Appendix D1

Far-Field Analysis of Brine Discharge

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memorandum

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to Eric Zigas

from Pablo Quiroga

subject Monterey Peninsula Water Supply Project – Dispersion and Dilution Analysis of the Brine Discharge

1. Introduction

ESA PWA has prepared this technical memorandum to present and describe the results of a water quality study of the hypersaline discharge (subsequently referred to as "brine discharge") associated with the desalination plant component of the CalAm-proposed Monterey Peninsula Water Supply Project (MPWSP). The objective of the water quality study was to investigate the mixing and transport of the brine plume upon discharge into Monterey Bay. Recent research on brine discharges from desalination plants stresses that appropriate discharge site selection, modeling of ocean currents, and proper plant maintenance and operation can minimize the spatial extent of the ecological effects of a brine discharge (Roberts, *et al* 2010). The total dilution of the brine discharge can be divided into near- and far-field[1] mixing zones. The near- and far-field dilution processes are affected by various forces and stressors acting at different times and spatial scales. The near-field modeling was completed by Flow Science in Pasadena, CA, and their report is included as Appendix A. The far-field modeling and the total dilution of the brine plume was completed by ESA PWA, and was used to determine the fate of the brine as it continues to slowly dilute in the ocean (far-field). This study also addresses the comments received during the MPWSP EIR scoping period concerning the fate and transport of the brine discharge plume beyond the near-field.

ESA PWA conducted the far field analysis by modeling the mixing and transport processes of the brine plume upon its discharge into the Bay and by analyzing how factors such as the bathymetry, open water circulation, wave effects, and other important oceanographic processes affect the dilution of the brine plume. This technical memorandum was prepared with assistance from Doug George and Elena Vandebroek, P.E. review was conducted by To Dang, Ph.D. and Bob Battalio, P.E.

Section 1 provides an introduction to the proposed project and an overview of the existing State regulations and the terminology and guidelines related to the brine discharge and ocean diffuser characteristics. Following the introduction, Section 2 describes and characterizes the ocean climate and water quality conditions in Monterey Bay. Section 3 describes the project conditions and the scenarios evaluated in this study as well the assumptions

1 The terms near-field and far-field are discussed in further detail in the following section.

and uncertainties of the methodology used. Section 4 describes the mixing processes, the methodology used to evaluate the far field, and the effects of ambient parameters such as bathymetry, currents and waves. Section 5 presents the results of the mixing analysis in terms of the total dilution of the brine plume and its salinity. The near-field mixing analysis and results prepared by Flow Science, Inc. are presented in Appendix A and the complete results for far-field and total dilution for the project and all the project variation scenarios are shown in Appendices B through F.

Project Background

Proposed by the California American Company (CalAm), the MPWSP would produce desalinated water, convey it to the existing CalAm distribution system on the Monterey Peninsula, and increase the system's use of storage capacity in the Seaside Groundwater Basin. The MPWSP would consist of several distinct components: a seawater intake system, a desalination plant, a brine discharge system, feedwater and product water conveyance pipelines and storage facilities, and an aquifer storage and recovery (ASR) system. Water drawn from subsurface intake wells would be conveyed to the proposed desalination plant in Marina. Based on the project information available the desalination plant would operate on a continuous basis throughout the year and achieve a 42% recovery of freshwater from seawater, producing 9.6 million gallons per day (MGD) of potable water and generating 13.98 MGD of brine discharge with an expected salinity that varies between seasons from 57.4 to 58.2 ppt., which would be discharged into Monterey Bay through the existing Monterey Regional Water Pollution Control Agency's (MRWPCA) regional wastewater treatment plant outfall.

In addition to the MPWSP, CalAm has also proposed a variation of the project (MPWSP Variant or project variant) that would combine a reduced-capacity desalination plant (a 6.4-mgd plant instead of the 9.6-mgd plant proposed under the project) with a water purchase agreement for 3,500 acre-feet per year (afy) of product water from the MRWPCA-proposed Groundwater Replenishment (GWR) project. This technical memorandum studies the fate and transport of the brine discharge from the MPWSP (proposed project), and the Project Variant.

Approach to the Study

The approach to the study is guided by the State Water Resources Control Board (SWCRB)'s regulations for discharges from desalination plants and from published research literature on brine discharges. The SWRCB's Ocean Plan establishes effluent quality requirements and management principles for specific waste discharges. Point discharges such as the brine discharge from the MPWSP desalination plant would be considered as "waste discharge" in the ocean waters as described in the Ocean Plan (SWRCB, 2013). The Ocean Plan amendments proposed that a brine discharge should meet an absolute increment of no more than 2 parts per thousand (ppt) above the naturally occurring ambient seawater within 100 m (SWRCB, 2014). The water quality analyses in this report focus on clearly-defined spatial extents for mixing of discharged brine with ambient seawater based on the literature and regulatory requirements.

The mixing zone is a region of non-compliance and limited water use around the diffuser. It consists of a limited area where rapid mixing takes place and where numeric water quality criteria can be exceeded but acutely toxic conditions[2] must be prevented. Specific dilution factors and water quality requirements must be met at the edge of the mixing zone (SWRCB, 2014). As an approach to the analysis for this study, the water quality objectives must be met at the edge of a regulatory mixing zone or the zone of initial dilution (ZID). The ZID is generally defined by the physical characteristics of a discharge and is limited to the area where the brine discharge

[2] Acute toxicity is defined as the effects of a substance on a biological species (e.g., its mortality rate) resulting from a single or multiple exposures of the substance in a short time period (usually less than 24 hours).

undergoes turbulent mixing. The size of the zone of initial dilution is defined in the Ocean Plan (SWRCB, 2012a) as the point where initial dilution is achieved and should not exceed a daily maximum of 2 ppt above the natural ambient salinity at the edge of the ZID. There is no vertical limit for this zone (SWRCB, 2014).

Figure 1 shows a schematic representation of the mixing zones and Table 1 summarizes the different mixing zones, as defined by SWRCB and the Central Coast Regional Water Quality Control Board (in the case of the MPWSP). The mixing zone is often divided into “near field” and “far field” regions, described in Table 1.

TABLE 1
RELEVANT MIXING ZONE TERMINOLOGY*

Term	Definition	Comments
Mixing Zone	A limited area where rapid mixing takes place and where numeric water quality criteria can be exceeded but acutely toxic conditions must be prevented. Specified dilution factors and water quality requirements must be met at the edge of the mixing zone.	
Regulatory mixing zone	As defined by the appropriate regulatory authority	Can be a length, an area, or a volume of the water body
Near field	Region where mixing is caused by turbulence and other processes generated by the discharge itself	Near field processes are intimately linked to the discharge parameters and are under the control of the designer. for further discussion, see Doneker and Jirka (1999), Roberts and Sternau (1997), and Roberts et al. (2010).
Far field	Region where mixing is due to ambient oceanic turbulence	Far field processes are not under control of the designer
Zone of initial dilution (ZID)	A region extending over the water column and extending up to one water depth around the diffuser	A regulatory mixing zone, as defined in the U.S. EPA's 301(h) regulations (USEPA 1994)

* Extracted from Table D-1, SWRCB, 2012a

This study assesses the expected salinity of the discharge relative to the ambient seawater in the far field, based on available observations and from outputs of a publically available numerical model used to assess regional ocean climate in Monterey Bay. As discussed later (Section 4), the far field methodology was informed by the project conditions such as the operational characteristics of the desalination plant and the near-field study on the brine discharge prepared by Flow Science, Inc. (2014).

2. Ocean Climate and Water Quality Conditions in Monterey Bay

Regional Ocean Climate

The regional ocean climate in Monterey Bay can be described through the three known ocean climate seasons: 1) a wind-induced upwelling[3] period; 2) a wind-relaxed oceanic period when upwelling ceases, and; 3) a current-reversal period known as the Davidson period (Broenkow, 1996). Early oceanographic studies inside Monterey Bay used the terms “cold water phase” or “upwelling period” for the months between mid-February to September when cool surface waters were found in Monterey Bay; the “warm water phase” or “oceanic period” between mid-August to mid-October; and the “low thermal gradient phase” or “Davidson Current period” between December and mid-February. These oceanic climate seasons overlap extensively and do not recur with exact consistency. Although local winds (typically directed oblique to the shoreline) drive upwelling along most of the

[3] Upwelling is an oceanographic phenomenon were wind blowing across the ocean surface pushes the warm water of the surface, then the deep cold water rises toward the surface to replace the water that was pushed away.

California coast, this is not the case inside Monterey Bay (Rosenfeld et al., 1994), where winds are more westerly (shore-perpendicular) owing to the shape of the mountains in the Salinas Valley. At a larger, regional scale, upwelling does occur, and the waters inside the Bay overturn as a result. The Monterey Submarine Canyon also helps deliver deep cold water to the Bay by providing a conduit for water transport during the upwelling period. When upwelling ceases towards the end of summer, the sea level along the coast and inside Monterey Bay rises and the southward-directed California Current slows. Later in the year (typically November), winter storms bring occasional strong winds flowing southward while the surface current flows northward. This is called the Davidson Current and it is the surfacing of the California Undercurrent.

This study was conducted using the following series of three months that correspond with the seasonal ocean climate conditions: June to August for the upwelling season, August to October for the oceanic season and December to February for Davidson (see Table 2). The nearest observation station to the point of brine discharge that contains data to explore the different seasons is a conductivity-temperature-depth (CTD) station called C1, operated by the Monterey Bay Aquarium Research Institute (MBARI, 2013) since 2002. It is located approximately five miles north (36.797˚N, 121.847˚W) of the wastewater ocean outfall. Figure 2 shows an overview of the study area and the location of the C1 station.

TABLE 2
OCEAN CLIMATE SEASONS IN MONTEREY BAY

Oceanic Phase	Short Description	Time Period	Scenario Dates	Mean Ambient Temperature (°C)*	Mean Ambient Salinity (ppt)*
Upwelling	Characterize by cold and warm temperatures, salty water (high salinity) and strong currents	Mid February to September,	June to August 2011	11.2 (52.2 ºF)	33.8
Oceanic	Warmer water temperatures and fresh water (low salinity), with average currents	Mid-August to mid-October	August to October, 2011	12.1 (53.8 ºF)	33.6
Davidson	Cold water temperatures, fresher waters (lower salinity) and slow currents	December through mid-February	December 2011 to February 2012	11.2 (52.2 ºF)	33.4

* Temperature and Salinity mean values were estimated at the discharge point at depth = 30 m using ROMS model data for the described scenario dates.

Ocean Circulation and Water Quality

In addition to the climate conditions, ocean circulation in Monterey Bay was studied by reviewing the seasonal distribution of temperature, salinity and currents in the study area and at the point of brine discharge through the outfall (see Figure 3). ESA PWA used the Regional Ocean Modeling System (ROMS) implemented in Monterey Bay to define the seasonal distribution. The Monterey Bay ROMS model was developed by the NASA Jet Propulsion Laboratory in Pasadena, CA, and made available through the National Oceanic and Atmospheric Administration (Chao *et al*., 2009, CenCOOS, 2013).

The Monterey Bay ROMS Model has three computational domains – the U.S. West Coast, the central California coast, and Monterey Bay – nested together with grid cell resolutions of 15 kilometers ([km] or ~49,213 feet), 4 km (~13,123 feet) and 1.5 km (~4,921 feet) [4] respectively. The three nested models have 32 vertical layers to produce snapshots of the state of the ocean every 6 hours. The model was forced by oceanographic and

4 1 kilometer = 3,280 feet

atmospheric variables calibrated to observation stations throughout Monterey Bay. The Central and Northern California Ocean Observing System (CeNCOOS) provided ocean circulation data from October 2010 to January 2013 (L. Rosenfeld, pers. comm.). Chao *et al* (2009) provide a more detailed description and validation of the model. Subsequent analysis of the data showed a nearly complete data set from January 2011 to March 2012, with data output every 6 hours at 03, 09, 15 and 21 GMT (19, 01, 07, and 13 PST); data from this time segment (January 2011-March 2012) were used for this study to describe the annual distribution of temperature, salinity and currents in the study area. A representative temperature, salinity, and density profile was determined using the ROMS data from June 2011 through February 2012 and was used to describe conditions for each of the three seasons at the outfall for the upper 98 feet of the water column (Figure 3). Water in the Davidson period (December – February) is the coldest and freshest, while it is the saltiest during upwelling (February – September) and warmest in the oceanic (August – October). The subsequent densities show the oceanic, Davidson and upwelling profiles in that order for increasing density. A time series of the temperature and salinity at the outfall location (depth = - 98 ft.) was extracted from the ROMS model to characterize the annual variability from January 2011 through February 2012 (Figure 4). The temperature varied between 8.5 and 15.2 degrees C (47.3 to 59.4 °F) with a mean of 11.3 degrees C (52.3 °F), while salinity showed a natural variability[5] of 3.3% with a range of 33.1-34.2 ppt and a mean of 33.6 ppt.

For standardization of the oceanographic variables used for this study, the two parameters salinity and temperature were converted to Absolute Salinity and Conservative Temperature based on the International Thermodynamic Equations of Seawater or TEOS (TEOS-10, 2010). When the two parameters were plotted with density contours (often called a T-S plot), the difference among the water masses during the different oceanic conditions was apparent (Figure 5). The three ocean climates (Table 2) were discernible as both parameters shifted concurrently from cool and fresh (during Davidson) to cold and salty (during Upwelling) then warm and fresh (during Oceanic). In general, the densest water occurs during the upwelling period and the least dense water is observed during the oceanic period. There is more variability during the upwelling period than during the other two. The importance of the ambient temperature and salinity conditions (e.g. Figure 5) to dilution of the brine discharge is discussed further in Section 5.

In addition to the temperature and salinity, annual and seasonal oceanic current patterns were extracted from the ROMS model at the discharge location at the surface (Figure 6) and at a water depth of 98 feet (Figure 7). The currents in the figures are shown according to the oceanographic convention showing the direction of the mass flow (i.e., the direction the currents move toward). On an annual basis, the directions of the surface currents show a mostly uniform distribution with velocities of commonly less than 0.5 feet per second (ft/s). On a seasonal basis, the dominant current direction varies widely. Currents during the Davidson period are mostly southwest-northeast, while during the upwelling period, average currents of 0.3 ft/s are mostly directed to the northeast, with occasional bursts up to 1.6 ft/s. The dominant directions for the oceanic period are northeast, southeast and northwest with velocities mostly less than 0.3 ft/s. At 98 feet of water depth, the currents show stronger seasonal signals and are slower than at the surface. Annually, the dominant current directions are northeast-southwest with a more northeasterly prevalence; velocities are mostly less than 0.4 ft/s but can reach above 0.65 ft/s toward the southwest. The Davidson period currents are the slowest and show a relatively uniform distribution of directions. These currents are typically less than 0.2 ft/s and are directed to the north and south. The upwelling period (mid-February to September) shows the fastest currents of up to 0.79 ft/s to the southwest even while a higher proportion of the currents head to northeast at approximately 0.2 ft/s. The currents during the oceanic period show similar directionality and magnitude as the upwelling but do not reach the same velocities.

[5] Natural variability = (Maximum Salinity – Minimum Salinity) / Average Salinity.

3. Study Conditions

Once the brine is discharged from the desalination plant, the extent of the mixing of the brine depends on its flow rate (related to the capacity of the desalination plant), the diffuser design through which it is discharged, the receiving waters and the hydrodynamics of the environment (related to the features such as the bathymetry and the ocean climate conditions). The near field methodology was based on ambient ocean conditions and operational conditions of the proposed project. The methodology for the far field also considered ocean currents.

Project Conditions

Treated wastewater from the MRWPCA regional wastewater treatment plant is discharged through the existing 2.1-mile-long outfall pipeline that terminates at a 1,100-foot-long diffuser resting at approximately 4 feet[6] above the ocean floor. The diffuser is equipped with 172 ports (120 ports are open and 52 are closed, each oriented perpendicular to the pipe with a 0 degree angle from horizontal). Each port has a 2-inch diameter (d) and is spaced 8 feet apart, on alternating sides of the pipe. The open ports are fitted with TideFlex duckbill check valves that aid in dilution (See Appendix A for details). At the diffuser location, the water depth ranges from 94 to 108 feet; this study assumes a constant depth of 98 feet for all 120 open ports. Two flow rates are considered for the proposed project: the brine-only discharge with a total flow rate of 162 gallons per second (gal/sec) and brine-with-wastewater discharge at 391 gal/sec (hypo-saline discharge). An even flow rate is assumed across all the ports, with a flow rate per port of 1.35 gal/sec for the brine-only discharge and 3.25 gal/sec for the brine with wastewater discharge. Two flow rates are also considered for the project variant: the brine-only discharge for the small plant with 104.1 gal/sec and 112.5 gal/sec for the small plant with GWR. The assumed flow rate per port is 0.87 gal/sec for the brine-only small plant and 0.94 gal/sec for the small plant brine discharge with GWR. During the irrigation season (summer months), there may be days when all of the wastewater flows are provided to irrigators, and only the project brine would be discharged into Monterey Bay through the outfall. Therefore, this study assumes that the brine would be discharged without dilution during the entire irrigation season (dry months) and the combined discharge (i.e., the brine-with-wastewater) would be discharged during the non-irrigation season (wet months) only, this corresponds to the Davidson phase (December-February). The brine only discharge (sinking or negatively buoyant plume) was evaluated for all three oceanic seasons, and the brine with wastewater discharge (rising or positively buoyant plume) was evaluated for the Davidson season by the Flow Science study, Appendix A. Table 3 summarizes the discharge and ambient flow parameters evaluated in this study.

Scenario Design, Assumptions and Uncertainties

The far-field analysis was developed by modeling the brine plume in the form of individual particles, where each brine particle was released from the diffuser at regular time intervals for a particular time period over an oceanic climate season (defined in Table 2). The particle modeling was conducted using different project scenarios to incorporate the various desalination plant operations and capacities under different ocean climate conditions, while considering the specific regulatory thresholds for water quality concerns. Table 4 summarizes the intake volume, the volume of (desalinated) water produced and the volume discharged (brine) through the MRWPCA outfall for the Proposed Project (9.6 mgd desalination plant), Project Variant (6.4 mgd desalination plant and GWR) and the 6.4 mgd desalination plant only.

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6 Most open diffuser ports are 4.0 feet above seafloor, while 19 ports are about 3.5 feet above seafloor.

TABLE 3
DISCHARGE AND AMBIENT FLOW PARAMETERS FOR THE FOUR SCENARIOS OF THE PROPOSED MPWSP

Ocean Seasons	Davidson 1	Davidson 2	Upwelling	Oceanic
Discharge Flow Parameters[1]				
Discharge Type	Brine + Wastewater	Brine Only	Brine Only	Brone Only
Total Discharge Q_{total} (mgd)	33.76	13.98	13.98	13.98
Discharge per Port $Q_{perport}$ (mgd)	0.28	0.116	0.116	0.116
Discharge Salinity (ppt)	24.2	57.4	58.2	57.6
Discharge Temperature (ºF)	61.9 (16.6 ºC)	52.9 (11.6 ºC)	49.8 (9.9 ºC)	52.0 (11.1 ºC)
Brine Density ρ_d (lb/ft^3)*	63.5 (1,017.2 kg m^{-3})	65.2(1,043.7 kg m^{-3})	65.22(1,044.7 kg m^{-3})	65.2 (1,043.9 kg m^{-3})
Nozzle Velocity U (ft/s)	20.0 (6.1 m/s)	8.1 (2.5 m/s)	8.1 (2.5 m/s)	8.1 (2.5 m/s)
Discharge Densimetric Froude	97.3	26.6	26.15	26.4
Ambient Flow Parameters[2]				
In Situ Ambient Salinity (ppt)	33.36	33.36	33.84	33.5
In Situ Ambient Temperature (ºF)	52.2 (11.2 ºC)	52.2 (11.2 ºC)	52.2 (11.2 ºC)	53.8 (12.1 ºC)
Ambient Density ρ_a (lb/ft^3)*	64.01(1025.2 kg m^{-3})	64.01(1025.2 kg m^{-3})	64.05(1025.6 kg m^{-3})	64.02(1025.2 kg m^{-3})
Average Current Velocity u (ft/s)	0.13 (0.04 m/s)	0.13 (0.04 m/s)	0.23 (0.07 m/s)	0.16 (0.05 m/s)
Ambient Froude Number F_a	0.38	0.38	0.67	0.48

1 Discharge Flow parameters based on proposed project
2 Ambient flow parameters obtained from the ROMS model at the discharge location at 30 m (~98 ft) depth.
** Densities were estimated using the TEOS package (http://www.teos-10.org/) and by converting the salinity and temperature to absolute salinity and conservative temperature.

TABLE 4
PROJECT DESIGNS FOR MODELING

Project Scenario	Nickname	Intake (Source Water) Volume	Production (Product Water) Volume	Outfall (Discharge) Volume
Proposed Project MPWSP Brine Only	Big Plant	24.1 MGD 27,000 AFY 37.29 cfs	9.6 MGD 10,800 AFY 14.9 cfs	13.98 MGD 15,660 AFY 21.6 cfs
Proposed Project MPWSP Brine + Wastewater	Big Plant with Wastewater	24.1 MGD 27,000 AFY 37.29 cfs	9.6 MGD 10,800 AFY 14.9 cfs	33.76 MGD 37,816 AFY 52.2 cfs
Project Variant MPWSP + GWR	Small Plant with GWR	15.5 MGD 17,360 AFY 23.98 cfs	6.4 MGD 7,170 AFY 9.9 cfs	9.72 MGD 10,890 AFY 15.04 cfs
Project Variant (Desalination Plant Only)	Small Plant Only	15.5 MGD 17,360 AFY 23.98 cfs	6.4 MGD 7,170 AFY 9.9 cfs	8.99 MGD 10,070 AFY 13.91 cfs

Units – MGD: million gallons/day, AFY: acre-feet/year, cfs: cubic feet/second

To study the mixing and the dilution of the brine plume, the methodology accounts for dispersion and dilution; both of which are a function of water mass considered as discrete particles in this study. The discrete particle model and the assumptions made for the model are explained in detail in Section 4.2. The modeling of the mixing and transport of the brine plume includes approximations and simplifications of the otherwise complex hydrodynamic process in Monterey Bay. It should be recognized that exact dispersion predictions cannot be made in these complex hydrodynamic situations. However, the methods are based on available literature and established semi-empirical equations (Csanady, 1973, Fischer *et al* 1979, Roberts and Toms, 1987, Roberts and Sternau 1997, Okubo, 1971 and Wesley *et al* 1984*)* and experiments and observations (Ledwell *et al*, 1998, Marti *et al*, 2011 and Okubo, 1971*)* as recommended by Jenkins *et al* (SWRCB, 2012a).

The study assumes that the far-field analysis (this study) continues forward from the point where the near-field analysis ends (Flow Science report [2014], Appendix A). The study also assumes that there is no interaction between the near and far field mixing zones. Conservative assumptions were made throughout this study, including neglect of currents at the initial dilution in the near field as recommended in the literature (Roberts and Sternau, 1997*)* and no vertical mixing of the plume as it travels in the far field. This last assumption, although reasonable at early stages of the brine plume formation due to the presence of density stratification[7] that inhibits vertical mixing, becomes conservative as the plume moves further from the outfall and dilutes on the seafloor. Due to these conservative assumptions, the actual brine concentrations occurring in the ocean are expected to be lower than predicted in this study.

4. Mixing Zone Dynamics

The total dilution of the brine discharge can be divided into near- and far-field mixing zones. The near- and far-field dilution processes are affected by various forces and stressors acting at different time and spatial scales. Figure 8 shows a conceptual diagram of the scale and primary influences of near- and far-field mixing. The near-field modeling was completed by Flow Science in Pasadena, CA, and their report is included as Appendix A. The far-field modeling and the total dilution of the brine plume was completed by ESA PWA.

Dilution of brine discharge with ambient seawater is driven by two main processes: (1) turbulence, which causes mixing (dispersion[8]) and (2) jet momentum and currents in the receiving waters which transport (advect[9]) the brine effluent away from the discharge point. The intensity and characteristics of turbulence change with distance from the discharge point. Following the guidance provided by the Science Advisory Panel on brine discharge (SWRCB, 2012a), the mixing zone of the brine discharged from the proposed desalination plant was analyzed to determine the immediate and localized effects of the brine (near-field) followed by the widespread and slower-moving fate and transport of the brine as the brine continues to dilute in the ocean (far-field).

The Near Field modeling is discussed and summarized below in Section 4.1 with the full report by Flow Science in Appendix A. The Far Field modeling is discussed in Section 4.2, and is described in the body of this report. Using the Near Field calculations as a starting point, this study examines the fate of the brine plume along the seafloor of Monterey Bay. This is an important aspect of the project because of the potential exposure of the pelagic, planktonic and especially benthic organisms to the brine plume. The general physics of near field and far field mixing are described below.

4.1 Near-Field Mixing

Near-field modeling from Flow Science required representative temperature and salinity profiles at the discharge site. These profiles (see Appendix A) were selected by ESA from measurements collected at the C1 station

7 Stratification is the presence of water mass layers separated due to different densities with the densest layer at the bottom.
8 Dispersion is defined as the spreading of mass from an area of higher concentration or accumulation areas to an area of lower concentration.
9 Advection is a transport mechanism of a substance or conserved property by a fluid due to the fluid's bulk motion.

beginning in 2002. The results from the near-field analysis served as the input for the far-field modeling conducted by ESA.

The initial near-field dilution is determined by the outfall design and the discharge characteristics. Near the diffuser, within the initial mixing region (see Figure 8), the velocity and the angle of the jet affects the effluent dilution by inducing shear stress[10]. The local currents also influence the dilution by supplying energy through turbulent (eddying) motions. The near-field region extends from a few feet to tens of feet vertically to tens of feet to a few hundred feet horizontally from the outfall location. The forces acting on the discharge relate to inertia, gravity, viscosity, surface tension, elasticity and pressure. The characteristics of dense plumes, such as brine plumes, are often assessed by comparing the strength of several of these forces. As an example, the Reynolds number (ratio of inertial forces to viscous forces) for the brine jet plume is sufficiently large to indicate that viscous forces can be neglected. When this is the case, the Densimetric (internal) Froude Number (ratio of inertial and gravity forces) is typically used to describe the plume behavior. The Densimetric Froude Number is defined as follows:

$$F = \frac{U}{\sqrt{g_0' d}} \qquad [1]$$

Where,

- U is the discharge jet velocity, *d* is the nozzle diameter and
- g_0' is called the "reduced gravity" or the "modified acceleration due to gravity" and is equal to the following:

$$g_0' = \frac{g(\rho_d - \rho_a)}{\rho_a} \qquad [2]$$

Where,

- g is the acceleration due to gravity,
- ρ_d is the density of the discharge, and
- ρ_a is the density of the ambient water.

A high densimetric Froude Number indicates that the effects of plume velocity are dominant when compared to the effects of gravity and density differences, and mixing with ambient water can be expected (Roberts and Toms 1987; Wesley et al. 1984). Marti *et al* 2011 show that the empirical methods described by Roberts and Sternau, (1997) estimate the dilution as predicted when compared with measurements for flows F > 20 although the thickness of the layer after the initial dilution was underestimated. Lai and Lee, 2012 also show that for flows with F > 20 the dimensionless dilution Si/F approaches a constant. For flows with F < 20 the dilution of the mixing zone is greater than predicted. Table 5 summarizes the near-field modeling results conducted by Flow Science. A buoyant and hypo-saline plume that combines the brine and wastewater was also evaluated for the near field and presented as Davidson 1 on Table 5. Detailed methods and results are presented in the Flow Science report in Appendix A.

