, and the dilution values reported in such experimental studies are the minimum values (similar to centerline dilution). A more defensible and measurable definition of dilution is therefore the minimum value. Earlier mathematical models were conservative in not including additional mixing due to such processes as internal hydraulic jumps, and minimum dilutions predictions.

In this report, the term near field is used for the region where dilution is effected by turbulence generated by the discharge itself and other processes that are associated with the discharge. "Dilution" refers to minimum values, so near field dilution is the minimum dilution occurring through the water column at the end of the near field.