[10] Shear stress in fluids is produced by the interaction of two fluids moving at different velocities.

TABLE 5
SEMI-EMPIRICAL METHOD NEAR-FIELD MODELING RESULTS*

Project Scenario	Densimetric Froude Number	Brine Salinity ** (ppt)	Near-Field Dilution Sm	Xm (ft)	Plume Salinity at Xm (ppt)	ppt Above Ambient	Plume Buoyancy Behavior
Proposed Project MPWSP							
Davidson 1 (Jan.)	104	24.23	--		--	--	Positive
Davidson 2 (Jan.)	26.5	57.4	16	12	34.8	1.5	Negative
Upwelling (July)	26.34	58.23	16	12	35.4	1.5	Negative
Oceanic (Sept.)	26.5	57.64	16	12	35.0	1.5	Negative
Project Variant MPWSP + GWR							
Davidson 1 (Jan.)	67.2	20.73	--		--	--	Positive
Davidson 2 (Jan.)	20.2	53.4	17	11	34.6	1.2	Negative
Upwelling (July)	20.1	54.16	17	11	35.0	1.2	Negative
Oceanic (Sept.)	20.17	53.61	17	11	34.7	1.2	Negative
Project Variant Desalination Plant Only							
Davidson 1 (Jan.)	69.5	18.5	--		--	--	Positive
Davidson 2 (Jan.)	17.1	57.4	15	10	35.0	1.6	Negative
Upwelling (July)	16.9	58.23	15	10	35.5	1.6	Negative
Oceanic (Sept.)	17.0	57.64	15	10	35.1	1.6	Negative

*- Conducted by Flow Science. More comprehensive results can be found in Appendix A. The more conservative values of the near-field results were used to determine the total dilution of near- and far-field modeling.
**-Brine Salinity from Flow Science is not yet converted to Absolute Salinity. See Section 3 for conversion equation which was applied for use by ESA.

SOURCE: Flow Science, 2014

The results show that the proposed project and project variant + GWR had flows with F > 20. The small plant only presents a flow with F < 20 which may indicate that the initial dilution for this case is under predicted although it is expected that the dilution will be less than the two other options.

The near-field modeling indicates that the brine plume will reach the seafloor about 10-12 feet (X_m) from the outfall for the different scenarios (Appendix A, Flow Science 2014). The mixing in the near field is estimated to produce a brine plume with salinity of 1.5 ppt above ambient levels for the Proposed Project for the brine only and a hyposaline plume (Davidson 1) when combined with wastewater. For the Project variant a brine plume of 1.2 ppt above ambient is expected due to the pre-dilution (prior to discharge) with fresh water present in the wastewater effluent. The discharge from the Small Plant Only scenario shows a brine plume of 1.6 ppt above ambient, a value that is slightly higher than the other alternatives due to the reduction in the discharge flow rate from 13.98 MGD to 8.99 MGD.

4.2 Far-Field Mixing

Farther from the diffuser, near-field turbulence begins to decay, and the mixing of the brine plume becomes primarily driven by regional turbulence naturally present in the ocean. This region is called the far-field mixing zone (Figure 8). The far-field region overlaps the discharge point and extends from hundreds of feet to several miles. The brine discharge is subject to further dispersion and transport in the environment as the plume continues to traverse the seabed in the form of a density current. The mixing of the plume then depends on the ambient conditions such as bathymetry, currents and waves, and the differences in density (a function of temperature and salinity) between the hypersaline plume and the receiving waters. These transport and dispersion processes are outside the control of the project design, but they are important in determining the changes in the water quality of the brine discharge in a specific area. The ambient conditions that affect the mixing of the brine discharge at the site vary as a result of seasonal weather cycles and may also be modified by global ocean climate events such as El Niño.

After the near-field mixing is complete, the plume is transported through passive advection by the ambient ocean current. A far-field particle tracking model was developed and implemented using the methodology described by Fischer et al. (1979) and Roberts and Sternau (1997). The model assumes that the ocean current is spatially homogeneous but variable with time and the seasons. Diffusion occurs in two dimensions: vertical and lateral, however the model assumes only lateral mixing. The presence of density stratification in the ocean inhibits the vertical diffusion, and therefore, this is a reasonable assumption at early stages of the brine discharge but becomes more conservative (tends to under predict the dilution) as the plume moves further from the outfall and dilutes on the seafloor. Also, the methodology does not account for other drivers of mixing and dilution including large scale motions or external forces such as internal waves or currents induced by wave motions. Implementation of a more sophisticated 3D model would be required to include vertical mixing and near- far field interaction and will likely show higher values of dilution. Due to the minimal dilution assumed, this current approach is considered conservative.

In the model, the mass of the plume is comprised of a number of particles. No interaction between the far-field and near-field is allowed in the model. The model assumes that the ocean currents do not vary spatially throughout the flow field. This assumption is expected to weaken over longer travel times. For this and other reasons, a limited time frame of 48 hours was selected to compute the final salinity concentration of discharged packets of water or “particles” as modeled. The modeling analysis involved releasing a particle of the brine discharge every 30 minutes and following the particle for 48 hours. This was conducted for the length of the season (~90 days), meaning that each discharge was tracked for 48 hours with 90 days of discharge.

A 48-hour window is commonly used as a standard measure of dilution of brine discharges (Roberts and Sternau, 1997, Hodges *et al* 2011) and as a standard for marine toxicity tests on organisms (Pillard *et al*, 1999; Iso *et al*, 1994; Graham, *et al* 2005; Roberts, *et al* 2010). In the case of open coastal areas, the plume size affects the diffusivities leading to accelerated plume growth (or larger plumes), a phenomenon that can be described by the so-called Richardson “4/3 law” of diffusion. The salinity concentration in the plume decreases as the plume expands. The brine dilution ratio is very small in the far-field mixing zone and the flow and mixing characteristics are dominated by large scales (i.e., miles and hours rather than meters and seconds). Batchelor (1952) shows that the rate of increase of dilution (represented by the mean square separation of the suspended solid particles) is equal to the following:

$$\frac{d\overline{s^2}}{dt} \propto \varepsilon^{1/3}\left[\overline{r^2}\right]^{2/3} \qquad [3]$$

Where,

- r is the separation between particles.
- s is the dilution and ds/dt is the rate of change of dilution over time
- ε is the diffusion coefficient

This leads to the “4/3 power law” for diffusion:

$$\text{Diffusion Coefficient, } \varepsilon = \alpha L^{4/3} \qquad [4]$$

Where,

- α is a constant depending on the energy dissipation rate, and
- *L* is a measure of the plume size in units of length, in this case in the horizontal.

Therefore, diffusion increases with the plume size while the salinity concentration decreases. The previous equation is often used for open water and atmospheric diffusion problems. Okubo (1971) have shown from observations of diffusing dye patches in the open ocean that, for engineering purposes, a reasonable estimate for α is given by a value between 0.002 – 0.01 $cm^{2/3}$ per second (s^{-1}) ([1]0.0011 to 0.0054 $in^{2/3}s^{-1}$). Using the 4/3 power law for eddy diffusivity the lateral dilution in a uniform current from Fischer (1979), the lateral diffusion of the far field can be defined as follows:

$$S_f = \left[erf\left(\frac{3/2}{\left(1+8\alpha L^{-2/3}t\right)^3-1}\right)^{1/2}\right]^{-1} \quad [5]$$

Where,

- *erf* stands for the error function often used to model diffusion processes (Fischer, *et al* 1979, Roberts and Toms 1997).

Equation 5 shows that the rate of increase of further dilution with time *t* is thus tempered by both α and *L*. Assuming an upper value for α of 0.01 $cm^{2/3}s^{-1}$ (0.0054 $in^{2/3}s^{-1}$), based on the recommendations of Csanady (1973) and Fischer *et al* (1979) and an initial field width equal to the outfall length (L) of 400 meters (1,312 ft), it provides a lateral diffusion coefficient equal to $\varepsilon = \alpha L^{4/3} = 1.37\ m^2/s$ (14.75 ft^2s^{-1}). This value is on the conservative side and consistent with the findings of Ledwell *et al* (1998) which measured horizontal eddy diffusivity and found coefficients of diffusion in the open ocean on the order of 2 m^2/s at scales of 1-30 km (approximately 0.5 - 18 miles). It is assumed that in the early stages of the dispersal, the lateral diffusion coefficient remains constant (Csanady, 1973) and that the brine plume does not change the ambient salinity. The location of the water particles released at time t < T can be expressed as the velocity multiplied by the time the particle has traveled. For the measured current velocity *u(t)* from $0 < t < T$ is equal to

$$x(t,T) = \int_t^T u(t)dt \quad [6]$$

Where,

- $x = 0$ is the diffuser location and
- the distance *x(t,T)* is a function of $t(0 < t < T)$, which represents the location of the particles released between $t = 0$ and $t = T$.

If $\zeta = T-t$ so that $d\zeta = -dt$. Then, we have

$$x(t,T) = \int_0^{T-t} u(T-\zeta)d\zeta \quad [7]$$

This integral can be obtained from the data by reversing time and integrating backwards. For this case the model was implemented with u(t) sampled every Δt = 30 min from the ROMS data at the outfall location for 90 days (for each season) resulting in a time series $\{u_i\}$ i = 1, 2,…., N. The currents at the proposed brine discharge location have typical mean speeds ranging from 0.13-0.22 ft/s. The speed and direction of the currents are highly variable. The location (i.e., latitude and longitude coordinates) of the brine plume was estimated directly using the ROMS model data of current speed and direction at the outfall location.

$$Lon(t) = x(t) = \sum_{i=1}^{n} u_i \Delta t \quad [8]$$

$$Lat(t) = y(t) = \sum_{i=1}^{n} v_i \Delta t$$

Where,

- *Lon(t)* and *Lat(t)* is the particle (brine particle) location at time t between time t_1 to time $t_1 + n\Delta t$ where n is the total length of the current speed records.

The modeling analysis involved creating thousands of simulated releases by varying the start time t_1, through the whole current time series for the events and computing trajectories up to the time $n\Delta t$. The particle trajectory was considered to be driven by density and limited by the local bathymetry. Bathymetry data from the California Seafloor Mapping Program for Southern Monterey Bay (CSUMB, 2010) were processed to generate a gridded surface with a resolution of 98 feet by 98 feet. This surface was used as an input to the model to determine the depth of the brine particle at every time step and controls the particle trajectory. If the depth of the particle was deeper than the depth of the brine discharge (~-98 feet), the particle was allowed to move in any lateral direction. However, if the particle was moving to shallower waters, it would be going 'up slope'. This was not permitted until it reached a density through dilution that was equal to or less than the mean ambient density plus one standard deviation; at this point the salinity of the brine discharge is assumed to be within the natural variability of the ambient water. When the particle achieves this lower density, it could begin to move again laterally.

Bathymetric Effects on Far-Field Mixing

The seafloor affects ocean circulation and mixing in many ways at different spatial scales. On a large scale, features such as ridges, reefs, and canyons can steer regional currents across the seafloor by influencing the direction of the currents. The diffuser of the MRWPCA outfall is located in Southern Monterey Bay, where the ocean floor gently slopes from east to west (from the shore to approximately 300 feet deep across 8 miles at less than 1 percent slope). The Monterey Submarine Canyon is located north of the diffuser with depths rapidly increasing from approximately 300 feet at the rim to more than 2,000 feet deep in less than 2 miles (16 percent slope). Because the broad flat shelf and the canyon are adjacent to each other, near-bed density plumes could spread downslope across the shelf to the west, or cascade over the canyon rim. Either direction would encourage rapid dilution of the brine plume from shear stresses between the different water masses.

On a small scale, the seabed roughness interacts with the horizontal flow of the brine plume to generate vertical mixing by decelerating the layer of fluid closest to the bed while the upper layers of fluid continue in transit. This difference in horizontal velocity with depth causes turbulence in the vertical direction, which in turn mixes the denser water mass with the ambient water. The substrate (typically sand or mud) influences the roughness and thus the flow. The sandy beds similar to those found in Southern Monterey Bay could induce more turbulence than muddy seafloors, but less than gravel or rocky beds. The slope of the seabed combined with the roughness of the sandy bed provides a minimum level of potential far-field dilution for the brine discharge.

Another important consideration is the localized effect of the existing pipeline or outfall structure on plume behavior. A pipeline structure could act similarly to a longitudinal reef that forms a barrier across the bathymetric contours. The plume could be trapped by the pipeline, blocking its offshore dispersion. If the plume settles against the pipeline, the extent of turbulent mixing could decrease and reduce the rate of dilution.

4.3 Current Effects

This report neglects mixing due to currents and waves. This is standard practice in the near field, and a simplification that leads to higher predicted concentrations in the far field. The following analysis was accomplished to help evaluate the potential for different results if current and wave mixing were included. Wave-induced vertical mixing is potentially an important process given the long wavelength swell and large wave heights that propagate into Monterey Bay.

Current Effects on the Initial Discharge

The dilution of the brine is affected by the ocean currents along with the ambient temperature and salinity. For this study, currents are considered non-existent following the California Ocean Plan guidelines (SWRCB, 2012a). However, it is instructive to evaluate the effect of currents on the behavior of the jet plume, especially for buoyant plumes which could move shoreward and concentrate. This section studies the potential effect of currents on mixing. Under certain conditions, the ocean currents and the currents induced by gravity waves at the water surface may modify the initial brine discharge from the diffuser. The effects of an ambient cross flow on negatively buoyant jets were investigated by Roberts and Toms (1987), who defined an ambient Froude number,

$$F_a = \frac{U_a}{\sqrt{g_0' d}} \qquad [9]$$

Where,

- U_a is the ambient current velocity.

The results from Roberts and Toms (1987) show that for a Froude number much less than 1 ($F_a << 1$), the jet plume is unaffected by ambient currents and for an ambient Froude number below 0.5, the plume is unaffected by cross flow currents. For values of a Froude number much greater than 1 ($F_a >> 1$), the jet plume is significantly affected by the cross flow. The dilutions were generally found to increase with the current speed, except for a brine discharge that flowed opposite of the currents at $F_a \sim 0.2$, when the jet fell back on itself. For most other current directions, the jet height reaches a maximum at $F_a \sim 0.5$ and then decreases with an increasing current speed until at $F_a \sim 2$ when the rise height is essentially independent of current direction.

The probability distribution of the ambient Froude number was calculated for the ocean currents and currents induced by waves at the discharge location (Figure 9) using ROMS output for the period spanning January 2011 to March 2012. The currents induced by waves were estimated using five years of wave data from the National Data Buoy Center (NDBC) wave buoy #46236 (36.761 N, 121.947 W, Figure 2) spanning the period from January 2007 to December 2012. The horizontal water particle velocity was estimated using wave linear theory:

$$u_w = \frac{H}{2}\frac{gT_w}{L_w}\frac{\cosh[2\pi(z+h)/L_w]}{\cosh(\frac{2\pi h}{L_w})} cos\theta \qquad [10]$$

Where,

- u_w is the current velocity induced by waves,
- H is the wave height,
- T_w is the wave period,
- L_w is the wavelength,
- z is the defined depth,
- h is the total depth and
- θ is the phase angle from 0 to 2π.

The maximum u_w can be computed under the wave crest, with the phase angle θ equal to zero and cos θ equal to one. The results show that for ocean currents (Figure 9), ambient Froude numbers higher than 1 occur ~5 percent of the time, values higher than 2 only 0.1 percent of the time, and values higher than 3 were not observed. For currents induced by waves (Figure 9), Froude values higher than 1 occur 40 percent of the time at a depth of 98 feet, although values of 2 occur less than ~5 percent of the time and values higher than 3 occur only 0.1% of the time. The maximum ambient Froude number estimated was 6 for a wave height of 25 feet with a peak period of 16 seconds. Hence, the oceanic currents will not have a significant effect on the jet plume and most of the time; currents induced by waves will also have a negligible impact. However, extreme waves, although infrequent (less than 0.1% of the time), could have a considerable effect on the jet plume by increasing mixing and transport.

Current Effects on the Far-field Mixing

As described above, after the near-field mixing is complete, the plume is transported in the form of a density current that moves along the seabed. Since the density of the current is greater than the ambient seawater (due to higher salinity), the flow is layered (stratified), with the fast-moving brine plume distinguishable from the slower-moving ambient seawater. A strongly stratified flow (i.e. large difference in salinity between the plume and the local seawater) can lead to a surprisingly stable plume by inhibiting vertical mixing (Pond and Pickard, 1983). The dimensionless Richardson Number (ratio of velocity shear and water column stability), is an indicator of the overall stability of the flow: a small Richardson Number indicates the flow is weakly stratified, which enables greater vertical mixing of the flow across the stratified gradient (Pond and Pickard 1983). A large Richardson number indicates the flow is strongly stratified and vertical mixing is small or does not occur. The Richardson number is defined as,

$$R_i = \frac{N^2}{\left(\frac{du}{dz}\right)^2} \qquad [11]$$

Where,

- N is the “Buoyancy Frequency” defined as

$$N = \sqrt{\frac{g d\rho}{\rho dz}} \qquad [12]$$

Where,

- $d\rho/dz$ is the local density gradient

In general, strong density differences between the plume and ambient water act to stabilize the plume, whereas turbulence generated by the plume movement along the bottom or by differences in velocity between the plume and ambient water acts to destabilize the plume by causing vigorous mixing. Through linear stability theory and laboratory experiments, it has been shown than when $R_i > ¼$ the density difference overpowers the velocity gradients and suppresses turbulent mixing. Although strong stratification inhibits vertical mixing, lateral mixing can still occur. Figure 10 (top) shows the Richardson number for ocean currents and waves just after near-field dilution has occurred. The results show that the assumption that vertical mixing is negligible at the edge of the near-field where the plume starts traveling along the sea bed is a reasonable approach. Given the observations above, ocean currents will likely have negligible effect on vertical dilution of the plume and currents induced by waves will likely have an effect less than 10 percent of the time (occurring only during extreme events). Once the plume travels away along the sea bed and dilutes, the effect of currents on the vertical mixing increases as shown on Figure 10 (bottom). But even when the plume is 3 percent above the ambient salinity (close to the natural variability of the system), the effects of ocean currents are negligible and the effects of currents induced by waves on the vertical dilution only occur ~15 percent of the time. The effects of currents on the vertical mixing of the plume become significant only when the plume salinity exceeds ambient seawater salinity by 1 percent.

This analysis shows that the model results under-predict dilution and over-predict salinity levels during periods of stronger wave action. However the assumption of no-vertical mixing is a very reasonable approach until the plume dilutes to the point that it is only 1 percent higher than the ambient salinity. This analysis considers only the velocity induced by waves, and does not consider wave acceleration, which can have an effect on the mixing and advection: Water motions driven by waves oscillate with each wave, with currents under the trough moving in the opposite direction as the waves. Hence the actual effects of the waves would be greater than estimated in this study using the magnitude of bed velocity, and the Richardson number analysis.

5. Results

This section presents the results for the Proposed Project, the Project Variant, and the Project Variant Desalination Plant Only because these operating scenarios could result in a negatively buoyant plume that could travel along the seafloor, while the other scenarios result in a positively buoyant plume. The mixing extent of the brine plume in seawater was assessed by studying the salinity of the brine plume as it travels in the far field. The results are presented in the form of the difference in salinity of the brine plume and that of the ambient ocean water expressed as ppt above the ambient salinity. All of the salinity values shown here were converted to Absolute Salinity[11] for standardization and comparison purposes. The conversion is defined by the following equation:

$$\text{Absolute Salinity, } S_A = \frac{35.16504}{35} \times S_{‰}(1 + R^{\delta}) \quad [13]$$

Where,

- $S_{‰}$ is the in situ salinity estimated by Flow Science at the dilution point and
- R^{δ} is the global Absolute Salinity Anomaly Ratio (TEOS-10, 2010).

The background salinity value for each ocean climate season was then used to calculate the salinity above ambient salinity and the expected salinity (Absolute Salinity). The results are the spatial extent of the plume under the three ocean climate seasons. The salinity of the brine plume above ambient were calculated using the dilution rate of the brine (discussed below). The results are plotted in terms of the maximum salinity or worst case scenario and the average salinity (chronic conditions) or long term effects as a function of location, estimated for the 90-day simulation period with 48-hour salinity values aggregated spatially. The model was described further in Section 4.2 (Far-Field Mixing).

Total Dilution

The ultimate or total dilution S_T at any location is computed as the product of the near- and far-field dilutions:

$$\text{Total Dilution (\%), } S_T = S_m \times S_f \quad [14]$$

Where,

- S_m is the dilution in the near field and
- S_f is the dilution in the far field.

[11] The mass fraction of dissolved material in seawater as defined by the Thermodynamic Equation Of Seawater - 2010 (TEOS-10). Absolute Salinity incorporates the spatial variations in the composition of seawater and is the newly established convention for oceanographic research as of 2010.

Once the total dilution at a point and time (S_T) is estimated, the new plume salinity can be estimated by,

$$\text{Salinity, (ppt), } S_{A\,new} = \frac{(S_{A\,brine} - S_{A\,ambient}) + (S_{A\,ambient} \times S_T)}{S_T} \quad [15]$$

This calculation considers that the brine salinity does not affect the ambient salinity.

Worst Case Scenario and Chronic Conditions

To inform the water quality analysis related to the impact from the brine discharge, this study accounts for the impacts to marine biological species in terms of their exposure to the plume salinity. Model output represents the spatial extent of elevated salinity. For each location along the modeled sea floor, there is a group of particles of computed salinity at the end of their 48-hour tracking period. The average and peak salinity values can then be derived for each location. Average values are an average of the particle salinities, and are called “chronic” to represent persistent conditions pertinent to biota used when considering protection from long-term exposure to elevated saline water. Peak salinities (worst case dilution scenario) for each location from a biological perspective, the maximum exposure during a short time frame (less than 24 hrs.). The persistent conditions and peak salinities can be plotted to show spatial distribution across the sea floor. When interpreting these outputs, it is important to understand that the values are not a “picture” of the plume salinities: Rather, the plots show average and peak salinities that are likely to occur under the modeled ocean conditions. For example, the plume of elevated concentrations may move northwest one day, and southwest another day. The model results indicate the zone where elevated salinities will occur on one or more days, but not simultaneously.

Peak salinities were computed using the minimum far-field dilution ($S_{min(x)}$) values at each location (model grid node): The chronic salinity levels were estimated by averaging the dilution values obtained at each location. This averaging is the harmonic average dilution and represent persistent conditions (Roberts and Sternau, 1997).

$$\text{Harmonic Average Dilution, } S_h = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{S_i}} \quad [17]$$

Where

- S_i is the ultimate dilution (from Eq. 14) at the ith particle, where it goes from 1 to n (n being the total number of particles for each grid cell).

The concept of harmonic average dilution is a standard statistical analysis criterion (EPA, 2014). The harmonic average dilution is then used to estimate the chronic salinity concentration levels at each grid cell. While dilution tends to go to infinity at the edge of the plume and arithmetic means usually give unreasonable results (Fischer, *et al*, 1979), dilutions are averaged harmonically in order to describe the average dilution in an area.

5.1 Proposed Project MPWSP

Density difference

The salinity and temperature of the negatively buoyant plume varies seasonally from 57.4 to 58.23 ppt (Table 5) and from 9.9 to 11.6°C, respectively. Therefore the seasonal variations in the density of the brine discharge are due to the salinity and temperature of the discharge. The colder and saltier the intake water (e.g., during the upwelling), the denser the discharge will be upon release into the ocean. Figure 11 shows the density difference between the initial discharge and the ambient water masses by each of the three seasons. The brine is almost twice as dense as the ambient conditions. After the near-field dilution, the brine remains denser than the ambient seawater but rapidly approaches the seasonal conditions (Figure 11, bottom). During the first 48 hours of a brine particle's dilution, the average density is already within the natural variability of the ambient water (Figure 12 and Figure 13). The upper end of the natural variability of the seawater density (and salinity) overlaps with the lower end of the density (salinity) range of brine discharge indicating that the brine plume mass dilutes to ambient seawater in the first 48 hours. The average salinity values during 48 hours of dilution also reflect this seasonality (Table 6). However, the rate of dilution within 48 hours shows that most of the dilution to less than 0.5 ppt above ambient conditions for all three ocean seasons occurs within the first 7 hours (Figure 14).

TABLE 6
SALINITY VALUES DURING THE FIRST 48-HOUR FAR-FIELD DILUTION PERIOD

Project Scenario	Brine Salinity* (ppt)	Ambient Absolute Salinity at Diffuser (ppt)	Chronic Average Salinity within 48 hours (ppt)	ppt Above Ambient	Standard Deviation	Acute Average Salinity within 48 hours (ppt)	ppt Above Ambient	Standard Deviation
Proposed Project MPWSP								
Davidson 2 (Jan.)	57.4	33.52	33.74	0.22	0.3	34.13	0.61	0.30
Upwelling (July)	58.23	34.00	34.24	0.24	0.32	34.58	0.58	0.29
Oceanic (Sept.)	57.64	33.66	33.9	0.24	0.32	34.26	0.60	0.30
Project Variant MPWSP + GWR								
Davidson 2 (Jan.)	53.39	33.52	33.71	0.19	0.25	34.06	0.35	0.23
Upwelling (July)	54.42	34.00	34.2	0.2	0.25	34.53	0.33	0.24
Oceanic (Sept.)	53.86	33.66	33.85	0.19	0.25	34.20	0.35	0.24
Project Variant (Desalination Plant Only)								
Davidson 2 (Jan.)	57.67	33.52	33.77	0.25	0.34	34.07	1.18	0.23
Upwelling (July)	58.51	34.00	34.26	0.26	0.34	34.53	0.53	0.24
Oceanic (Sept.)	57.91	33.66	33.91	0.25	0.34	34.20	0.54	0.24

* -Salinity converted from Flow Science to Absolute Salinity (see Section 3).

The discharge does not equal ambient conditions even after 48 hours but reaches the natural variability (3.3% or ~1.1 ppt above ambient) of the ambient water of the ocean in the first 4 hours. If a different metric of change to absolute salinity is used, the brine discharge reaches within one standard deviation of ambient conditions for each season within the first 18 to 20 hours (Figure 15).

Plume behavior

The brine plume at 98 feet of water depth was tracked using the dilution rates (discussed in Section 4) to study the chronic conditions and the worst case scenario salinity levels. From the dilution rates, the expected salinity and salinity above ambient were calculated. All three parameters were predicted spatially for each brine particle computed at 48 hours after discharge, with a particle released every time step for the entire season (about 90 days). The chronic salinity concentrations are slightly elevated above ambient salinity: Values are from 0.5-1 ppt above ambient close to the outfall for all the seasons and values are below < 0.5 ppt above ambient everywhere else (Figure 16-18). Therefore, the chronic plume salinities are predicted to be below the natural salinity variability of +/- 3.3 percent in all locations. The worst case scenario for all the seasons show an area of salinity values higher than the natural variability of the system with values above 1.5 ppt. ppt above ambient (Figure 19-21). The cover area for values higher than 1.5 ppt above ambient salinity is summarized on Table 7.

TABLE 7
MODELED PLUME EXTENT AREAS AT WATER DEPTH OF 98 FT

EIR Name Project Scenario	Nickname	Ocean Season	Area Showing Salinity 1.5 ppt Above Ambient (~ 3.3%)[2] (acres)	
			Chronic Conditions	*Worst Case Scenario*
Proposed Project MPWSP	Big Plant	Davidson	---	---
		Upwelling	---	---
		Oceanic	---	---
Project Variant[1] MPWSP + GWR	Small Plant with GWR	Davidson	---	---
		Upwelling	---	---
		Oceanic	---	---
Project Variant Small Plant Only	Small Plant Only	Davidson	---	69.4
		Upwelling	---	147.1
		Oceanic	---	99.7

1 The Project Variant MPWSP + GWR plume is between the natural variability of the receiving waters when the groundwater recharge plant is in operation.
2 3.3% is the natural variability of the system and is used here as indicator of values higher than the ambient.

During chronic conditions the footprint of the brine plume is largest during the Upwelling season and smallest during the Davidson season (Figure 16-18). The shape of the footprint for the Oceanic season is similar to the Upwelling period but in a smaller extent. In all seasons for chronic conditions and worst case scenario the salinity values of the brine discharge are below the natural variability of the environment. For all three climate seasons, while the plume extends over hundreds of feet, the plume salinity is only slightly greater than the ambient water (Figure 19-21). Other parameters (e.g., dilution rate and expected salinity) to show the worst case scenario and chronic conditions are included as Appendix B. It should be noted that the spatial extents of high salinity values do not occur simultaneously, but rather these high salinities occurred within the plotted zones once or more. The durations are based on the total time during the 90-day simulation periods.

The spatial extent of the plume is directly correlated to the currents from the ROMS model and as such, seasonal differences are observable. The Davidson period has the slowest currents, which cause the smallest dispersion and the least extent of far-field dilution (Figures 16 and 19); the largest extent of the far-field dilution in the form of largest plume area occurs during Upwelling (Figure 17 and 20) with oceanic conditions producing a mid-sized plume (Figure 18 and 21). The shape of the plume at 98 feet is also seasonal with the currents during the oceanic and upwelling periods, elongating and stretching the brine dilution zone along a northeast-southwest axis; the currents in the Davidson period do not deform the plume in any dominant direction.

5.2 Project Variant MPWSP + GWR

Density difference

The initial salinity for the Project Variant changes seasonally from 53.6 to 54.2 ppt (Table 5). These values are smaller than the proposed project due to the blending with other freshwater sources before the discharge. As with the Proposed Project, the density differences between the brine discharge and the ambient seawater conditions show distinct water masses just after the near-field dilution (Appendix C). The average density is already between the ambient conditions for each season after 48 hours of dilution on the far field (Appendix C and Table 6).

Plume behavior

In general, the plume for the brine from the Project Variant behaves similarly to that under the Proposed Project. The most significant difference is that the plume produced by the Project Variant MPWSP + GWR does not exceed the natural variability of the receiving waters even on the worst case scenario (Table 5 and 7, Appendix D) at the edge of the near-field. The plume is shaped and sized in the same manner as the Proposed Project in each of the three ocean climate regimes, but was generally lower than the upper limit for natural variability of the ambient seawater. The average salinity values (chronic) are lower than 1 ppt above ambient and show a rapid dilution to values below > 0.5 ppt above ambient for all the three ocean conditions. For the worst case scenario the plume salinity was within the natural variability of the receiving waters for the three oceanic seasons. Upwelling shows the largest area of the plume, followed by the Oceanic and Davidson seasons.

5.3 Project Variant – Desalination Plant Only

Density difference

The initial discharge salinity for the Desalination Plant Only varies from 57.6 to 58.2 ppt (Table 5), which is slightly higher than the proposed project due to the decrease of the flow, which ultimately reduces shear stress with the ambient water and produces less dilution on the near field mixing. The seasonal density differences for the smaller desalination plant alone are nearly identical to the results for the Proposed Project (Appendix E) with only a slight increase in salinity after 48 hours of dilution (Table 6). Results show as well that after 48 hours of dilution the plume average salinity is already within the variability of the receiving waters.

Plume behavior

The plume for the small plant operations show values larger than the proposed project and because of a smaller volume of water, the affected area is larger due to smaller dilution in the near field (Table 5 and 7, Appendix F). The chronic condition under the Oceanic season shows the smallest plume, while the plume was largest for the Upwelling season. Both seasons show small values that are below the natural variability of the ambient water. The worst case scenario showed an area with salinity values > 1.5 ppt above ambient for the three seasons. The Upwelling season show the largest spatial extent and area with values > 1.5 pp above ambient of 147.1 acres. During the Davidson season, the footprint has an area of 69.4 acres for values larger than > 1.5 ppt, compared with 99.7 acres for the Oceanic season. (Table 7, Appendix F).

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Notation

The following symbols are used on this memo:

α	=	Constant dependent of the energy dissipation rate.
d	=	Nozzle diameter
ε	=	Diffusion Coefficient
F	=	Densimetric Froude Number
F_a	=	Ambient Froude Number
g	=	Acceleration due to gravity
g'_o	=	Modified Acceleration
H	=	Wave Height
h	=	Total Depth
Θ	=	Conservative Temperature
L	=	Measure of the initial cloud size of the brine
L_w	=	Wave Length
N		Buoyancy Frequency
R^δ	=	Global Absolute Salinity Anomaly Ratio
r	=	Separation between particles
ρ_a	=	Density of the ambient water
ρ_d	=	Brine Density
$S_{‰}$	=	In Situ salinity
S_A	=	Absolute Salinity
$S_{A\ ambient}$	=	Absolute Ambient Salinity
$S_{A\ new}$	=	Absolute salinity of the brine discharge after dilution
S_f	=	Lateral dilution of the far field
S_h	=	Harmonic average dilution
S_i	=	Total dilution at time step i
S_m	=	Near Field Dilution
S_{min}	=	Minimum estimated dilution
S_T	=	Total Dilution
T	=	Total time
T_w	=	Wave Period
t	=	Time
θ	=	Phase angle from 0 to 2π
U	=	Discharge jet velocity
U_a	=	Ambient Current Velocity
u	=	Current velocity
u_i	=	Current velocity (Horizontal)
u_w	=	Current velocity induced by waves
v_i	=	Current velocity (Vertical)
X_m	=	Distance from the port to the impact point
z	=	Defined depth

7. Figures

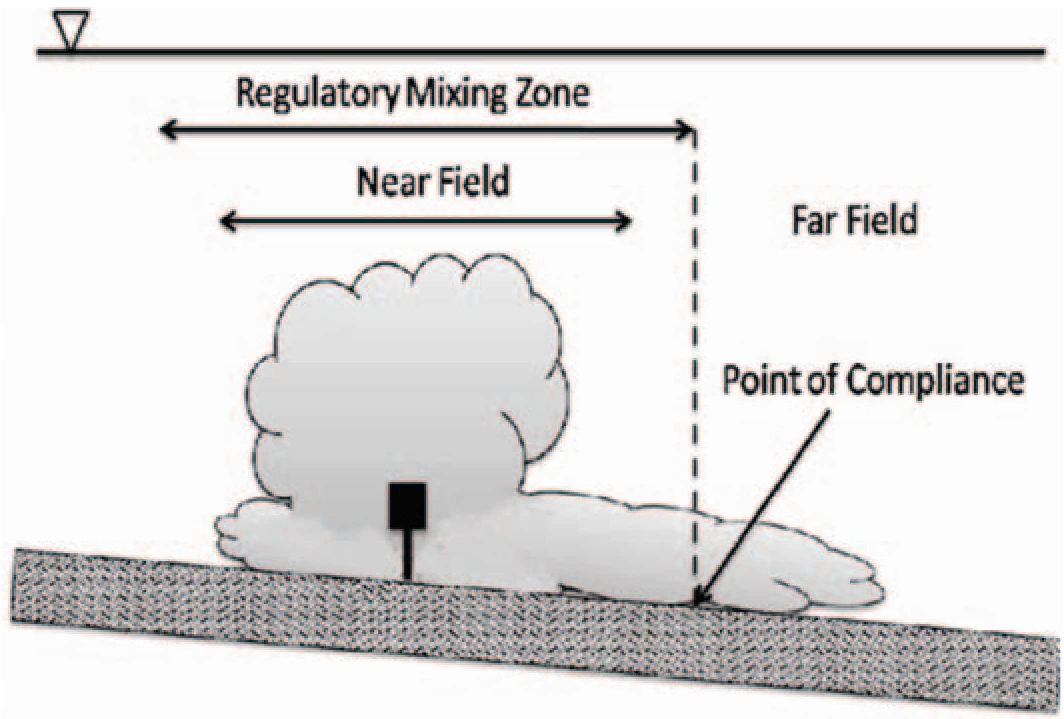

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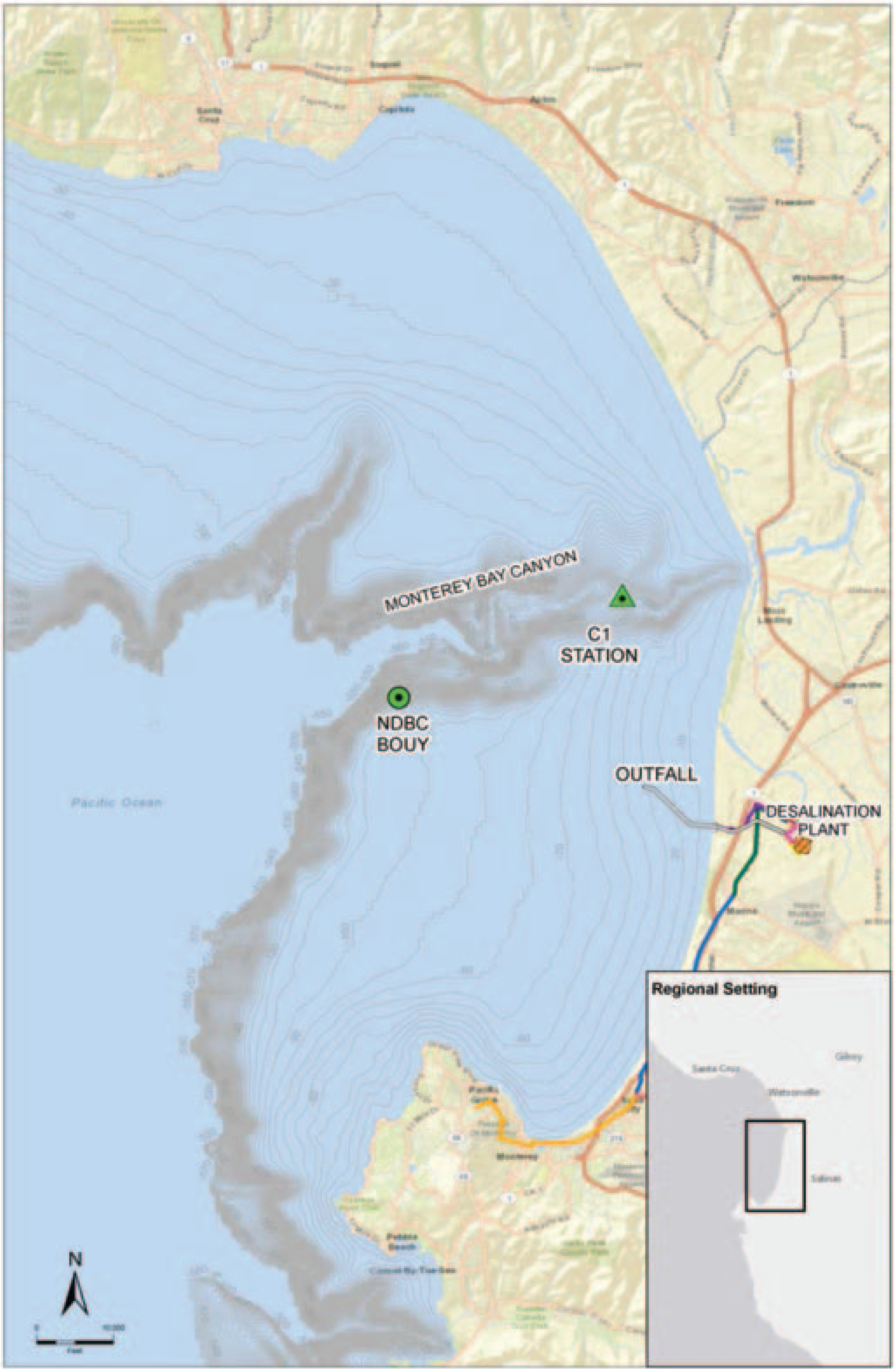
Figure 1
Mixing Zones as Described by the
State Water Resources Control Board
(SWRCB, 2012a)



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Monterey Peninsula Water Supply Project, D205335.01

Figure 2
Location Map

Basemap Sources: Esri, Delorme, NAVATEQ, USGS, Intermap, IPC, NRCAN, Esri Japan, METI, Tom, Tom, 2013
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Benthic Habitat from California Seafloor Mapping Program, CSUMB

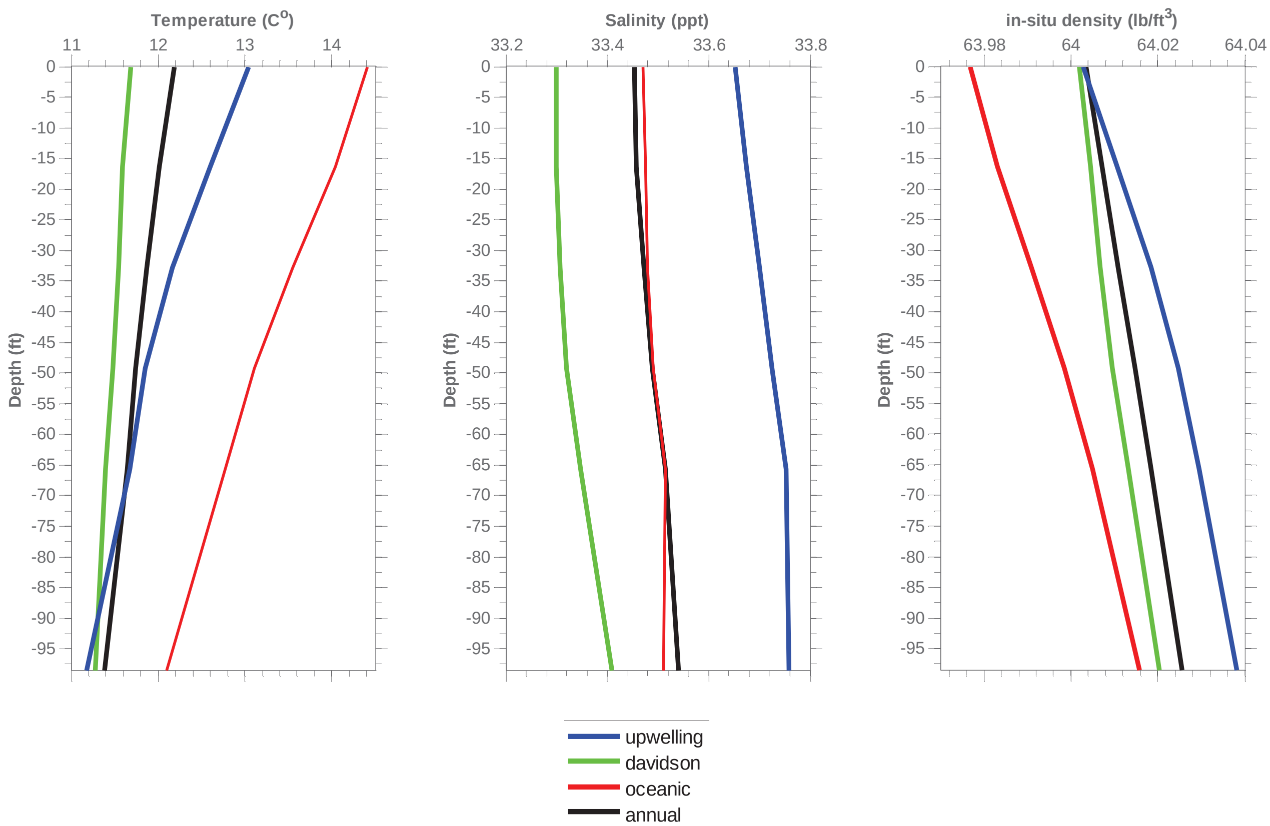

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Figure 3

Seasonal Water Column Profiles at the Wastewater Discharge Location in the ROMS Model for the Upper 98 ft of the Water Column

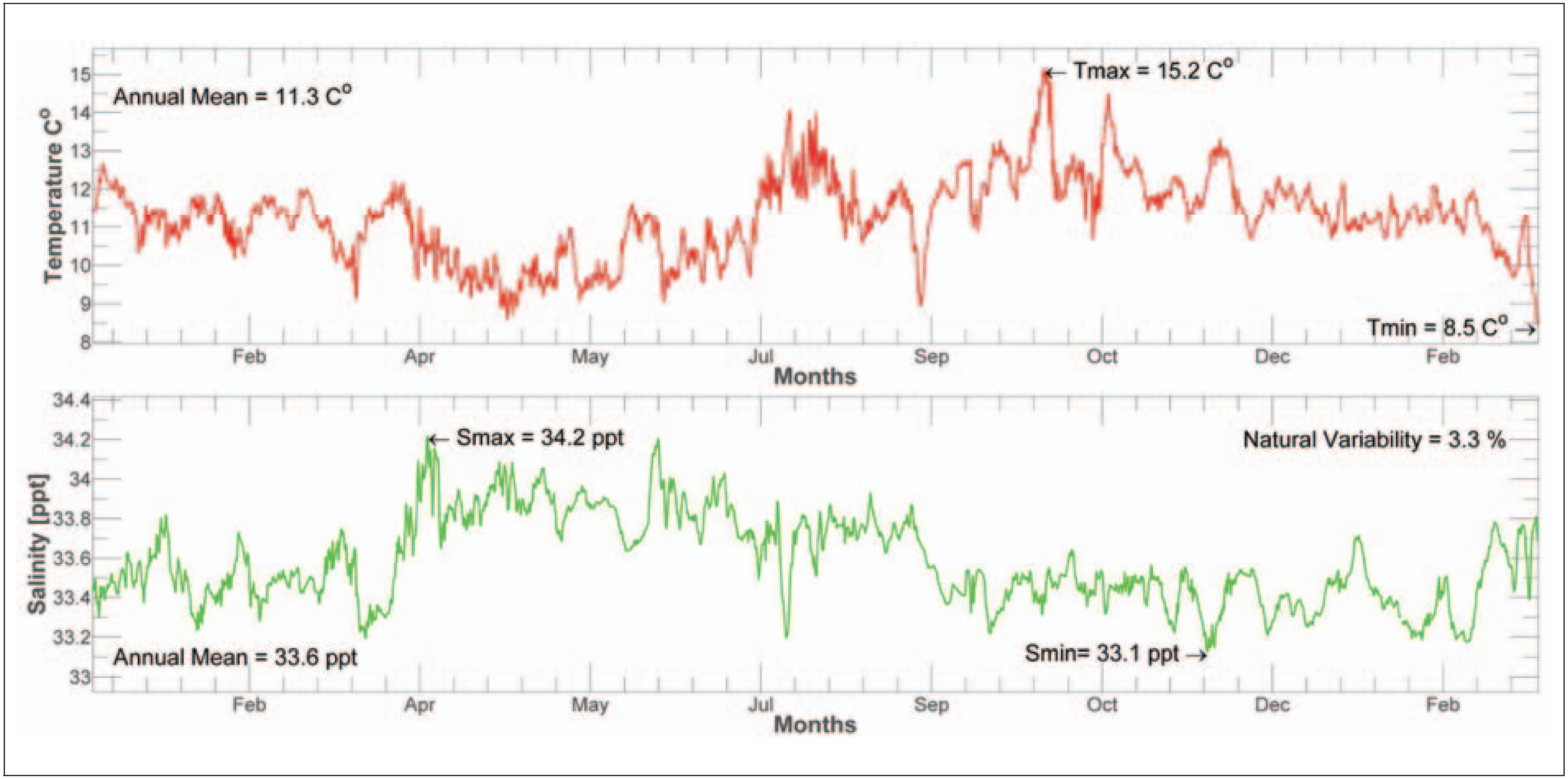

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Figure 4

Temperature and Salinity Distributions at Discharge Point at depth = 30m from January 2011 to March 2012. from ROMS Model

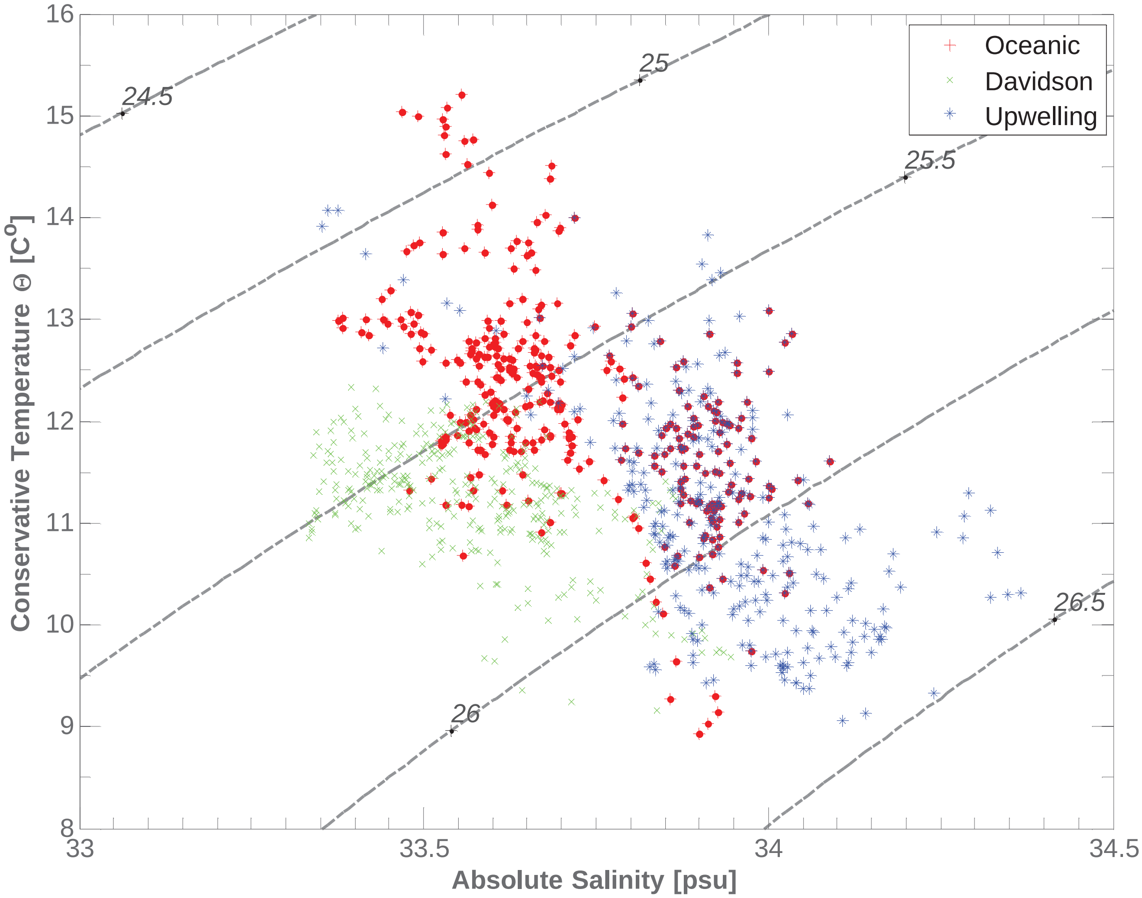

Figure 5
Temperature, Salinity And Density At Discharge Point from ROMS Model (06/11-02/12) During Ocean Seasons

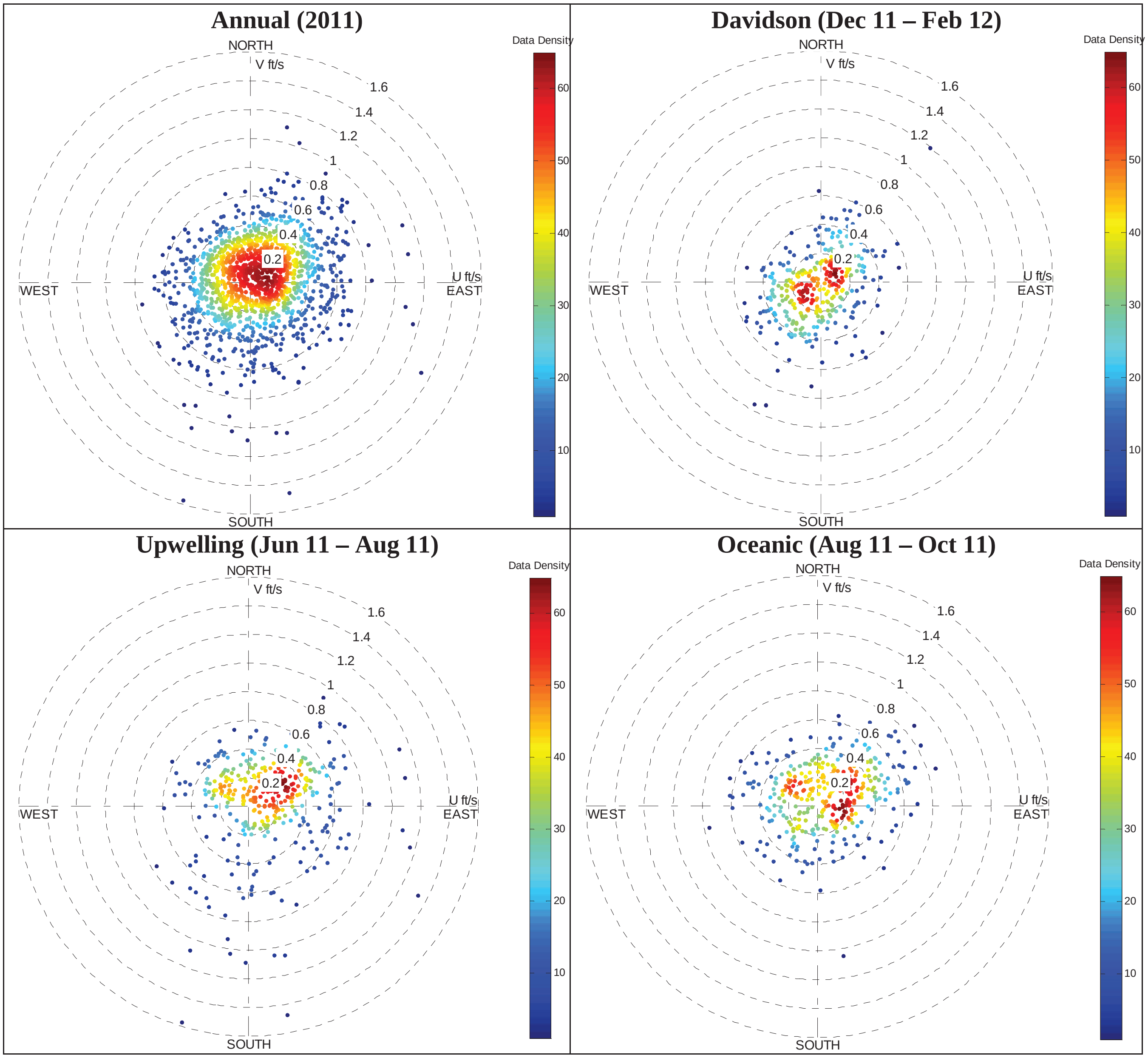

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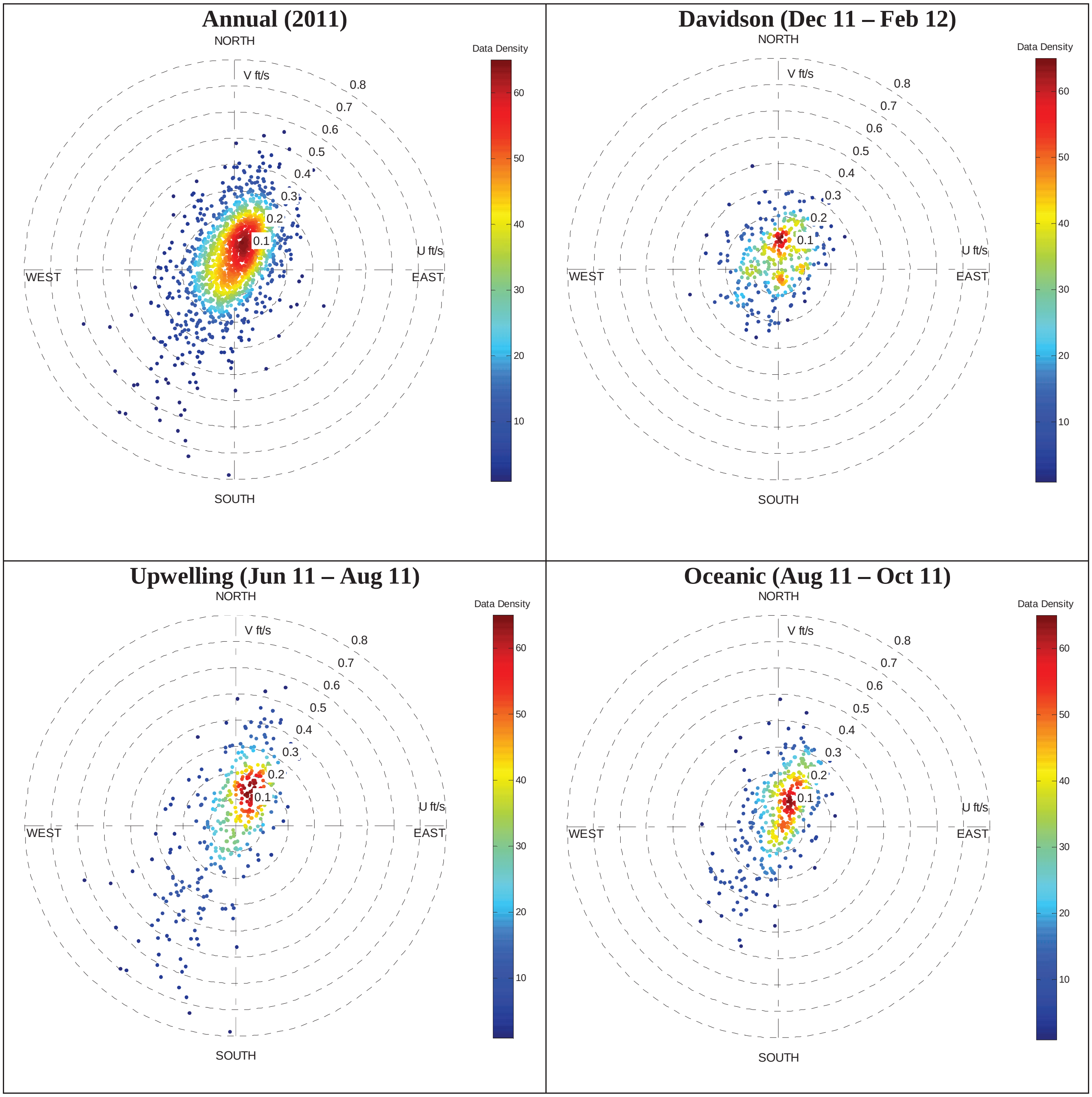
Figure 6

Directional Current Distribution at Water Surface

(Current Velocities in ft/s, current direction shown on Oceanographic convention)



Monterey Peninsula Water Supply Project, D205335.01

Figure 7

Directional Current Distribution at Water Depth of 98 ft

(Current Velocities in ft/s, current direction shown on Oceanographic convention)

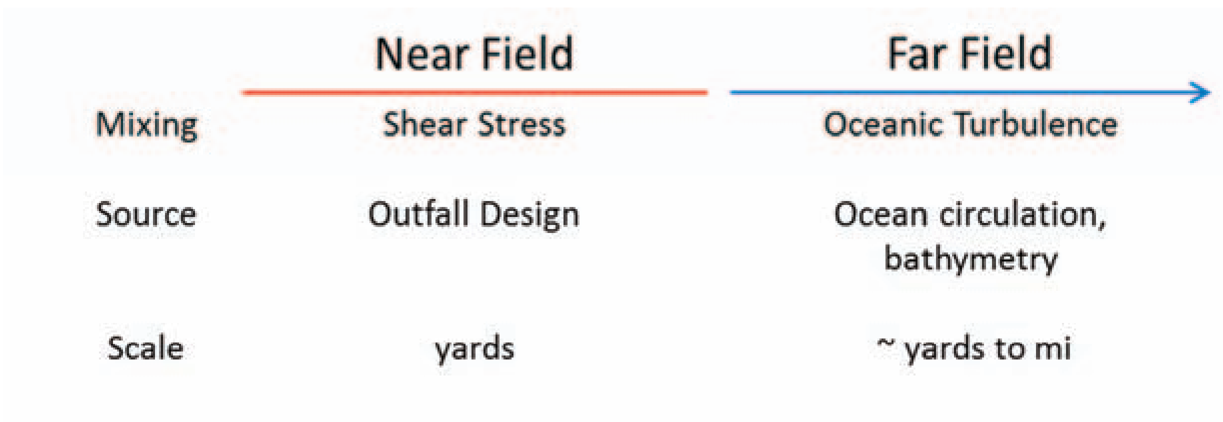


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Figure 8
Conceptual Diagram for a Brine Discharge Mixing Zone

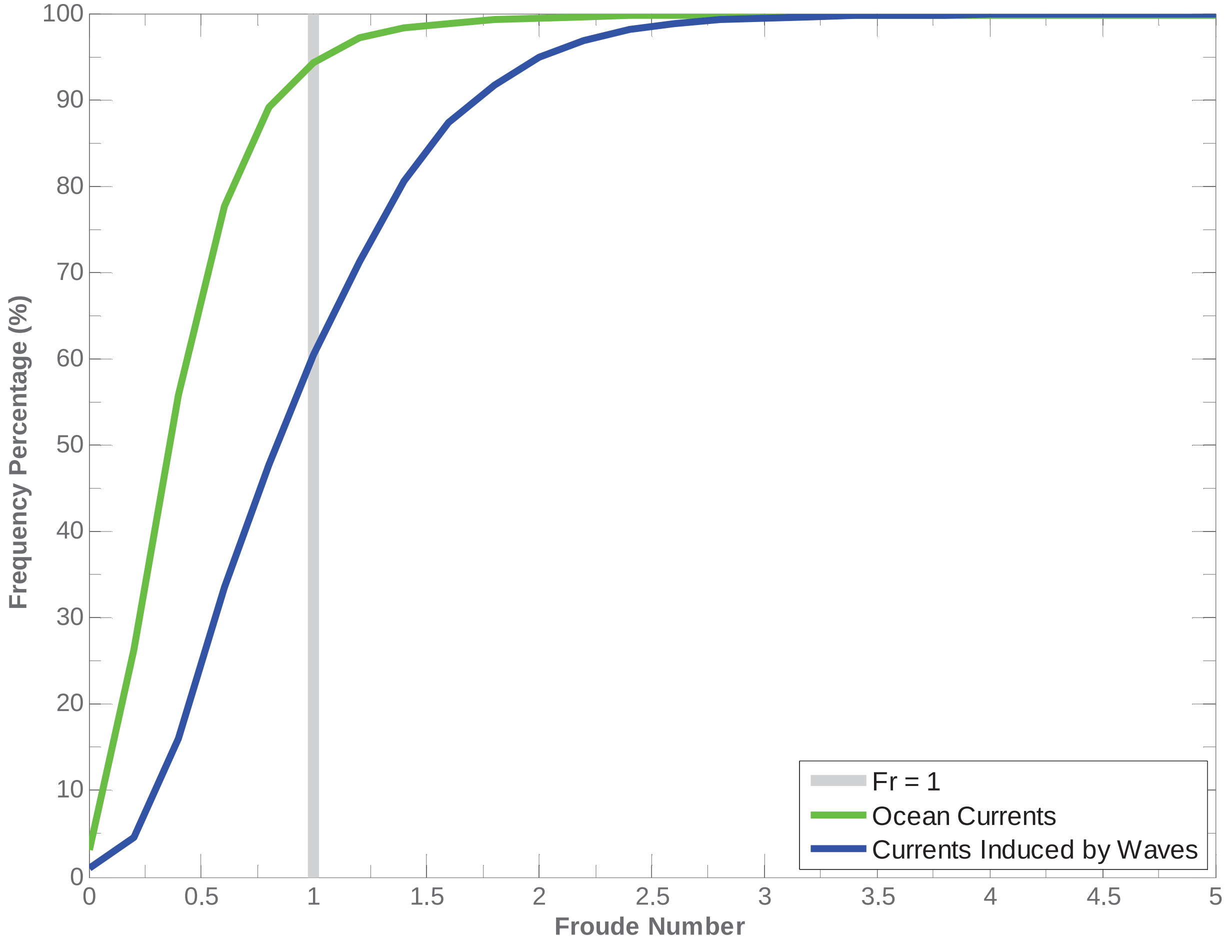

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Figure 9

Froude Number Plot of Probability Density

Based on Currents and Wave-induced Currents

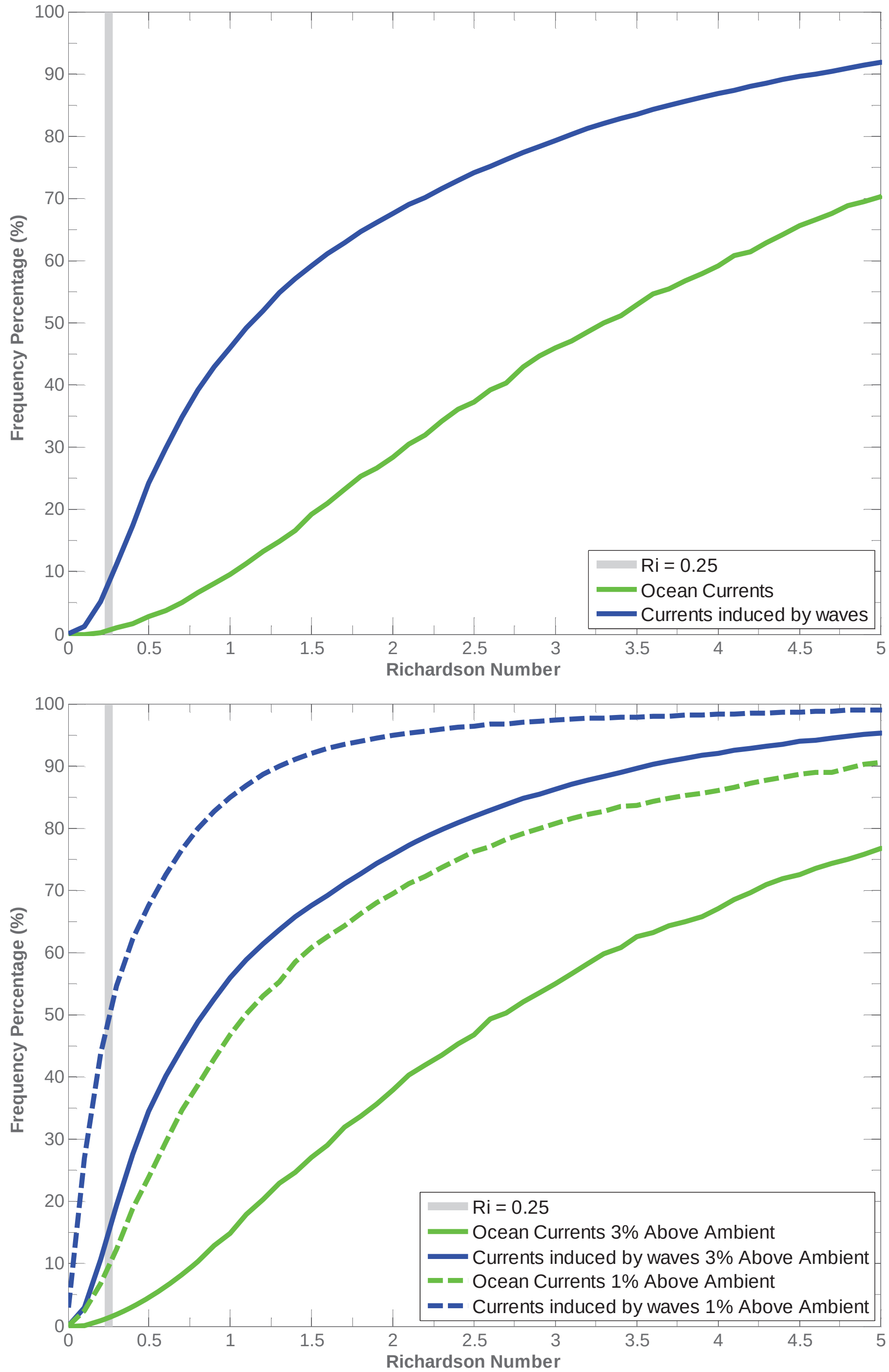

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Figure 10

Richardson Number Plots of Probability Density

After Near Field Dilution (top) and Far Field Dilution(bottom)

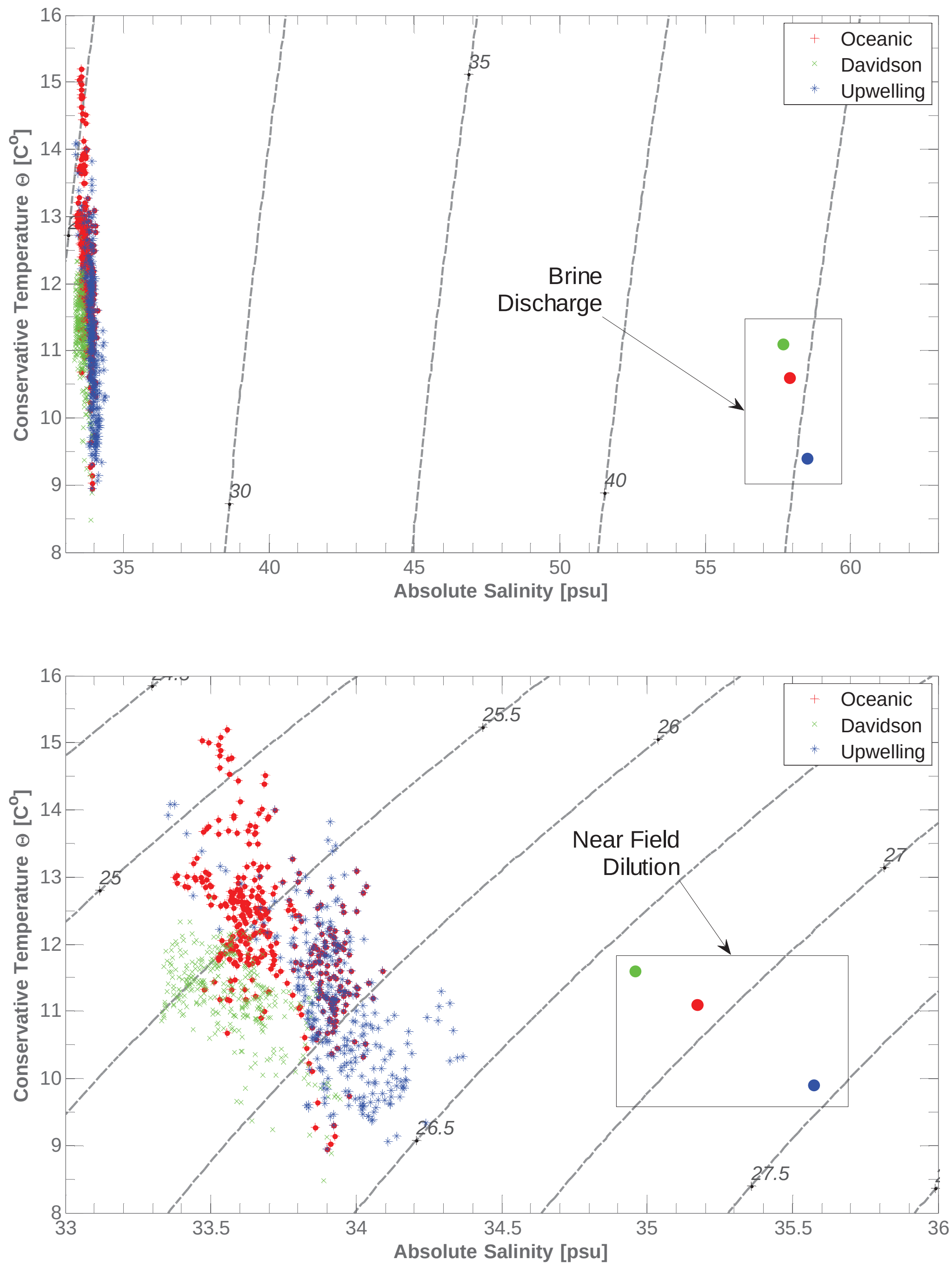

Figure 11

Temperature, Salinity And Density At Discharge
Point In ROMS Model During Ocean Seasons Compared To Brine
Discharge (Top) And After Near Field Dilution (Bottom)

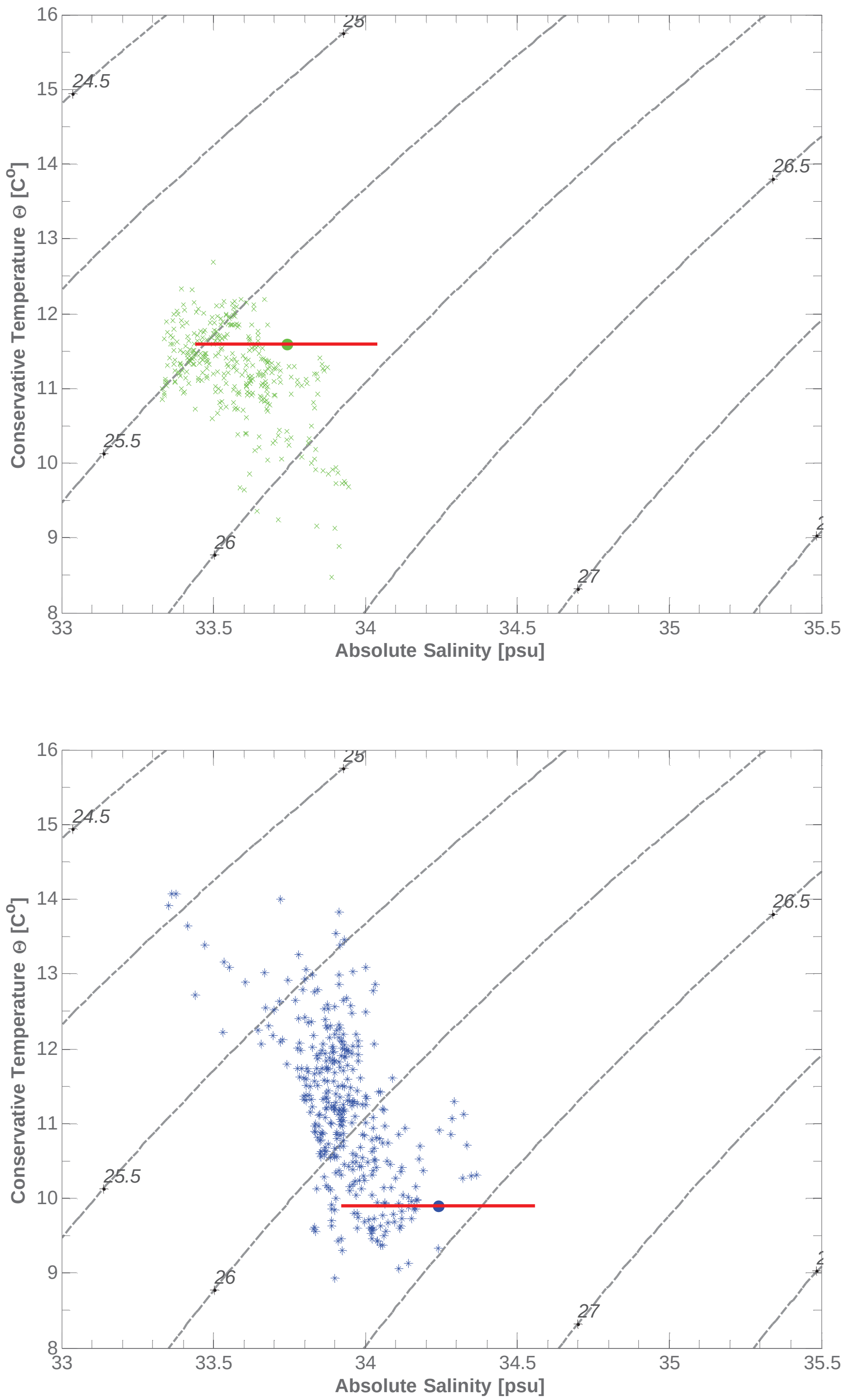

Figure 12

Temperature, Salinity And Density At Discharge Point In ROMS Model During Davidson (Top) And Upwelling (Bottom). Conditions Compared To Brine Discharge After Far-Field Dilution In 48 Hrs. Red Line Is One Standard Deviation Of Diluted Brine Discharge.

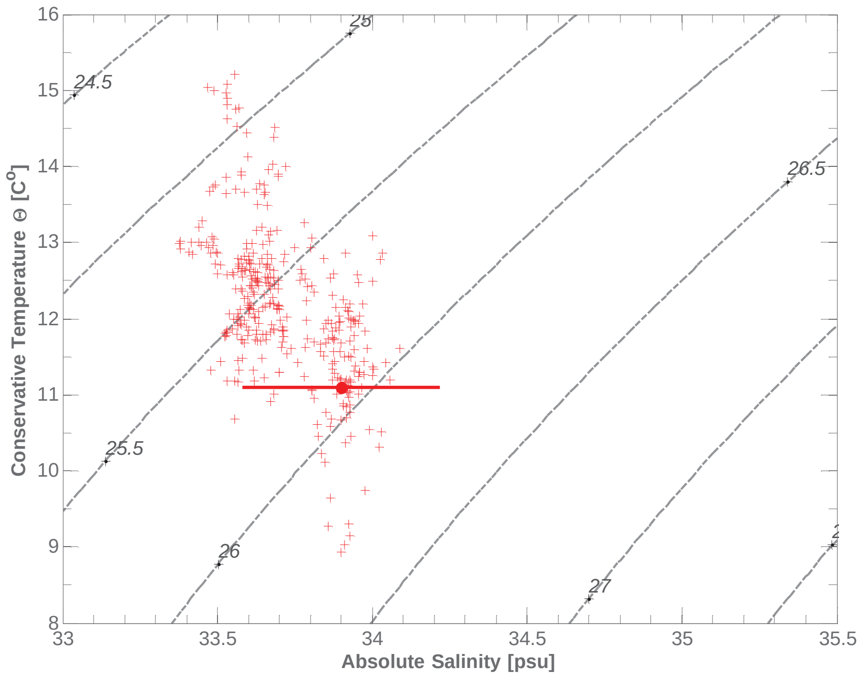

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Figure 13

Temperature, Salinity And Density At Discharge Point In ROMS Model During Oceanic Conditions. Compared To Brine Discharge After Far-Field Dilution In 48 Hrs. Red Line Is One Standard Deviation Of Diluted Brine Discharge.

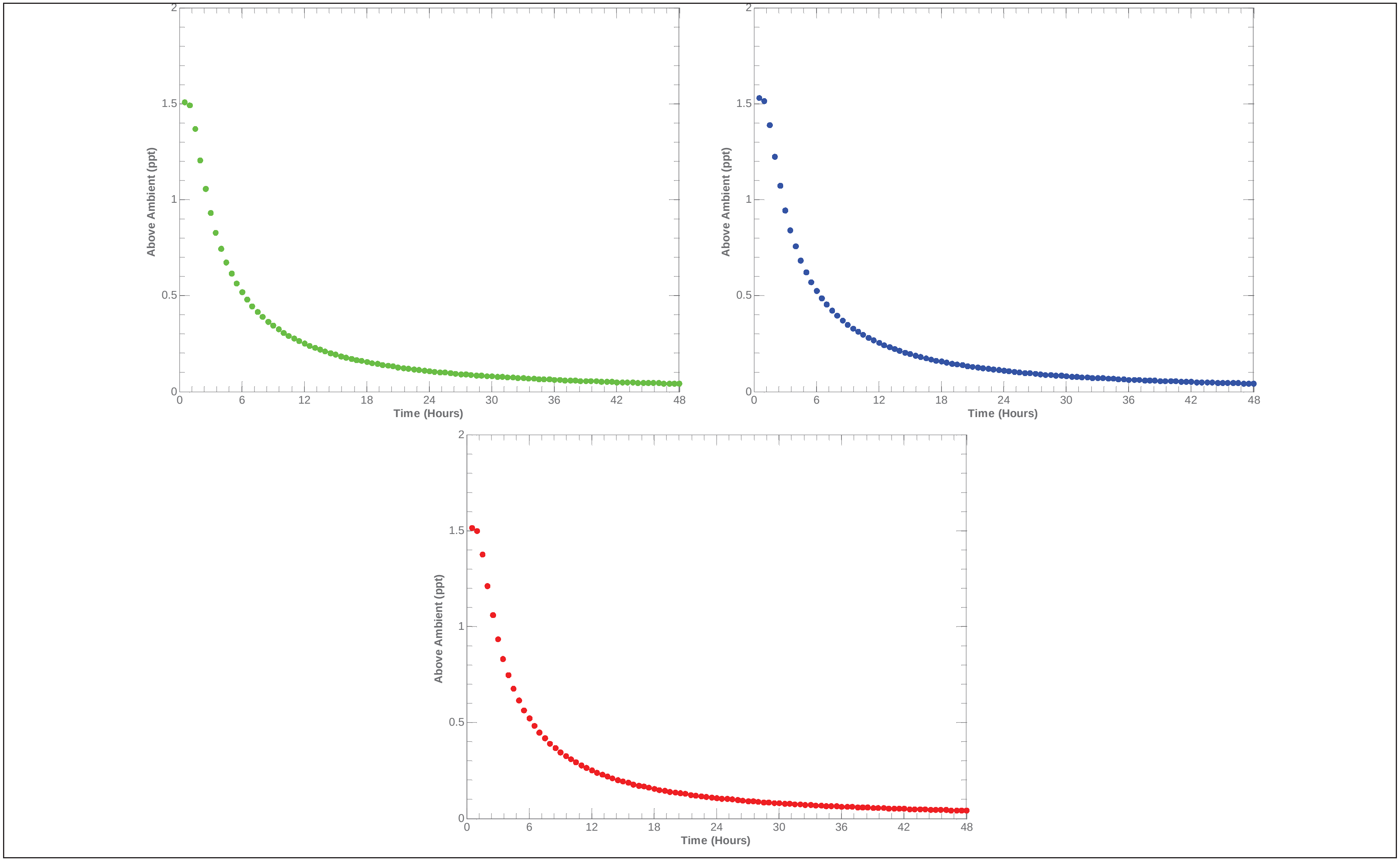

Figure 14

Dilution Rate During the Initial 48 Hours After Discharge by Percent of Ambient Salinity for Davidson (green), Upwelling (blue), and Oceanic (red) Conditions.

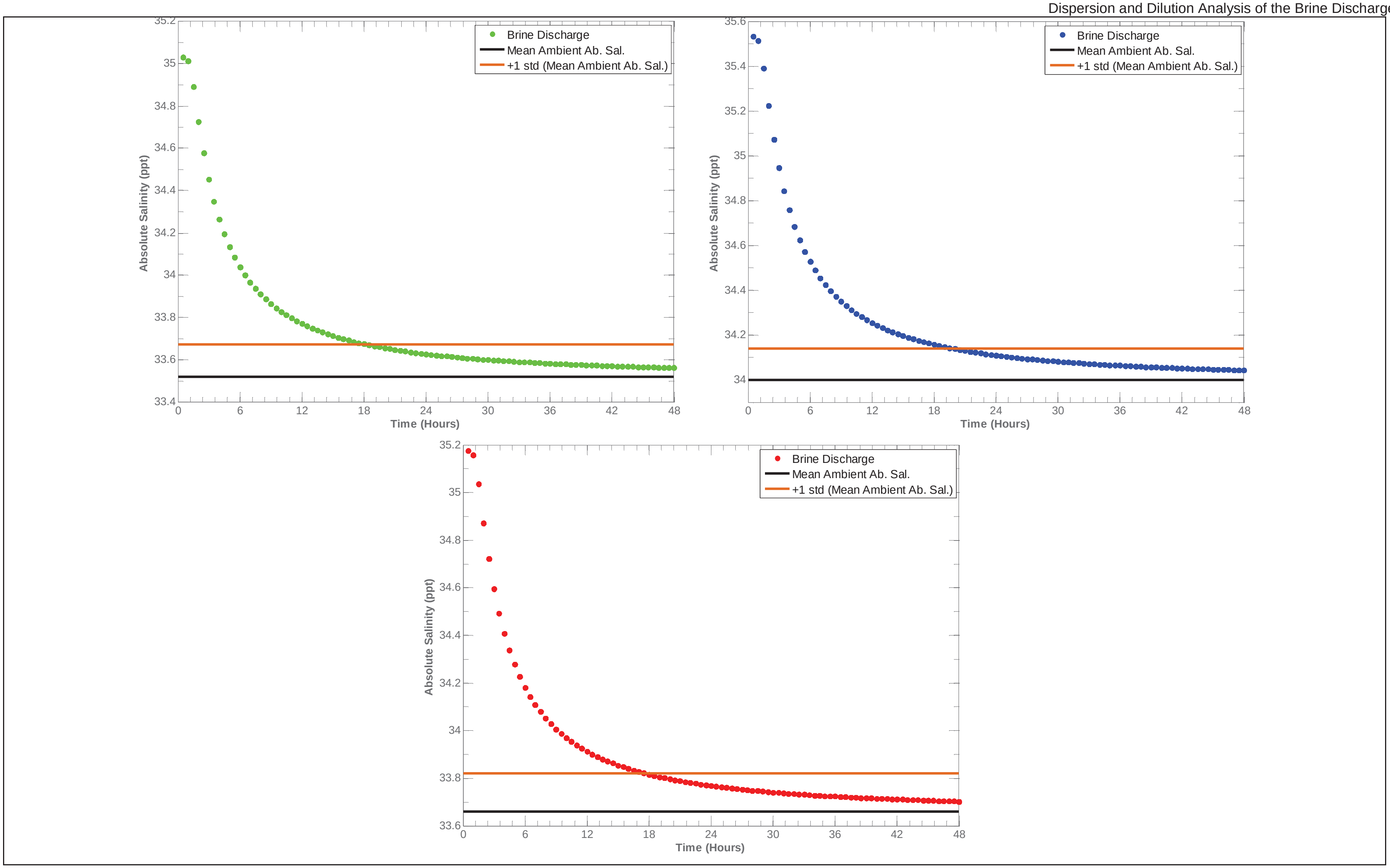

Figure 15

Dilution Rate During the Initial 48 Hours After Discharge by Absolute Salinity for Davidson (green), Upwelling (blue), and Oceanic (red) Conditions.

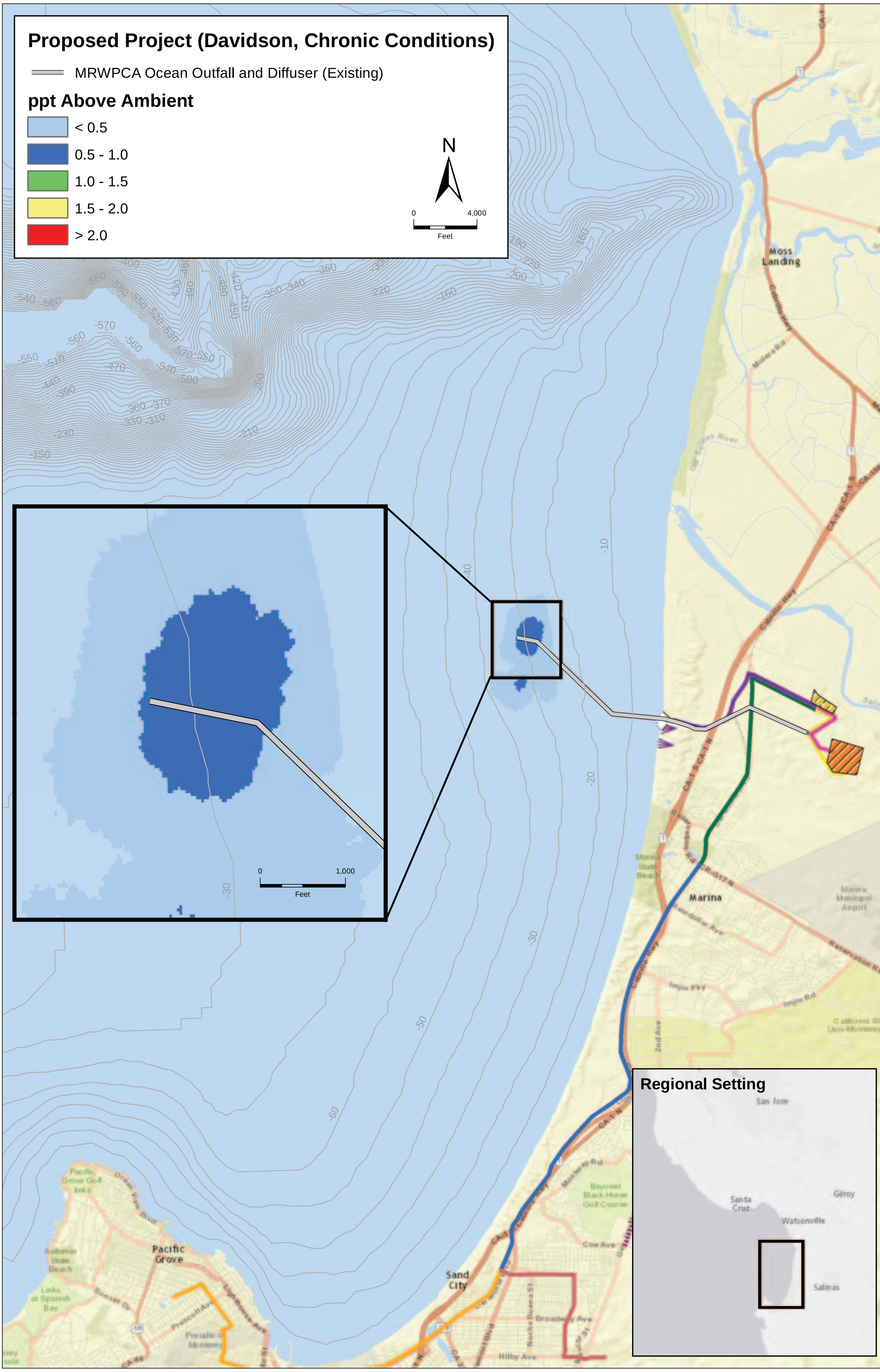

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Figure 16
Parts per Thousand Above Ambient
(Proposed Project: Davidson, Chronic Conditions)

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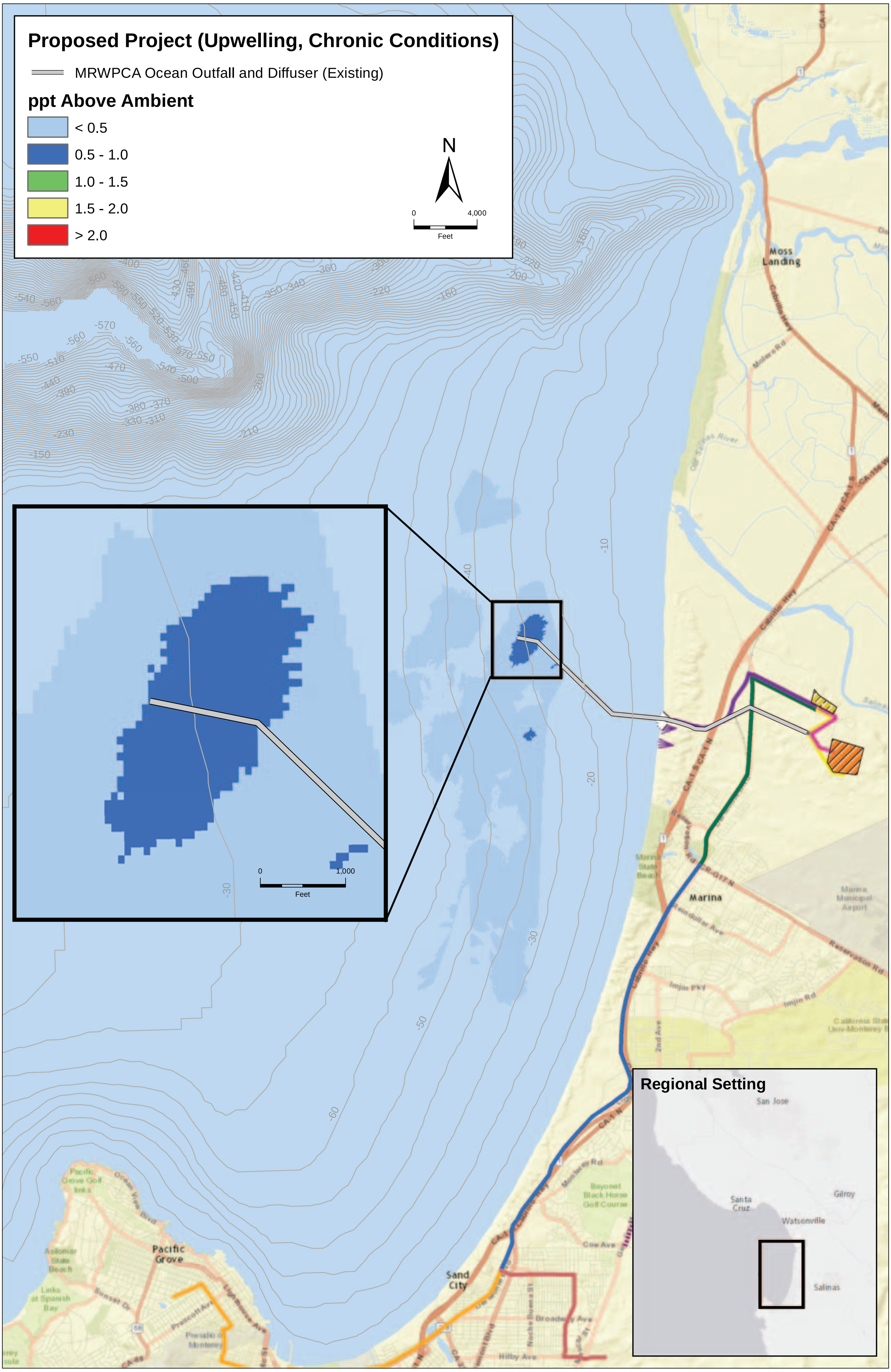

Basemap Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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Figure 17
Parts per Thousand Above Ambient
(Proposed Project: Upwelling, Chronic Conditions)

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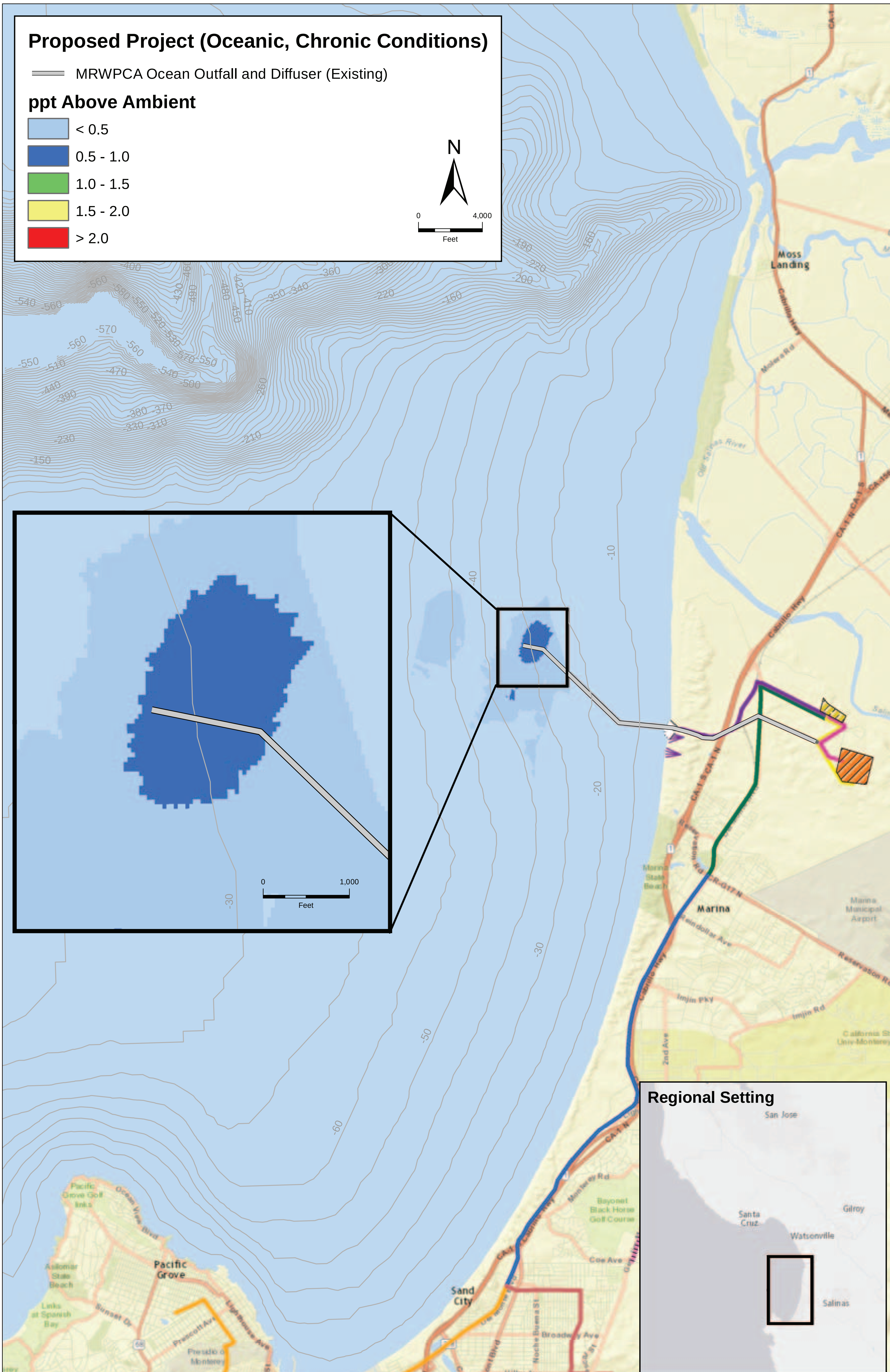

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Figure 18
Parts per Thousand Above Ambient
(Proposed Project: Oceanic, Chronic Conditions)

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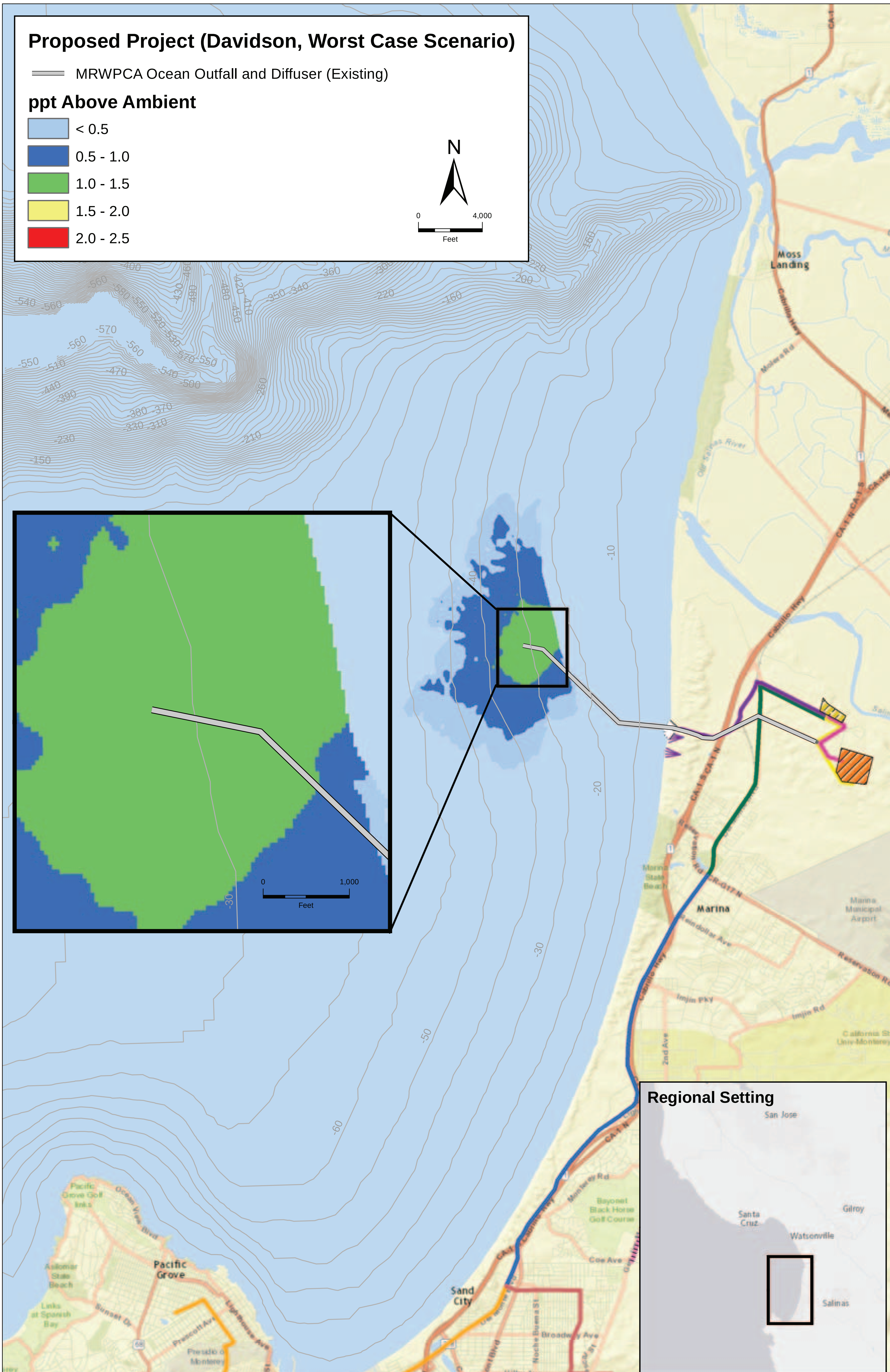

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Figure 19
Parts per Thousand Above Ambient
(Proposed Project: Davidson, Worst Case Scenario)

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4/2/2015

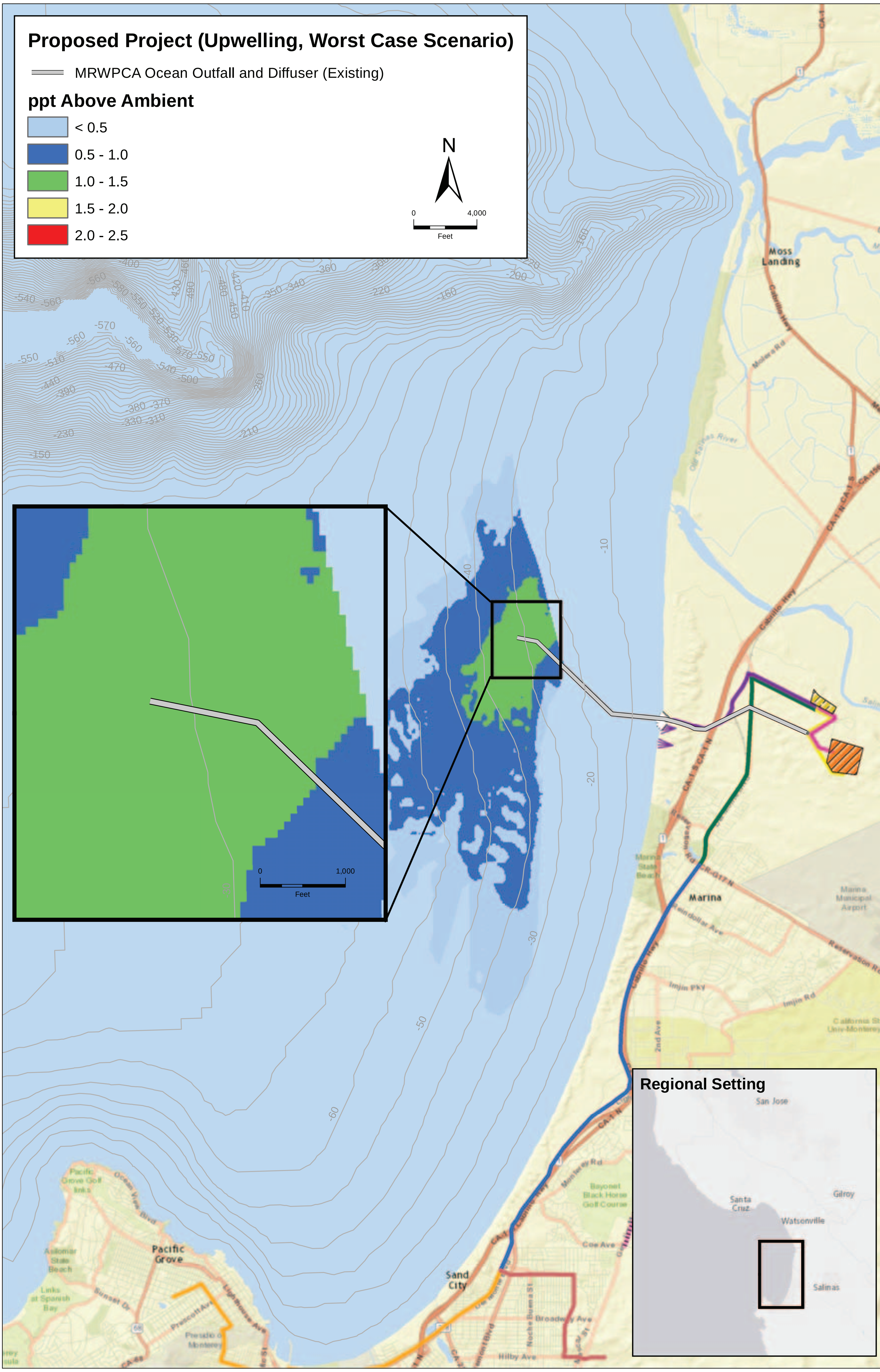

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Figure 20
Parts per Thousand Above Ambient
(Proposed Project: Upwelling, Worst Case Scenario)

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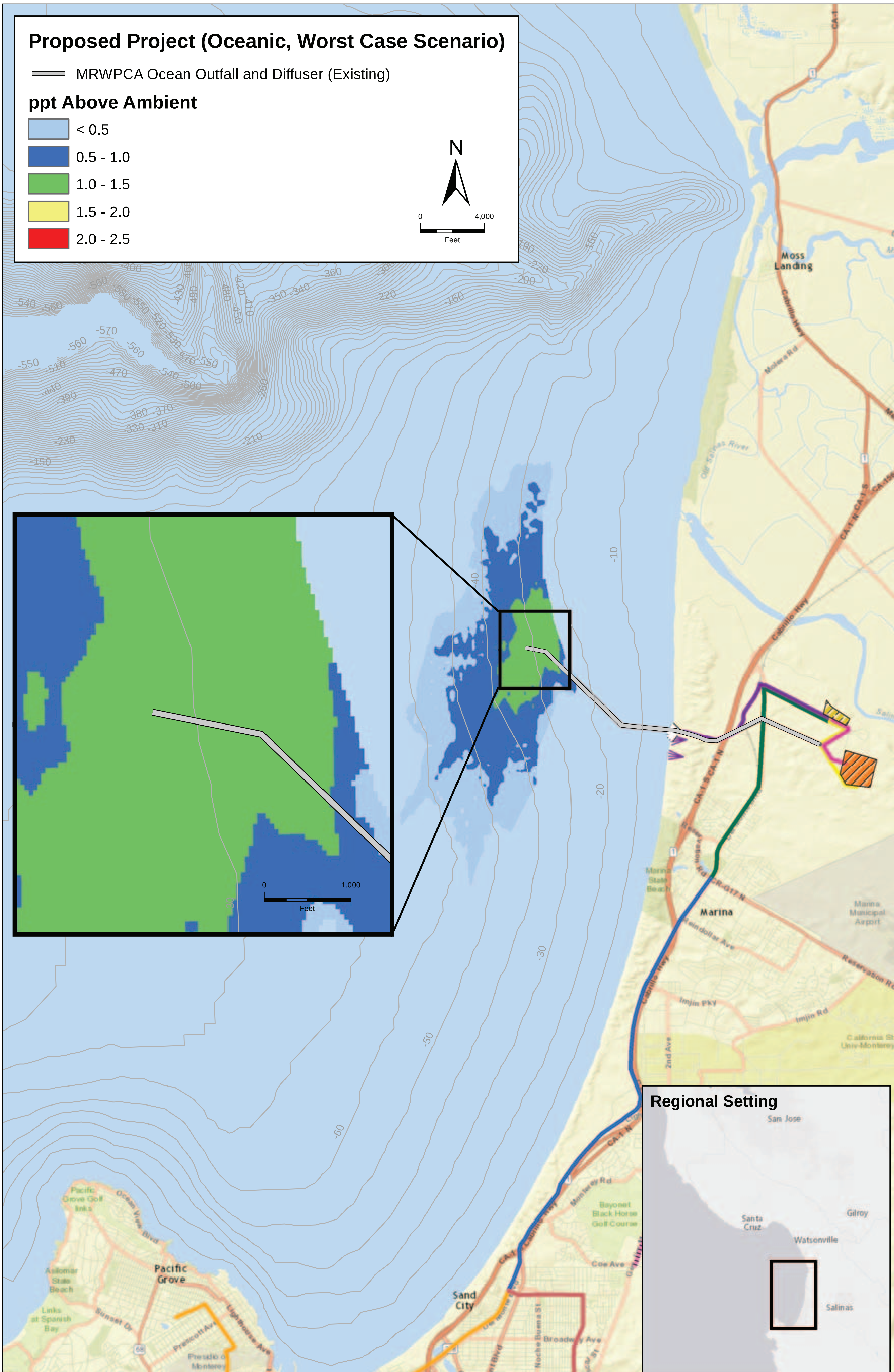

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Monterey Peninsula Water Supply Project . 205335.01
Figure 21
Parts per Thousand Above Ambient
(Proposed Project: Oceanic, Worst Case Scenario)

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4/2/2015

9. Appendices

Appendix A Flow Science 2014 Near-Field Modeling Report
Appendix B Proposed Project - Seasonal Plume Behavior
Appendix C Project Variant T-S Diagrams
Appendix D Project Variant - Seasonal Plume Behavior
Appendix E Project Variant Desalination Plant Only T-S Diagrams
Appendix F Project Variant Desalination Plant Only - Seasonal Plume Behavior

Appendix A

Flow Science 2014 Near-Field Modeling Report

Flow Science Incorporated
48 S. Chester Ave., Suite 200, Pasadena, CA 91106
(626) 304-1134 • FAX (626) 304-9427

DRAFT TECHNICAL MEMORANDUM

DATE: August 29, 2014

TO: Environmental Science Associates (ESA)

FROM: Gang Zhao, Ph.D., P.E., Aaron Mead, P.E., E. John List, Ph.D., P.E.

SUBJECT: **MRWPCA Brine Discharge Diffuser Analysis**
FSI 134032

1. Introduction

As part of the EIR preparation process for the Monterey Peninsula Water Supply Project, Flow Science Incorporated (Flow Science) was retained to analyze the effect that discharging desalination brine through the existing Monterey Regional Water Pollution Control Agency (MRWPCA) ocean outfall would have on ocean water quality adjacent to the outfall.

In August 2014, Flow Science performed a modeling analysis of four discharge scenarios for the Monterey Peninsula Water Supply Project, as summarized in **Table 1**. For each scenario, effluent dilution was analyzed for zero ocean current conditions.

Table 1 – Diffuser scenarios modeled

Scenario No.	Scenario Name	Discharge Rate (mgd*)
1	Upwelling (July), Brine Only	13.98
2	Davidson (Jan.), Brine Only	13.98
3	Davidson (Jan.), Brine and Wastewater	33.76 (= 13.98+ 19.78)
4	Oceanic (Sept.), Brine Only	13.98

*mgd = million gallons per day.

This Technical Memorandum (TM) summarizes the analyses Flow Science completed for the four scenarios presented in **Table 1** and describes the input data, results, and methods Flow Science used to analyze the proposed discharges. Analyses for additional discharge scenarios were also completed by Flow Science,and the TM for these additional discharge scenarios is attached as **Appendix C**.

2. Analysis Input Data

Diffuser Configuration

The existing MRWPCA diffuser has 172 ports. Half of the ports discharge horizontally from one side of the diffuser and half discharge horizontally from the other side of the diffuser in an alternating pattern. Since Visual Plumes does not have the capability to model ports on alternating sides of a diffuser, all ports were modeled to be on one side of the diffuser. This simplification has no effect on the dilution of negatively buoyant plumes because all modeled negatively buoyant plumes (Scenarios 1,2 and 4) did not overlap or interact before reaching the ocean floor—i.e., within the zone of initial dilution (ZID). For the positively buoyant cases (Scenario 3) the model results are conservative because the plumes from individual ports overlap more quickly under modeled conditions than in reality, and so modeled effluent dilutions for the positively buoyant scenarios are somewhat lower than would be reflected in reality.

According to MRWPCA, the fifty-two (52) ports nearest to the shore (i.e., the shallowest ports) are currently closed. In this analysis, Flow Science calculated plume concentrations for effluent discharged through the 120 open ports. A typical section of the current diffuser is shown in **Figure 1**, although the actual cross-sectional profile of the pipe ballast may have changed over time. The ports are approximately 6 inches above the rock bedding of the diffuser pipeline, and drawings[1] (see **Figure 1**) indicate that they are located a minimum of approximately 3.5 feet above the seafloor. The gravel bedding dimensions are nominal, as shown in **Figure 1**, and therefore, the port height above the seafloor is not known with high accuracy. Momentum of the effluent is a key factor in determining the dilution within the ZID. Toward the end of the ZID, the plume slows down and mixing is not as strong as at the beginning of the ZID. Therefore, the dilution results are not likely to change by much if the port height is not precisely known and, considering the overall uncertainty in the analysis, it is not critical to determine the diffuser port height with high accuracy. In this analysis, it was assumed that effluent plumes do not interact with the ballast, which is supported by the plume dimensions computed. Details of the current diffuser configuration are summarized in **Table 2**.

[1] Section F, Drawing P-0.03, Contract Documents Volume 1 of 1: Ocean Outfall Contract No. 2.1, January 1982 by Engineering Science for MRWPCA.

Table 2 – Current diffuser configuration.

Parameter	Value
Diffuser length	1368 feet (417 m*)
Depth of diffuser ports	95 to 109 feet below MSL
Number of open ports	120
Port spacing	8 feet (2.44 m*)
Port diameter	2 inches (0.051 m*)
Port exit condition	Tideflex Series 35 4-inch duckbill valves
Port vertical angle	0° (horizontal)
Port elevation above sea floor	3.5 feet (1.07 m*)

*m = meters

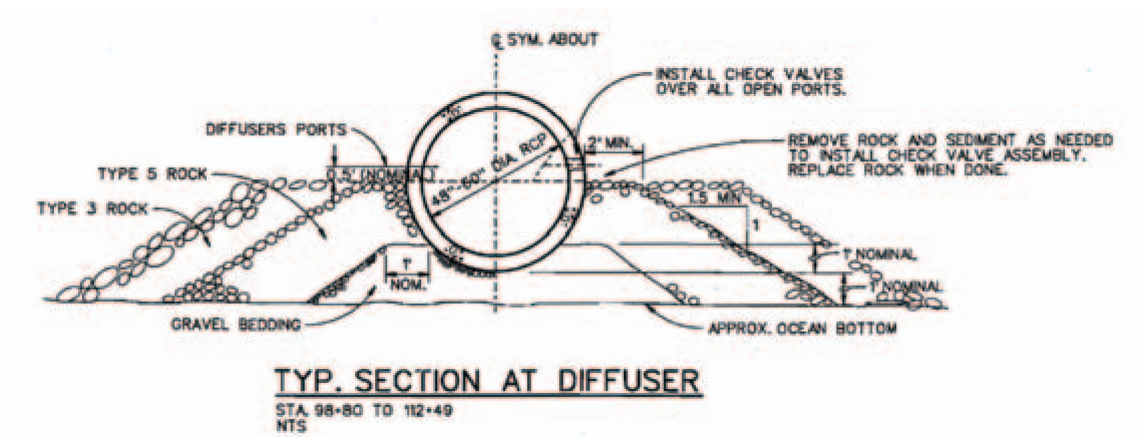

Figure 1. Typical diffuser section (currently in place).

The 120 ports that are currently open are fitted with Tideflex "duckbill" check valves, as shown in **Figure 2**. The shape of the duckbill valve opening is elliptic and the area of the opening depends on the discharge flow rate. The valve opening area in this analysis was determined from an effective open area curve provided by Tideflex Technologies (included as **Appendix A**). Although the ports were modeled as round openings with the same opening area as the "duckbill" valves, because of the oblateness of the actual port opening, the actual dilution will be slightly higher than the dilution computed assuming circular ports. This is because the perimeter of ellipse, which is where the entrainment of diluting water occurs, is larger than that of a circle.

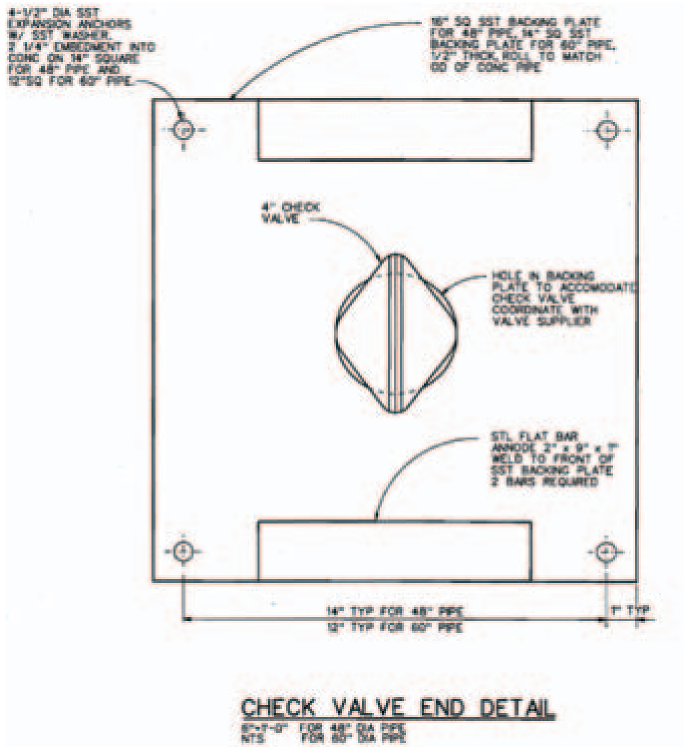

Figure 2. Typical "duckbill" valve detail (shown closed, i.e., with no flow).

Discharge Characteristics

Salinity (or total dissolved solids [TDS]) and temperature data for the brine (Scenarios 1 through 4) and the MRWPCA wastewater (Scenario 3) have been provided by ESA. TDS is a measure of water salinity, and salinity and temperature are used to calculate the density of the effluent and ambient ocean water, which are important parameters in dilution analyses.

As summarized in **Table 1**, ESA selected three seasonal ocean conditions for analysis: Upwelling (July), Davidson (January), and Oceanic (September). Therefore, discharge rate, temperature, and salinity/TDS data for these months, presented in **Table 3**, were used in the analysis. For the combined brine and wastewater flow scenario (Scenario 3), the desalination brine was assumed to be fully mixed with the wastewater. Thus, the temperature and salinity of the combined flow were calculated as the flow-weighted average temperature and salinity of the brine and wastewater.

The analyses completed as part of this study are summarized in **Table 3**. All scenarios were analyzed for zero ocean current velocity conditions, which represent worst-case conditions since any ocean current only increases dilution. Ocean currents increase the amount of dilution that occurs because they increase the flow of ambient water past the diffuser (i.e., increase the amount of ambient water available for mixing with the discharge). Although ocean currents increase effluent dilution, the California Ocean Plan (State Water Resources Control Board, SWRCB, 2009) requires that the no-current condition should be used in initial dilution calculations.

Table 3 – Summary of analyses for Scenarios 1 through 4.

Scenario	Analysis Number	Effluent Flow (mgd)	Effluent Salinity (ppt*)	Effluent Temp. (^oC)	Seasonal Condition	Diffuser Port Angle	Effective Port Diameter (in)
1	1.1	13.98	58.23	9.9	Upwelling (July)	0°	1.86
2	2.1	13.98	57.40	11.6	Davidson (Jan.)	0°	1.86
3	3.1	33.76	24.23	16.5	Davidson (Jan.)	0°	2.29
4	4.1	13.98	57.64	11.1	Oceanic (Sept.)	0°	1.86

* ppt = parts per thousand.

Receiving Water Profiles

ESA provided Flow Science with representative ocean receiving water profile data (temperature and salinity) for the three months corresponding to the selected discharge scenarios (July, January, and September). Receiving water profile data were collected by the Monterey Bay Aquarium Research Institute (MBARI) at station C1 at the head of Monterey Canyon, approximately five miles northwest of the MRWPCA wastewater ocean outfall (see **Figure 3**). This location has been occupied since 1988 by MBARI. Monthly conductivity, temperature, and depth (CTD) profiles have been collected since 2002. The proximity of the location to the MRWPCA ocean outfall and the long data record make this the most appropriate and useful data set to characterize the ambient conditions for the brine discharge analysis. Vertical profiles of temperature and salinity were analyzed for the upper 50 meters of the water column for the years 2002-2012, and a single representative profile was selected for each of the three ocean seasons. For the July model run, temperature and salinity profiles from 2011 were selected. For the September model run, profiles from 2004 were selected. For the January model runs, a temperature profile from 2004 and a salinity profile from 2011 were selected. Profile data are shown in tabular form in **Appendix B**. Maximum and minimum values for each profile are shown in **Table 4**.

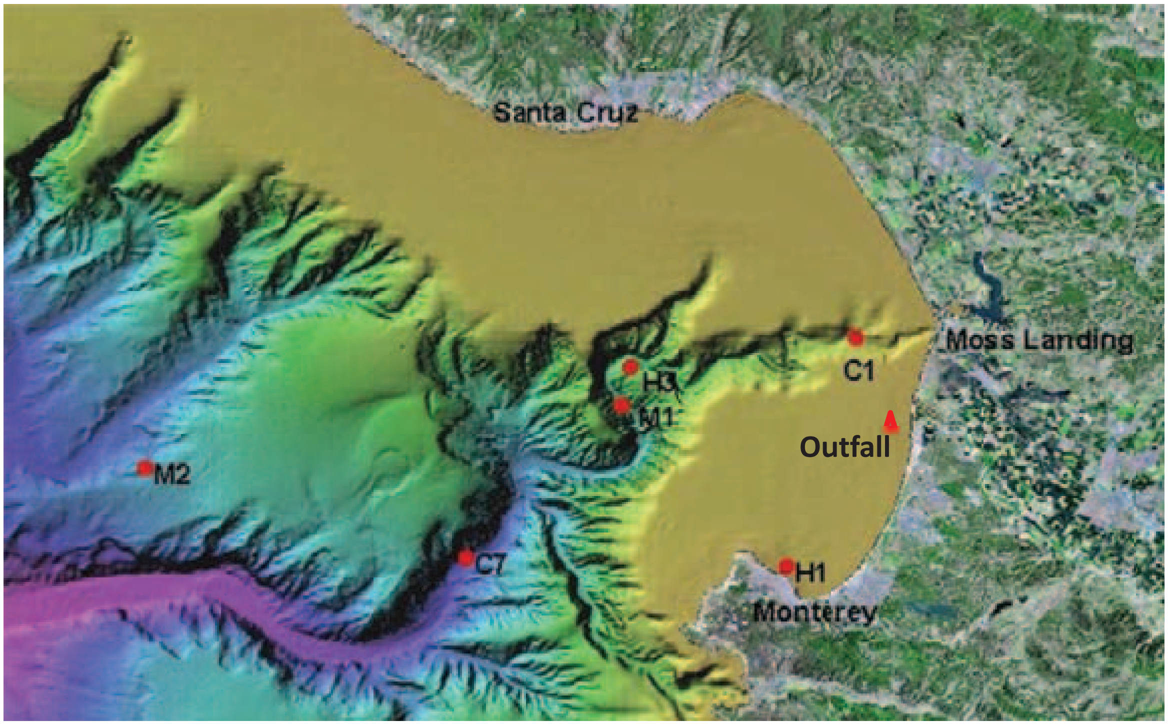

Figure 3. Location map, MBARI ocean monitoring stations and MRWPCA outfall.

Table 4 – Maximum and minimum ocean profile data.

Parameter	Season	Minimum	Maximum
Salinity (ppt)	Upwelling (July)	33.7	33.9
	Davidson (January)	33.2	33.5
	Oceanic (September)	33.5	33.6
Temperature (C^o)	Upwelling (July)	10.0	13.0
	Davidson (January)	10.7	12.7
	Oceanic (September)	10.6	15.8

Source: ESA (2013); Appendix B.

Receiving water flow conditions

As detailed in **Figure 1**, the existing diffuser ports are located just above the mid-point of the outfall pipe (i.e., below the crown of the outfall pipe), about 6 inches above the top of the ballast used to anchor the diffuser to the seafloor. Because the outfall rises above the seafloor, it will influence the patterns of currents (receiving water flow velocity) at the ports, and the current velocity at each individual port will be a complex function of the local geometry. Local field data collection would be required to characterize the actual current conditions at the diffuser ports, which was beyond the scope and budget of this analysis. To simplify the analysis, effluent dilution was analyzed for a uniform 0.0 fps current, which amounts to a "worst case," stagnant (no current) receiving water condition. Stagnant conditions are typically used as the basis for developing NPDES permits, and the California Ocean Plan (SWRCB, 2009) requires the no-current condition be used in initial dilution calculations.

3. Negatively Buoyant Plume and ZID

The effluent and ocean profiles data presented in **Tables 3** and **4** indicate the effluent is negatively buoyant for Scenarios 1, 2 and 4. A sketch of the trajectory of a negatively buoyant jet is shown in **Figure 4**, where θ_0 is the port angle, d is the port diameter, s is distance in the direction of the port centerline, n is distance in the direction perpendicular to the port centerline, z_{me} is the maximum rise of the plume, M_0 is the initial momentum flux at the point of discharge, and M_b is the buoyancy-generated momentum flux. The impact point is the location where the plume centerline returns to the port height level, and x_{0R} is the distance between the port and the impact point.

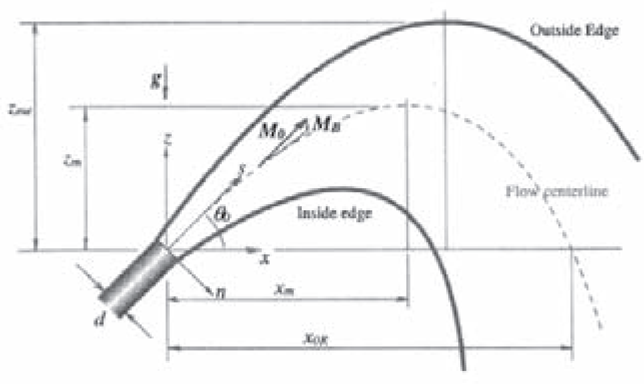

Fig. 1. Schematic diagram of the generic discharge configuration

Figure 4. Definition schematic for negatively buoyant jet (Kikkert, et al., 2007).

The methods described in the next section calculate the size of the plume and dilution of the discharged effluent within the "Zone of Initial Dilution" or ZID. The ZID is defined as the zone immediately adjacent to a discharge where momentum and buoyancy-driven mixing produces rapid dilution of the discharge. In this analysis, the ZID ends at the point where the discharge plume impacts the seafloor for a dense (sinking) plume; and for a positively buoyant (rising) effluent, the ZID ends at the point where the effluent plume reaches the water surface or attains a depth level where the density of the diluted effluent plume becomes the same as the density of ambient water (i.e., the "trap" level).

Typically, within the ZID, which is limited in size, constituent concentrations are permitted to exceed water quality standards. A discharge is generally required to meet the relevant water quality standards at the edge of the ZID.

Beyond the point where the plumes reach the seafloor, some additional mixing will occur, and the discharged brine (now diluted) will travel along the seafloor as a density current. Based on the bathymetry near the diffuser, which steadily slopes out to sea, there is no “bowl” in which effluent could accumulate indefinitely. Rather diluted effluent driven by gravity would flow downslope and gradually disperse. Estimation of the spreading of the plume on the seafloor would require detailed bathymetry data near the diffuser and use of additional analysis methods, such as a three-dimensional model or a physical model of the discharge. Similarly, the analysis of the buoyant (rising) plume within and beyond the “trap” level would require additional analysis methods. In the analysis presented here the spreading of the effluent on the seafloor, or within and beyond the trapping level and the subsequent additional dilution that would ensue, has not been analyzed. Flow Science recommends that the computed dilution at the seafloor, or at the trapping level, (i.e., at the end of the ZID), be used as the basis for any NPDES permitting activities and to analyze impacts.

4. Plume Analysis Methods

Two analysis methods have been used to evaluate the discharge of desalination brines (negatively buoyant plumes) from the MRWPCA diffuser: a semi-empirical method based on the work of Roberts et al. (1997) and Kikkert et al. (2007) and EPA’s Visual Plumes method. The Visual Plumes method was also used to model scenarios where the effluent density is less than seawater (positively buoyant, or rising, plumes). Both the semi-empirical method and Visual Plumes were used to characterize negatively buoyant plumes in order to understand the range of dilution that might be expected for discharge from the MRWPCA diffuser system. The semi-empirical method also provides some level of redundancy and confirmation of results because Visual Plumes, although widely used in diffuser discharge analysis, has only very recently been validated against limited experimental data for the case of a negatively buoyant plume. The main advantage of the semi-empirical analysis method is that it is well-grounded in empirical observations, and thus is well-tested and has been verified by comparison to a relatively large dataset for this specific discharge condition. The main disadvantage is that the semi-empirical method requires longer to complete an analysis for a given discharge scenario. The analysis techniques for these two methods are described below.

4.1 Semi-Empirical Analysis Method

Laboratory studies of negatively buoyant jets and plumes have been conducted by many researchers (e.g., Kikkert et al., 2007; Roberts et al., 1997). Most of these have been conducted for inclined jets (i.e., jets that discharge upward at an angle), which increases the initial mixing of the plume. Fewer studies are available to characterize the mixing of negatively buoyant plumes from horizontally-oriented discharge ports. In the following sections, the general equations for a negatively buoyant jet from an angled port are presented first. The equations for a horizontal discharge are then derived from the general equations.

Discharge of a negatively buoyant jet from an angled port

Plume trajectory

The trajectory of a negatively buoyant discharge under a stagnant flow condition (i.e., no ambient current) can be computed from the following equations (Kikkert, et al., 2007) (see Figure 4 for nomenclature).

$$\frac{dn_*}{ds_*} = \frac{M_{B*}\cos\theta_0}{1 - M_{B*}\sin\theta_0} \qquad (1)$$

where:

$$s_* = s/d$$
$$n_* = n/d$$

s and n are the distances in directions along and perpendicular to the discharge port centerline, respectively; d is the effective diameter of the port (see **Figure 4**); and M_{B*} is the dimensionless buoyancy-generated momentum flux, which can be calculated from Eq. (2).

$$M_{B*} = 0.154\frac{s_*^2}{F_0^2} \qquad (2)$$

where F_0 is the initial densimetric Froude number:

$$F_0 = \frac{U_0}{\sqrt{gd(\rho_0 - \rho_a)/\rho_a}}$$

where

U_0 = initial jet velocity
g = gravitational acceleration
ρ_0 = initial density of the jet
ρ_a = ambient water density

Substituting Eq. (2) into Eq. (1) and integrating gives an equation for the discharge trajectory:

$$n_* = \frac{2.6F_0}{\tan\theta_0 \sin^{1/2}\theta_0}\left[-\frac{s_* \sin^{1/2}\theta_0}{2.6F_0} + \frac{1}{2}\ln\left(\frac{2.6F_0 + s_* \sin^{1/2}\theta_0}{2.6F_0 - s_* \sin^{1/2}\theta_0}\right)\right] \qquad (3)$$

Results from Eq. (3) agreed well with experimental data (Kikkert, et al., 2007).

Discharge of a negatively buoyant jet from a horizontal port

Plume trajectory

The plume trajectory of a horizontal discharge can be estimated using the equations for an angled jet. Specifically, for a horizontal discharge (i.e., $\theta_0 = 0$), Eq. (3) simplifies to the following relationship:

$$n_* = 0.051\frac{s_*^3}{F_0^2} \qquad (4)$$

Plume dilution for a horizontal discharge

For the horizontally discharged effluent, the empirical equations from Fischer et al., 1979 (Table 9.2, pp. 328) were used to compute the width and dilution of the effluent. i.e.,

*Plume width=2*0.13*distance along plume* (5)

The plume width calculated from Eq. (5) defines the edge of the plume as the location where the concentration is 37% (= e^{-1}, which is often used to characterize plume width) of the centerline concentration.

The volume flux and dilution are specified by:

Volume flux $\mu = 0.25M^{1/2}$ **distance along plume* (6)

Dilution = μ /(discharge flow rate) (7)

where $M=QU_0$ is the initial momentum flux of the effluent (Q and U_0 are the flow rate and initial velocity of the effluent, respectively).

Note that the semi-empirical analysis uses Kikkert for the trajectory and Fischer for dilution for 0º discharges.

4.2 Visual Plumes Analysis Method

Methodology

The UM3 model—part of the EPA Visual Plumes diffuser modeling package—was used to simulate the discharge of desalination brine and wastewater from the existing MRWPCA ocean diffuser. Visual Plumes is a mixing zone computer model developed from a joint effort led by US EPA. Visual Plumes can simulate both single and merging submerged plumes, and stratified ambient flow can be specified by the user. Visual Plumes can be used to compute the plume dilution, trajectory, diameter, and other plume variables (US EPA, 2003).

The UM3 model is based on the projected area entrainment hypothesis, which assumes ambient fluid is entrained into the plume through areas projected in directions along the plume centerline and perpendicular to the centerline (US EPA, 1994). In addition, shear entrainment is included. The plume envelope is assumed to be in steady state, and as a plume element moves through the envelope, the element radius changes in response to velocity convergence or divergence, and entrainment of ambient fluid. Conservation equations of mass, momentum and energy are used to calculate plume mass and concentrations.

The actual depth of the diffuser ports varies between 95 and 109 feet below mean sea level (MSL) since the diffuser is quite long and is situated on a sloping portion of the ocean floor. However, since Visual Plumes cannot model a sloping diffuser, an average depth of 104 feet below MSL was used (the deepest 120 ports on the diffuser are assumed to discharge in this case, thereby increasing the average port depth). Modeled ocean conditions are summarized in **Table 5**.

As with the semi-empirical method, Visual Plumes assumes circular discharge ports, so the actual elliptical discharge area was calculated for each port (**Appendix A**) and then converted to an effective circular discharge diameter for use in Visual Plumes.

A study by Palomar et al. (2012a, 2012b) showed that the UM3 model of the Visual Plumes can be applied to simulate negatively buoyant discharges. However, the study also showed that the UM3 model underpredicted centerline dilution ratios at the impact point by more than 50% for a negatively buoyant effluent discharged into a stagnant environment; for a number of scenarios with negatively buoyant effluent discharged into an ambient current, centerline dilution ratios at the impact point calculated by the UM3 model ranged from 40% lower to 7% higher than experimental data. The UM3 model of the Visual Plumes was used in this analysis to model negatively buoyant effluent discharged into a stagnant environment. As noted, the study of Palomar et al. (2012a, 2012b) has shown that the centerline dilution ratios computed using the UM3 model were more than 50% lower than data from experiments with similar discharge conditions. For this reason, the average dilution ratios calculated using UM3, which are nearly double the centerline dilution ratios, were used to estimate dilution of negatively buoyant plumes in this analysis. Since Visual Plumes has been more thoroughly validated for positively buoyant plumes, it alone was used for scenarios with rising plumes.

Table 5 – Visual Plumes modeled seasonal ocean conditions.

Depth (m)	Upwelling (July)		Davidson (January)		Oceanic (September)	
	Temp. (°C)	Salinity (ppt)	Temp. (°C)	Salinity (ppt)	Temp. (°C)	Salinity (ppt)
0	12.98	33.78	12.65	33.20	15.75	33.46
2	12.87	33.77	12.65	33.22	15.75	33.46
4	12.64	33.74	12.65	33.22	15.75	33.46
6	11.97	33.71	12.65	33.23	15.53	33.46
8	11.61	33.70	12.74	33.24	14.46	33.46
10	11.34	33.70	12.57	33.26	13.81	33.46
12	11.10	33.73	12.50	33.28	13.17	33.46
14	10.84	33.75	12.42	33.30	12.27	33.46
16	10.51	33.78	12.33	33.30	11.83	33.46
18	10.38	33.79	12.24	33.30	11.52	33.46
20	10.38	33.80	12.22	33.28	11.19	33.46
22	10.38	33.80	12.07	33.30	11.06	33.46
24	10.38	33.82	12.05	33.30	11.22	33.49
26	10.38	33.82	11.90	33.30	11.39	33.50
28	10.38	33.84	11.81	33.32	11.39	33.50
30	10.38	33.84	11.71	33.34	11.31	33.50
32	10.37	33.84	11.71	33.37	11.23	33.50
34	10.31	33.84	11.63	33.39	11.22	33.50
36	10.30	33.84	11.63	33.42	11.05	33.50
38	10.30	33.84	11.54	33.43	10.97	33.50

Source: Interpolated from ESA | Water (2013) ocean profile data, Appendix B.

5. Dilution Results

Several key results for the effluent plumes are reported at the edge of the ZID. As noted above, the ZID is defined as the zone immediately adjacent to a discharge where momentum and buoyancy-driven mixing produces rapid dilution of the discharge. Results for positively buoyant plumes presented in this Technical Memorandum were taken at the point where the plumes just reached the trap level, which is the depth level where the density of the diluted plume becomes the same as ambient seawater. Horizontal spreading of plumes at their trap levels was not included in this analysis. Results from each scenario generally include the following quantities:

- the horizontal distance from the diffuser port to the point at which the plume impacts the seafloor or reaches the trap level
- the dilution of the plume at the point at which the plume impacts the seafloor or reaches the trap level; for the semi-empirical method and the Visual Plumes analyses of rising plumes, centerline dilution is provided, while for the Visual Plumes analyses of negatively buoyant discharges, the average dilution within the plume is provided, in recognition of the conservative nature of Visual Plumes results for negatively buoyant plumes (see, e.g., Palomar et al., 2012a and 2012b)
- an estimate of the size of the plume (diameter) at the point of impact or just below the trap level (i.e., at the edge of the ZID)
- the maximum salinity at the seafloor (edge of ZID for negatively buoyant plumes)
- the percentage by which the maximum plume salinity at the seafloor (edge of ZID for negatively buoyant plumes) exceeds the ambient salinity.

Figure 5 shows a sample schematic graphic of the trajectory of a negatively buoyant plume from a horizontal discharge drawn approximately to scale. As the effluent travels away from the discharge port, it entrains ambient seawater, which increases the diameter of the plume and decreases the plume concentration.

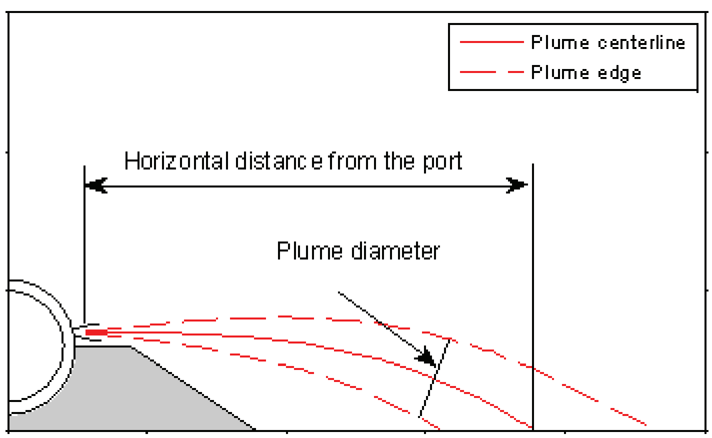

Figure 5. Sample graphic showing plume trajectory for the horizontal discharge configuration.

Table 6 presents analysis results for the four modeled scenarios. The plume in analysis 3.1 was positively buoyant (i.e., had discharge densities less than ambient seawater). This is because the plume in this analysis was a mixture of desalination brine and relatively significant amounts of comparatively non-saline (i.e., "fresh") wastewater effluent. For all other analyses the plumes were negatively buoyant (i.e., water denser than ambient seawater is discharged) since they consisted only of desalination brine, which is more dense than regular seawater. Results in **Table 6** show that the trajectory, diameter and dilution of the negatively buoyant plumes were nearly the same across all three modeled seasons, because the trajectories of these negatively buoyant plumes were short and close to the seafloor, where the differences in salinity and temperature (hence the difference in density) between the effluent and ambient sea water changed only slightly over the modeled seasons. Therefore for brine only cases, characteristics of the resulting plumes were nearly the same for the three modeled scenarios.

Dilution values predicted by the semi-empirical method were lower than the dilution values predicted by the Visual Plumes method. The predicted maximum plume salinity at the seafloor was 1.5 ppt above ambient ocean salinity.

Figures 6 and **7** illustrate the trajectory and shape of the negatively buoyant plume computed from Visual Plumes for Analysis 1.1 (as listed in **Table 3** and **Table 6**). **Figure 8** is an illustration of positively buoyant plumes just reaching the trap level, as computed from Visual Plumes for Analysis 3.1. Spreading of the plume within and beyond the trap level is not shown. Plumes computed for other scenarios have similar trajectories and shape as shown in these figures.

Table 6– Analysis results.

Analysis number	Effluent discharge flow rate (mgd)	Discharge Velocity (feet/ second)	Seasonal Condition	Diffuser port angle (θ_o)	Effluent salinity (ppt)	Ocean bkgrd. salinity at diffuser depth (ppt)	Semi-empirical method						VP method					
							Plume diam. (d) (inch)	Center-line Dilution	Horiz. Distance from port (ft)	Max. height above port (z_{me}) (ft)	Plume salinity at calc. dilution (ppt)	Salinity increase above ambient (ppt)	Plume diam. (inch)	Average Dilution	Horiz. Distance from port (ft)	Max. height above port (z_{me}) (ft)	Plume salinity at calc. dilution (ppt)	Salinity increase above ambient (ppt)
1.1	13.98	9.5	Upwelling (July)	0^o	58.23	33.84	36	16	12	--	35.36	1.5	42	25	8.6	--	34.82	1.0
2.1	13.98	9.5	Davidson (Jan.)	0^o	57.40	33.36	37	16	12	--	34.83	1.5	42	25	8.7	--	34.30	0.9
3.1	33.76	15.2	Davidson (Jan.)	0^o	24.23	33.36	--	--	--	--	--	--	230	68 [a]	47	32 [b]	--	--
4.1	13.98	9.5	Oceanic (Sept.)	0^o	57.64	33.50	35	16	12	--	35.01	1.5	42	25	8.7	--	34.47	1.0

Source: Flow Science Analysis, 2014.

[a] For Analysis 3.1, the dilution value is centerline dilution because the Visual Plumes model has been validated for positively buoyant plumes and no significant underprediction of dilution has been reported.

[b] These values are trap levels above the diffuser.

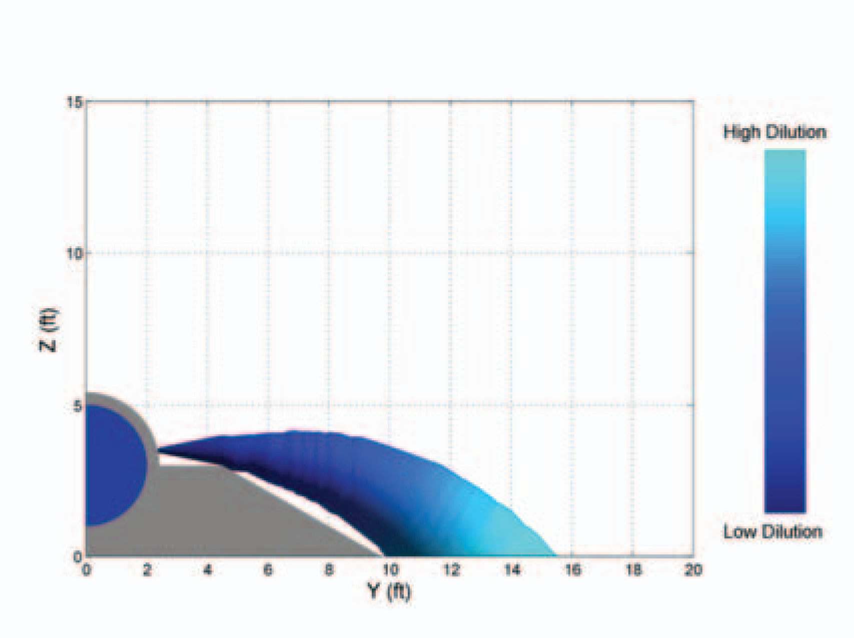

Figure 6. Analysis 1.1 (13.98 mgd, 58.23 ppt), plume computed from VP. Minimum dilution at seafloor is 25 (maximum salinity of 34.82 ppt).

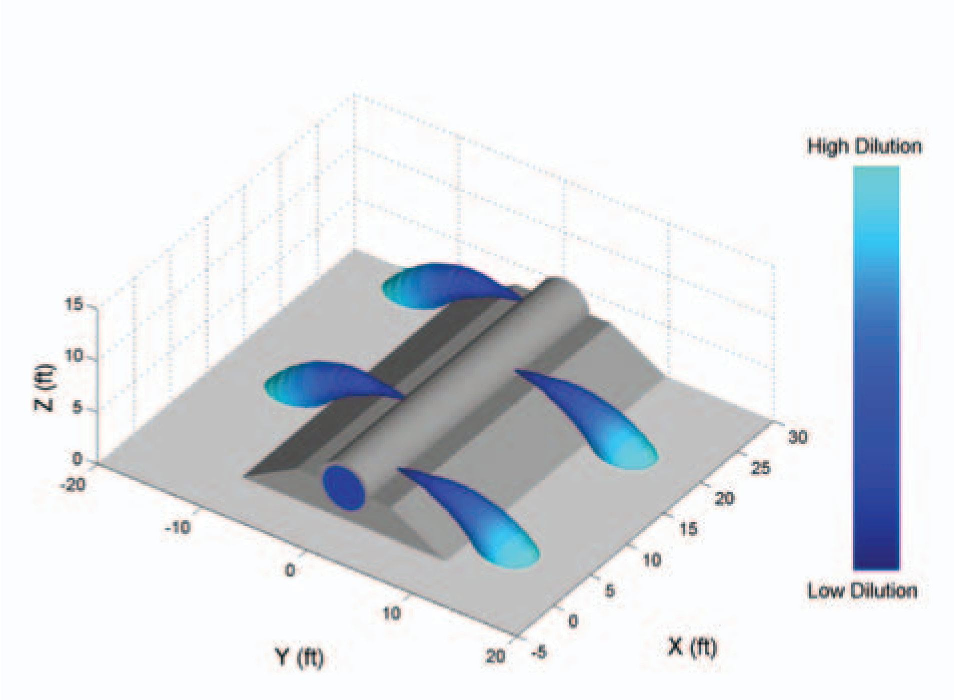

Figure 7. Analysis 1.1 (13.98 mgd, 58.23 ppt), plume computed from VP (3D view, only 4 ports are shown). Minimum dilution at seafloor is 25 (maximum salinity of 34.82 ppt).

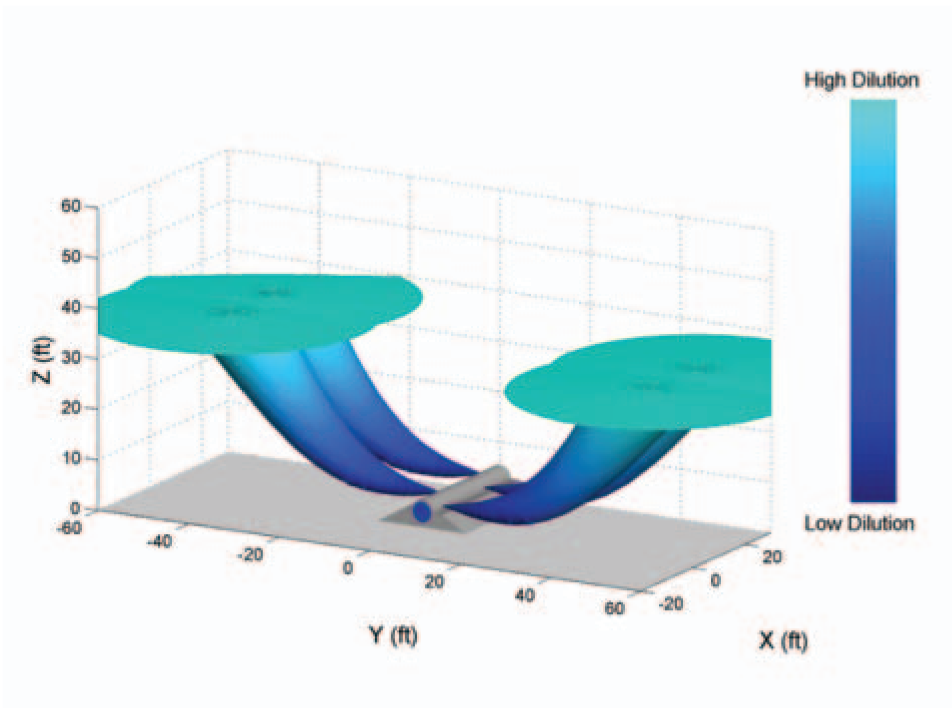

Figure 8. An illustration of the positively buoyant effluent plumes of Analysis 3.1. Note that only four diffuser ports are illustrated.

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APPENDIX A – DUCKBILL VALVE, EFFECTIVE OPEN AREA

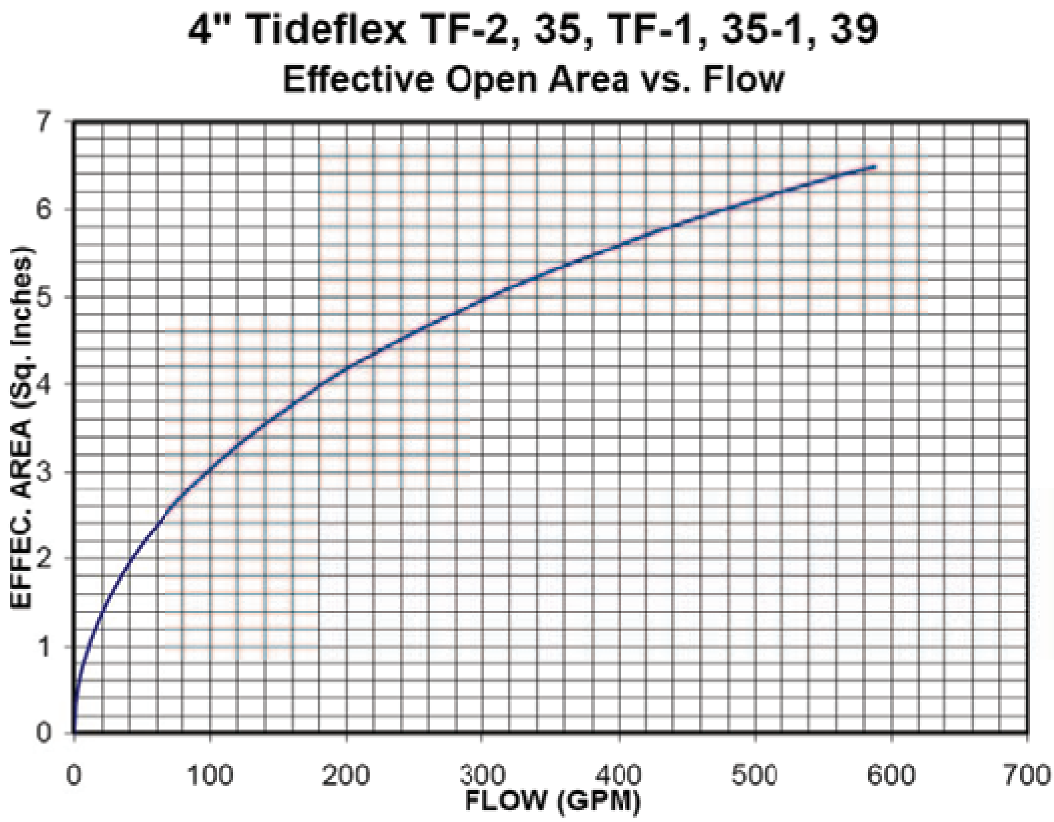

Chart provided by Tideflex Technologies.

APPENDIX B – AMBIENT OCEAN PROFILE DATA

**Table B1- Ambient ocean profile data, MBARI station C1
(Source: ESA)**

Upwelling (July)				Transition-Oceanic (Sept)				Davidson (Jan)			
2011 Profile		2011 Profile		2004.2 Profile		2004.1 Profile		2011 Profile		2004 Profile	
S (ppt)	Z (m)	T (^{o}C)	Z (m)	S (ppt)	Z (m)	T (^{o}C)	Z (m)	S (ppt)	Z (m)	T (^{o}C)	Z (m)
33.78	-0.93	12.98	-0.59	33.46	-3.30	15.83	-4.22	33.20	-0.41	12.65	-2.35
33.76	-1.97	12.91	-1.63	33.46	-4.29	15.66	-4.22	33.22	-0.40	12.65	-2.35
33.78	-1.98	12.84	-2.68	33.46	-5.28	15.66	-5.22	33.22	-1.44	12.65	-3.34
33.78	-3.03	12.77	-2.68	33.46	-6.28	15.75	-6.21	33.22	-2.47	12.65	-4.33
33.76	-4.06	12.77	-3.73	33.46	-7.27	15.83	-6.21	33.22	-3.51	12.65	-5.32
33.74	-4.05	12.70	-3.73	33.46	-8.27	15.75	-6.21	33.22	-4.54	12.65	-6.31
33.72	-4.04	12.63	-4.78	33.46	-9.26	15.66	-6.21	33.22	-5.57	12.65	-7.30
33.74	-5.10	12.56	-4.78	33.46	-10.25	15.23	-6.21	33.22	-6.61	12.74	-7.30
33.72	-5.09	12.35	-4.80	33.46	-11.25	15.15	-6.21	33.24	-6.60	12.74	-8.29
33.70	-6.13	12.28	-4.80	33.46	-12.24	15.06	-6.21	33.24	-7.63	12.65	-8.29
33.70	-7.17	12.21	-4.80	33.46	-13.23	14.98	-7.21	33.26	-8.65	12.57	-9.29
33.70	-8.22	12.14	-4.81	33.46	-14.23	14.89	-7.21	33.26	-9.69	12.57	-10.28
33.70	-9.27	12.07	-5.85	33.46	-15.22	14.81	-7.21	33.28	-10.71	12.57	-11.27
33.70	-10.32	12.00	-5.86	33.46	-16.22	14.72	-7.21	33.28	-11.74	12.48	-12.27
33.72	-11.37	11.93	-5.86	33.46	-17.21	14.64	-7.21	33.30	-12.77	12.48	-13.26
33.74	-12.43	11.86	-6.91	33.46	-18.20	14.55	-7.21	33.30	-13.80	12.39	-14.26
33.74	-13.48	11.79	-6.91	33.46	-19.20	14.47	-8.20	33.30	-14.83	12.39	-15.25
33.74	-14.52	11.72	-6.92	33.46	-20.19	14.38	-8.20	33.30	-15.87	12.31	-16.24
33.76	-14.53	11.65	-7.97	33.46	-21.18	14.30	-8.20	33.30	-16.90	12.31	-17.23
33.78	-15.59	11.58	-7.97	33.46	-22.18	14.21	-9.19	33.30	-17.93	12.22	-18.23
33.78	-16.64	11.51	-9.02	33.46	-23.17	14.12	-9.19	33.30	-18.97	12.22	-19.22
33.78	-17.69	11.44	-9.02	33.50	-24.16	14.04	-9.19	33.28	-20.01	12.22	-20.21
33.80	-18.74	11.36	-10.07	33.50	-25.16	13.95	-9.19	33.28	-21.05	12.14	-21.21
33.80	-19.79	11.29	-10.07	33.50	-26.15	13.87	-10.19	33.30	-22.07	12.05	-22.20
33.80	-20.84	11.29	-11.11	33.50	-27.14	13.78	-10.19	33.30	-23.10	12.05	-23.19
33.80	-21.89	11.22	-11.12	33.50	-28.14	13.70	-10.19	33.30	-24.14	12.05	-24.19
33.80	-22.93	11.15	-11.12	33.50	-29.13	13.61	-10.19	33.30	-25.17	11.97	-25.18
33.82	-23.99	11.08	-11.13	33.50	-30.12	13.53	-11.18	33.30	-26.20	11.88	-26.18
33.82	-25.04	11.08	-12.17	33.50	-31.12	13.44	-11.18	33.32	-27.23	11.88	-27.17
33.82	-26.08	11.01	-13.22	33.50	-32.11	13.36	-12.17	33.32	-28.26	11.80	-28.16
33.82	-27.13	10.94	-13.22	33.50	-33.11	13.27	-12.17	33.34	-29.28	11.80	-29.16
33.84	-28.19	10.87	-13.22	33.50	-34.10	13.19	-12.17	33.34	-30.32	11.71	-29.16
33.84	-29.24	10.80	-14.27	33.50	-35.09	13.10	-12.17	33.36	-31.34	11.71	-30.15
33.84	-30.28	10.73	-15.32	33.50	-36.09	13.02	-12.17	33.38	-32.36	11.71	-31.14
33.84	-31.33	10.66	-15.32	33.50	-37.08	12.93	-12.17	33.38	-33.40	11.71	-32.13
33.84	-32.38	10.59	-15.33	33.50	-38.07	12.85	-12.17	33.40	-34.42	11.63	-33.13
33.84	-33.42	10.52	-15.33	33.50	-39.07	12.76	-13.17	33.42	-35.44	11.63	-34.12
33.84	-34.47	10.45	-16.38	33.50	-40.06	12.67	-13.17	33.42	-36.48	11.63	-35.11
33.84	-35.52	10.38	-17.42	33.50	-41.06	12.59	-13.17	33.42	-37.51	11.63	-36.10
33.84	-36.57	10.38	-18.46	33.50	-42.05	12.50	-13.17	33.44	-38.53	11.54	-37.10
33.84	-37.61	10.38	-19.51	33.50	-43.04	12.42	-13.17	33.44	-39.57	11.54	-38.09
33.84	-38.66	10.38	-20.55	33.54	-44.03	12.33	-14.16	33.44	-40.60	11.46	-39.09
33.84	-39.71	10.38	-21.59	33.54	-45.03	12.25	-14.16	33.44	-41.64	11.37	-40.08
33.84	-40.75	10.38	-22.63	33.54	-46.02	12.16	-14.16	33.46	-42.66	11.29	-41.08
33.84	-41.80	10.38	-23.67	33.54	-47.01	12.08	-14.16	33.46	-43.69	11.20	-42.07
33.84	-42.85	10.38	-24.71	33.54	-48.01	11.99	-15.16	33.46	-44.73	11.20	-43.06
33.84	-43.90	10.38	-25.76	33.57	-49.00	11.91	-15.16	33.46	-45.76	11.20	-44.05
33.84	-44.94	10.38	-26.80	33.57	-49.99	11.82	-15.16	33.46	-46.79	11.12	-45.05

Table B1 (continued)

Upwelling (July)				Transition-Oceanic (Sept)				Davidson (Jan)			
2011 Profile		2011 Profile		2004.2 Profile		2004.1 Profile		2011 Profile		2004 Profile	
S (ppt)	Z (m)	T (^{o}C)	Z (m)	S (ppt)	Z (m)	T (^{o}C)	Z (m)	S (ppt)	Z (m)	T (^{o}C)	Z (m)
33.84	-45.99	10.38	-27.84			11.82	-16.15	33.48	-47.82	11.03	-46.05
33.86	-47.05	10.38	-28.88			11.74	-17.14	33.50	-48.84	11.03	-47.04
33.86	-48.09	10.38	-29.92			11.65	-18.14	33.50	-49.87	10.95	-48.03
33.86	-49.14	10.38	-30.97			11.57	-18.14	33.51	-50.90	10.86	-49.03
33.86	-50.19	10.37	-32.01			11.48	-18.14	33.51	-51.93	10.86	-50.02
33.86	-51.23	10.37	-33.05			11.39	-18.14	33.53	-52.95	10.77	-51.01
33.86	-52.28	10.30	-34.09			11.31	-18.14	33.53	-53.99	10.77	-52.01
		10.30	-35.14			11.22	-19.13			10.77	-53.00
		10.30	-36.18			11.22	-20.12			10.69	-53.99
		10.30	-37.22			11.14	-20.12			10.69	-54.98
		10.30	-38.26			11.14	-21.12				
		10.30	-39.30			11.05	-21.12				
		10.30	-40.34			11.05	-22.11				
		10.30	-41.39			11.14	-23.11				
		10.30	-42.43			11.22	-24.10				
		10.23	-43.47			11.31	-25.09				
		10.23	-44.52			11.39	-26.09				
		10.16	-45.56			11.39	-27.08				
		10.16	-46.60			11.39	-28.07				
		10.16	-47.65			11.39	-29.07				
		10.09	-48.69			11.31	-30.06				
		10.09	-49.73			11.31	-31.06				
		10.09	-50.78			11.22	-32.05				
		10.02	-51.82			11.22	-33.04				
						11.22	-34.04				
						11.14	-35.03				
						11.05	-36.02				
						11.05	-37.02				
						10.97	-38.01				
						10.88	-39.01				
						10.88	-40.00				
						10.88	-40.99				
						10.88	-41.99				
						10.80	-42.98				
						10.79	-43.98				
						10.79	-44.97				
						10.71	-45.96				
						10.71	-46.96				
						10.62	-47.95				
						10.62	-48.94				
						10.62	-49.94				
						10.62	-50.93				
						10.62	-51.93				
						10.62	-52.92				
						10.62	-53.91				

APPENDIX C – ANALYSES FOR ADDITIONAL SCENARIOS

TECHNICAL MEMORANDUM

DATE: August 25, 2014

TO: Environmental Science Associates (ESA)

FROM: Gang Zhao, Ph.D., P.E., Aaron Mead, P.E., E. John List, Ph.D., P.E.

SUBJECT: **MRWPCA Brine Discharge Diffuser Analysis – Additional Scenarios FSI 134032**

1. Introduction

In August 2014, Flow Science performed additional modeling analyses to evaluate the dilution of the desalination brines that may be generated in the future from two primary sources (the proposed Monterey desalination facility and the Groundwater Replenishment Project (GWR Project)). A mixture of brines from these two sources was also evaluated. Specifically, Flow Science modeled thirteen (13) additional discharge scenarios; calculated the desalination brine discharge rate that would be required to achieve a mixed salinity that would be at most 2 ppt above ambient salinity at the seafloor; and calculated the amount of seawater or treated wastewater that would be required to pre-dilute the desalination brine such that the mixed effluent would cause an increase of no more than 2 ppt above ambient salinity at the seafloor. Dilution analyses were conducted using both a semi-empirical method and USEPA's Visual Plumes suite of models, and dilution was evaluated for three seasonal conditions [Davidson current (January), Upwelling conditions (July), and Oceanic conditions (September)]. These analyses are part of the EIR preparation process for the planned Monterey Peninsula Water Supply Project, and the discharge scenarios presented in this Technical Memorandum supplement the discharge scenarios analyzed by Flow Science and presented in a previous Technical Memorandum (Flow Science 2014).

This Technical Memorandum (TM) describes the input data and the analysis methodology used by Flow Science to evaluate the dilution of desalination brines and summarizes the results of the dilution analyses.

2. Analysis Input Data

Discharge Scenarios

In August 2014, Flow Science performed additional analyses for the Monterey Peninsula Water Supply Project. The three tasks that made up these additional modeling analyses are summarized below.

Task 1. Model 13 additional discharge scenarios as specified in ESA's e-mail of October 10, 2013 and presented in **Table C1** below.

Task 2. Calculate the desalination brine discharge rate required to achieve a mixed salinity that is less than 2 ppt above ambient salinity at the impact point for the three seasonal conditions summarized in **Table C3**. No pre-dilution of the desalination brine was assumed for this task. A series of discharge rates were analyzed to determine the discharge rate required to keep the effluent salinity less than 2 ppt above ambient salinity.

Task 3. Calculate the amount of pre-dilution required for the desalination brine to achieve the less than 2 ppt salinity exceedance at the impact point for the mixed effluent. For this task, it was assumed that ambient seawater or treated wastewater would be used to pre-dilute the desalination brine before discharging to the outfall. A flow rate of 13.98 mgd was used for the desalination brine. Properties of the seawater and wastewater used to pre-dilute the brine are summarized in **Table C3**.

Table C1 – Discharge scenarios

Discharge Condition	Ambient Condition & Effluent Component[a,b]	Scenario Number	Discharge (mgd)[c]	Discharge Salinity (ppt)[d]	Discharge Temperature (^{o}C)
Existing	Davidson (Jan) WW	0.0	19.78	0.8	20.0
Desal Project Only	Upwelling (July) BR	5.1	8.99	58.23	9.9
	Davidson (Jan) BR	6.1	8.99	57.40	11.6
	Davidson (Jan) BR+WW	7.1	28.77	18.48	17.4
	Oceanic (Sept) BR	8.1	8.99	57.64	11.1
Desal Project	Upwelling (July) BR+GWR	9.1	9.72	54.16	11.0

Discharge Condition	Ambient Condition & Effluent Component[a,b]	Scenario Number	Discharge (mgd)[c]	Discharge Salinity (ppt)[d]	Discharge Temperature (^oC)
with GWR	Davidson (Jan) BR+GWR	10.1	9.72	53.39	12.2
	Davidson (Jan) + BR+GWR+WW	11.1	25.64	20.73	17.1
	Oceanic (Sept) BR+GWR	12.1	9.72	53.61	12.1
GWR Only	Upwelling (July) GWR	13.1	0.73	4	24.4
	Davidson (Jan) GWR	14.1	0.73	4	20.2
	Davidson (Jan) GWR+WW	15.1	16.65	0.93	20.0
	Oceanic (Sept) GWR	16.1	0.73	4	24.4

[a] BR: desalination brine. WW: wastewater. GWR: Monterey Peninsula Groundwater Replenishment Project.

[b] Salinity and temperature of the combined discharges were calculated as flow-weighted averages of BR, WW and GWR salinity and temperature data provided by ESA.
[c] mgd: million gallons per day.
[d] ppt: part per thousand.

Diffuser Configuration

The existing MRWPCA diffuser has 172 ports. Half of the ports discharge horizontally from one side of the diffuser and half discharge horizontally from the other side of the diffuser, in an alternating pattern. The ports are approximately 6 inches above the rock bedding of the diffuser pipeline, and drawings[2] (see **Figure C1**) indicate that they are located a minimum of approximately 3.5 feet above the seafloor. The gravel bedding dimensions are nominal, as shown in **Figure C1**, and therefore, the port height above the seafloor cannot be determined with high accuracy. Momentum of the effluent is a key factor in determining the dilution within the ZID. Toward the end of the ZID, the plume slows down and mixing is not as strong as at the beginning of the ZID. Therefore, the dilution results are not likely to change by much if the port height is off slightly. Considering the overall uncertainty in the analysis, it is not critical to determine the diffuser port height with high accuracy. According to MRWPCA, the fifty-two (52) ports nearest to the shore (i.e., the shallowest ports) are currently closed. In this analysis, Flow

[2] Section F, Drawing P-0.03, Contract Documents Volume 1 of 1: Ocean Outfall Contract No. 2.1, January 1982 by Engineering Science for MRWPCA

Science calculated plume concentrations for effluent discharged horizontally through the 120 open ports. A typical section of the current diffuser is shown in **Figure C1**, although the actual cross-sectional profile of the pipe type 3 rock may have changed over time. In this analysis, it was assumed that effluent plumes do not interact with the ballast. Details of the current diffuser configuration are summarized in **Table C2**.

Table C2 – Current diffuser configuration.

Parameter	Value
Diffuser length	1368 feet (417 m*)
Depth of diffuser ports	95 to 109 feet below MSL
Number of open ports	120
Port spacing	8 feet (2.44 m*)
Port diameter	2 inches (0.051 m*)
Port exit condition	Tideflex Series 35 4-inch duckbill valves
Port vertical angle	0° (horizontal)
Port elevation above sea floor	3.5 feet (1.07 m*)

*m = meters

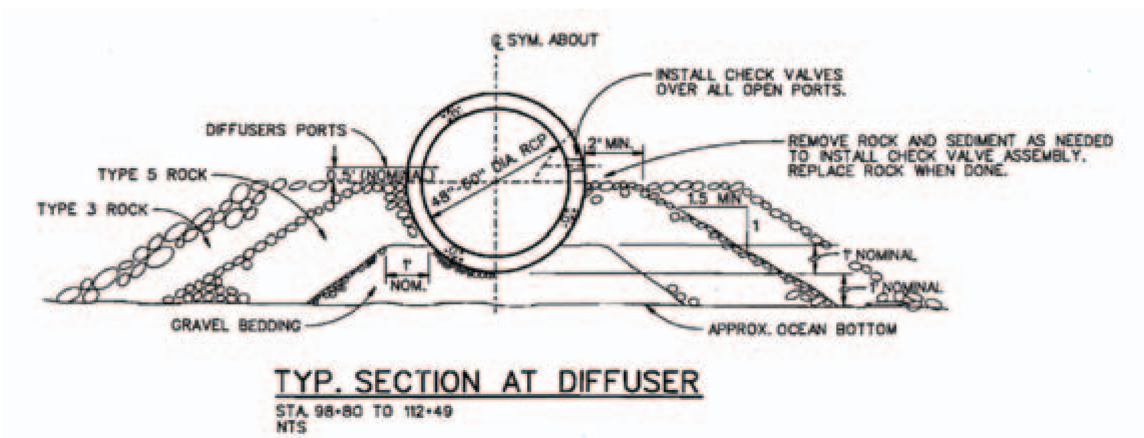

Figure C1. Typical diffuser section (currently in place).

The 120 ports that are currently open are fitted with Tideflex "duckbill" check valves, as shown in **Figure C2**. The shape of the duckbill valve opening is elliptic, and the area of the opening depends on the discharge flow rate. The valve opening area in this analysis was determined from an effective open area curve provided by Tideflex Technologies (included as **Appendix A**). Although the ports were modeled as round openings with the same opening area as the "duckbill" valves, the actual dilution will be higher than the dilution computed assuming circular ports because of the oblateness of the actual port opening.

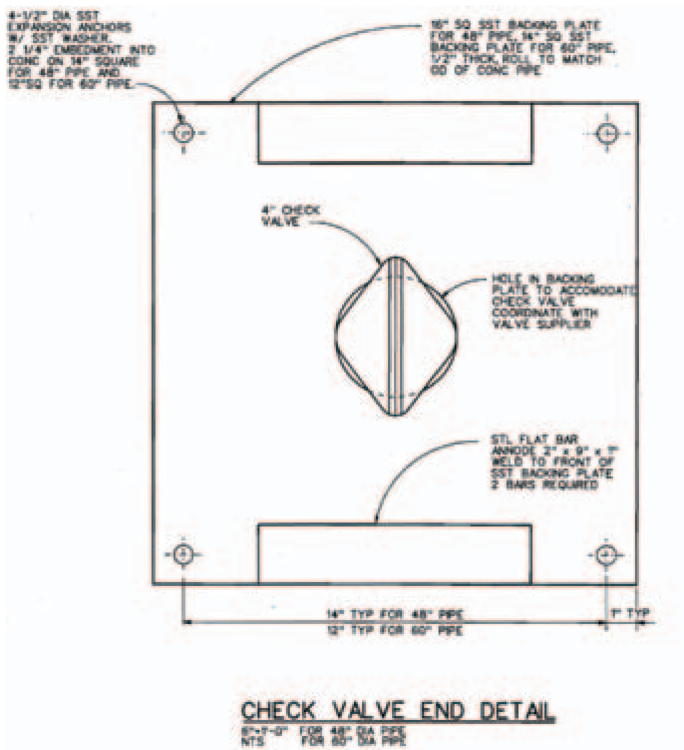

Figure C2. Typical "duckbill" valve detail (shown closed, i.e., with no flow).

Discharge Characteristics

Salinity (or total dissolved solids [TDS]) and temperature data for the brine, GWR concentrate, ambient seawater and the MRWPCA wastewater were provided by ESA. TDS is a measure of water salinity, and salinity and temperature are used to calculate the density of the effluent and ambient ocean water, which are important parameters in dilution analyses.

As summarized in **Table C3** below, ESA selected three seasonal ocean conditions for analysis: Upwelling (July), Davidson (January), and Oceanic (September). Therefore, discharge rate, temperature, and salinity/TDS data for these months were used in the analysis. For each discharge scenario, the desalination brine(s) and water from other sources were assumed to be fully mixed prior to discharge from the diffuser. Thus, the temperature and salinity of the combined flow were calculated as the flow-weighted average temperature and salinity of the brine and wastewater.

Table C3 – Three seasonal conditions of the desalination brine

Effluent Discharge Season	Brine		Pre-dilution Seawater		Wastewater	
	Salinity (ppt)	Temp. (C^o)	Salinity (ppt)	Temp. (C^o)	Salinity (ppt)	Temp. (C^o)
July (Upwelling)	58.23	9.9	33.8	9.9	0.8	24
January (Davidson)	57.40	11.6	33.4	11.6	0.8	20
September (Oceanic)	57.64	11.1	33.5	11.1	0.9	24

Source: average values provided by ESA.

Receiving Water Profiles

ESA provided Flow Science with representative ocean receiving water profile data (temperature and salinity) for the three months corresponding to the selected discharge scenarios (July, January, and September). Receiving water profile data were collected by the Monterey Bay Aquarium Research Institute (MBARI) at Station C1 at the head of Monterey Canyon, approximately five miles northwest of the MRWPCA wastewater ocean outfall (see **Figure C3**). This location has been occupied since 1988 by MBARI. Monthly conductivity, temperature, and depth (CTD) profiles have been collected since 2002. The proximity of the location to the MRWPCA ocean outfall and the extended data record make this the most appropriate and useful data set to characterize the ambient conditions for the brine discharge analysis. Vertical profiles of temperature and salinity were analyzed for the upper 50 meters of the water column for the years 2002-2012, and a single representative profile was selected for each of the three ocean seasons. For the July model runs, temperature and salinity profiles from 2011 were selected. For the September model runs, profiles from 2004 were selected. For the January model runs, a temperature profile from 2004 and a salinity profile from 2011 were selected. Profile data are shown in tabular form in **Appendix B**. Maximum and minimum values for each profile are shown in **Table C4**, and profile values used in this analysis for the three seasonal conditions are shown in **Table C5**.

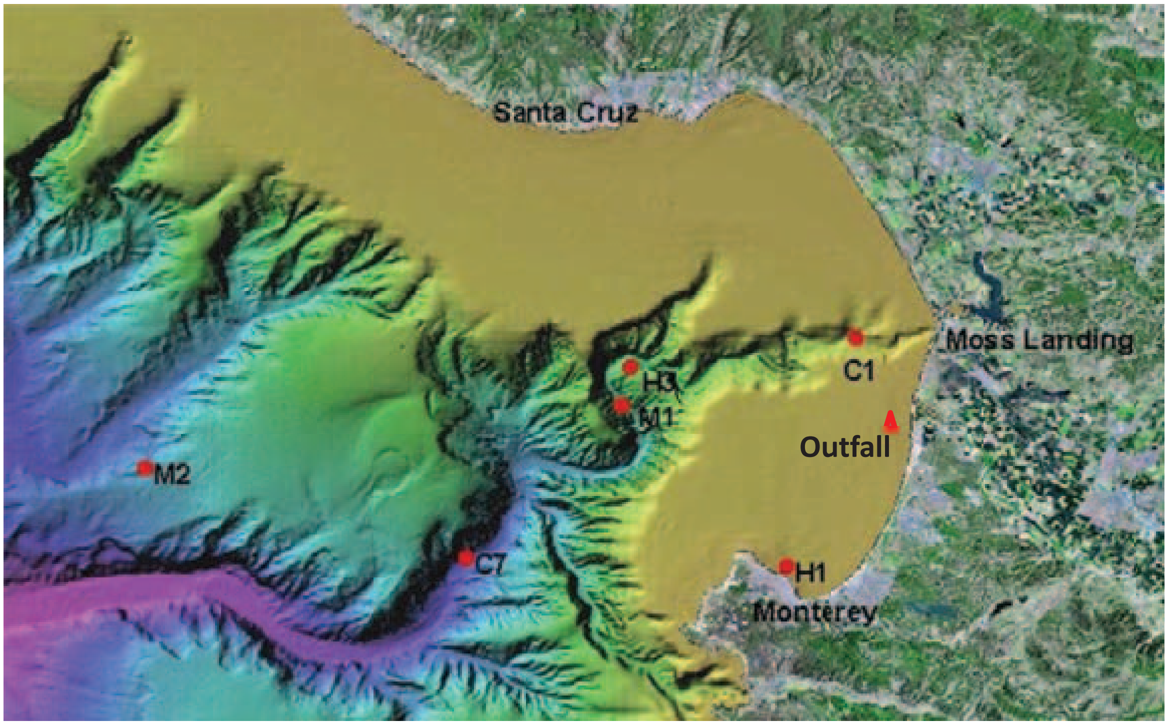

Figure C3. Location map, MBARI ocean monitoring stations and MRWPCA outfall.

Table C4 – Maximum and minimum ocean profile data.

Parameter	Season	Minimum	Maximum
Salinity (ppt)	Upwelling (July)	33.7	33.9
	Davidson (January)	33.2	33.5
	Oceanic (September)	33.5	33.6
Temperature (C^o)	Upwelling (July)	10.0	13.0
	Davidson (January)	10.7	12.7
	Oceanic (September)	10.6	15.8

Source: ESA (2013); Appendix B.

Table C5 – Modeled seasonal ocean conditions.

Depth (m)	Upwelling (July)		Davidson (January)		Oceanic (September)	
	Temp. (^{o}C)	Salinity (ppt)	Temp. (^{o}C)	Salinity (ppt)	Temp. (^{o}C)	Salinity (ppt)
0	12.98	33.78	12.65	33.20	15.75	33.46
2	12.87	33.77	12.65	33.22	15.75	33.46

Depth (m)	Upwelling (July)		Davidson (January)		Oceanic (September)	
	Temp. (°C)	Salinity (ppt)	Temp. (°C)	Salinity (ppt)	Temp. (°C)	Salinity (ppt)
4	12.64	33.74	12.65	33.22	15.75	33.46
6	11.97	33.71	12.65	33.23	15.53	33.46
8	11.61	33.70	12.74	33.24	14.46	33.46
10	11.34	33.70	12.57	33.26	13.81	33.46
12	11.10	33.73	12.50	33.28	13.17	33.46
14	10.84	33.75	12.42	33.30	12.27	33.46
16	10.51	33.78	12.33	33.30	11.83	33.46
18	10.38	33.79	12.24	33.30	11.52	33.46
20	10.38	33.80	12.22	33.28	11.19	33.46
22	10.38	33.80	12.07	33.30	11.06	33.46
24	10.38	33.82	12.05	33.30	11.22	33.49
26	10.38	33.82	11.90	33.30	11.39	33.50
28	10.38	33.84	11.81	33.32	11.39	33.50
30	10.38	33.84	11.71	33.34	11.31	33.50
32	10.37	33.84	11.71	33.37	11.23	33.50
34	10.31	33.84	11.63	33.39	11.22	33.50
36	10.30	33.84	11.63	33.42	11.05	33.50
38	10.30	33.84	11.54	33.43	10.97	33.50

Source: Interpolated from ESA | Water (2013) ocean profile data, Appendix B.

Receiving water flow conditions

As detailed in **Figure C1**, the existing diffuser ports are located just above the mid-point of the outfall pipe (i.e., below the crown of the outfall pipe), about 6 inches above the top of the ballast used to anchor the diffuser to the seafloor. Because the outfall rises above the seafloor, it will influence the patterns of currents (receiving water flow velocity) at the ports, and the current velocity at each individual port will be a complex function of the local geometry. Ocean currents increase the amount of dilution that occurs because they increase the flow of ambient water past the diffuser (i.e., increase the amount of ambient water available for mixing with the discharge). However, due to the complex outfall geometry, local field data collection would be required to characterize the actual current conditions and ambient turbulence levels at the diffuser ports, which was beyond the scope and budget of this analysis. To simplify the analysis, effluent dilution was analyzed for a uniform 0.0 fps current, which amounts to a “worst case,” stagnant (no current) receiving water condition. Stagnant conditions are typically used as the basis for developing NPDES permits, and the California Ocean Plan (SWRCB, 2009) requires the no-current condition be used in initial dilution calculations.

3. Trajectory and ZID of a Negatively Buoyant Plume

The effluent and ocean profiles data presented in **Tables C1 and C5** indicate the effluent is negatively buoyant for some scenarios. A schematic sketch of the trajectory of a negatively buoyant jet is shown in **Figure C4**, where θ_0 is the port angle, d is the port diameter, s is distance in the direction of the port centerline, n is distance in the direction perpendicular to the port centerline, z_{me} is the maximum rise of the plume, M_0 is the initial momentum flux at the point of discharge, and M_b is the buoyancy-generated momentum flux. x_{0R} is the horizontal distance between the port and the point where the plume centerline returns to the port height level. In this analysis, the diffuser ports are about 3.5 ft above seafloor, and the impact point is the location where the plume centerline reaches seafloor.

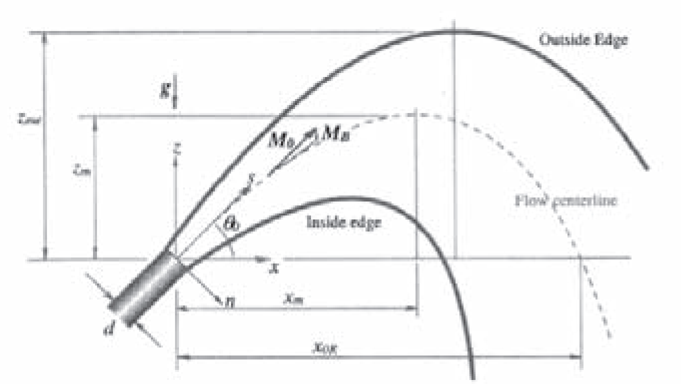

Fig. 1. Schematic diagram of the generic discharge configuration

Figure C4. Definition schematic for negatively buoyant jet (Kikkert, et al., 2007).

The methods described in **Section 4** were used to calculate the size of the plume and dilution of the discharged effluent within the “Zone of Initial Dilution,” or ZID. The ZID is defined as the zone immediately adjacent to a discharge where momentum and buoyancy-driven mixing produces rapid dilution of the discharge. In this analysis, the ZID ends at the point where the discharge plume impacts the seafloor for a dense (sinking) plume; for a positively buoyant (rising) effluent, the ZID ends at the point where the effluent plume reaches the water surface or attains a depth level where the density of the diluted effluent plume becomes the same as the density of ambient water (i.e., the “trap” level). Typically, within the ZID, which is limited in size, constituent concentrations are permitted to exceed water quality standards. A discharge is generally required to meet the relevant water quality standards at the edge of the ZID.

Beyond the point where the plumes reach the seafloor, some additional mixing will occur, and the discharged brine (now diluted) will travel along the seafloor as a density current. Based on the bathymetry near the diffuser, which steadily slopes out to sea, there is no “bowl” in which effluent could accumulate indefinitely. Rather, diluted effluent would flow downslope and gradually disperse. In the analysis presented here, the spreading of the effluent on the seafloor (or within and beyond the trapping level) and the subsequent additional dilution that would ensue, have not been analyzed. Flow Science recommends that the computed dilution at the seafloor, or at the trapping level (i.e., at the end of the ZID) be used as the basis for any NPDES permitting activities and to analyze impacts.

4. Plume Analysis Methods

Two analysis methods have been used to evaluate the discharge of desalination brines (negatively buoyant plumes) from the MRWPCA diffuser: a semi-empirical method based on the work of Roberts et al. (1997) and Kikkert et al. (2007), and EPA's Visual Plumes method. The Visual Plumes method was also used to model scenarios where the effluent density is less than seawater (positively buoyant, or rising, plumes). Both the semi-empirical method and Visual Plumes were used to characterize negatively buoyant plumes in order to understand the range of dilution that might be expected for discharge from the MRWPCA diffuser system. The semi-empirical method also provides some level of redundancy and confirmation of results because Visual Plumes, although widely used in diffuser discharge analysis, has only very recently been validated against limited experimental data for the case of a negatively buoyant plume. The main advantage of the semi-empirical analysis method is that it is well-grounded in empirical observations, and thus is well-tested and has been verified by comparison to a relatively large dataset for this specific discharge condition. The main disadvantage is that the semi-empirical method requires longer to complete an analysis for a given discharge scenario. The analysis techniques for these two methods are described below.

Semi-Empirical Analysis Method

Laboratory studies of negatively buoyant jets and plumes have been conducted by many researchers (e.g., Kikkert et al., 2007; Roberts et al., 1997). Most of these have been conducted for inclined jets (i.e., jets that discharge upward at an angle), which increase the initial mixing of the plume. Fewer studies are available to characterize the mixing of negatively buoyant plumes from horizontally-oriented discharge ports. In the following sections, the general equations for a negatively buoyant jet from an angled port are presented first. The equations for a horizontal discharge are then derived from the general equations.

Discharge of a negatively buoyant jet from an angled port

Plume trajectory

The trajectory of a negatively buoyant discharge under a stagnant flow condition (i.e., no ambient current) can be computed from the following equations (Kikkert, et al., 2007) (see **Figure C4** for nomenclature).

$$\frac{dn_*}{ds_*} = \frac{M_{B*}\cos\theta_0}{1 - M_{B*}\sin\theta_0} \tag{1}$$

where:

$s_* = s/d$

$n_* = n/d$

s and n are the distances in directions along and perpendicular to the discharge port centerline, respectively; d is the effective diameter of the port (see **Figure C4**); and M_{B*} is the dimensionless buoyancy-generated momentum flux, which can be calculated from Eq. (2).

$$M_{B*} = 0.154\frac{s_*^2}{F_0^2} \tag{2}$$

where F_0 is the initial densimetric Froude number:

$$F_0 = \frac{U_0}{\sqrt{gd(\rho_0 - \rho_a)/\rho_a}}$$

where

U_0 = initial jet velocity
g = gravitational acceleration
ρ_0 = initial density of the jet
ρ_a = ambient water density

Substituting Eq. (2) into Eq. (1) and integrating gives an equation for the discharge trajectory:

$$n_* = \frac{2.6F_0}{\tan\theta_0 \sin^{1/2}\theta_0}\left[-\frac{s_*\sin^{1/2}\theta_0}{2.6F_0} + \frac{1}{2}\ln\left(\frac{2.6F_0 + s_*\sin^{1/2}\theta_0}{2.6F_0 - s_*\sin^{1/2}\theta_0}\right)\right] \tag{3}$$

Results from Eq. (3) agreed well with experimental data (Kikkert, et al., 2007).

Discharge of a negatively buoyant jet from a horizontal port

Plume trajectory

The plume trajectory of a horizontal discharge can be estimated using the equations for an angled jet. Specifically, for a horizontal discharge (i.e., $\theta_0=0$), Eq. (3) simplifies to the following relationship:

$$n_* = 0.051\frac{s_*^3}{F_0^2} \qquad (4)$$

Plume dilution for a horizontal discharge

For the horizontally discharged effluent, the empirical equations from Fischer et al., 1979 (Table 9.2, pp. 328) were used to compute the width and dilution of the effluent. i.e.,

*Plume width=2*0.13*distance along plume* (5)

The plume width calculated from Eq. (5) defines the edge of the plume as the location where the concentration is 37% (= e^{-1}, which is often used to characterize plume width) of the centerline concentration.

The volume flux and dilution are specified by:

Volume flux $\mu = 0.25M^{1/2}$ **distance along plume* (6)

Dilution = μ /(discharge flow rate) (7)

where $M=QU_0$ is the initial momentum flux of the effluent (Q and U_0 are the flow rate and initial velocity of the effluent, respectively).

Note that the semi-empirical analysis for 0º discharges uses Kikkert et al. (2007) for the trajectory and Fischer et al. (1979) for dilution.

Visual Plumes Analysis Method

Methodology

The UM3 model—part of the EPA Visual Plumes diffuser modeling package—was used to simulate the discharge of desalination brine and wastewater from the existing MRWPCA ocean diffuser. Visual Plumes is a mixing zone computer model developed from a joint effort led by USEPA. Visual Plumes can simulate both single and merging submerged plumes, and density-stratified ambient flow can be specified by the user. Visual Plumes can be used to compute the plume dilution, trajectory, diameter, and other plume variables (USEPA, 2003).

The UM3 model is based on the projected area entrainment hypothesis, which assumes ambient fluid is entrained into the plume through areas projected in directions along the plume centerline and perpendicular to the centerline (USEPA, 1994). In addition, velocity shear entrainment is also included. The plume envelope is assumed to be in steady state, and as a plume element moves through the envelope, the element radius changes in response to velocity convergence or divergence, and entrainment of ambient fluid. Conservation equations of mass, momentum and energy are used to calculate plume mass and concentrations.

The actual depth of the diffuser ports varies between 95 and 109 feet below mean sea level (MSL) since the diffuser is quite long and is situated on a sloping portion of the ocean floor. However, since Visual Plumes cannot model a sloping diffuser, an average depth of 104 feet below MSL was used (the deepest 120 ports on the diffuser discharge in this case, thereby increasing the average port depth). Modeled ocean conditions are summarized in **Table C5**.

As with the semi-empirical method, Visual Plumes assumes circular discharge ports, so the actual elliptical discharge area of the Tideflex valves was calculated for each port (**Appendix A**) and then converted to an effective circular discharge diameter for use in Visual Plumes.

A study by Palomar et al. (2012a, 2012b) showed that the UM3 model of the Visual Plumes can be applied to simulate negatively buoyant discharges. However, the study also found that the UM3 model underpredicted centerline dilution ratios at the impact point by more than 50% for a negatively buoyant effluent discharged into a stagnant environment; for a number of scenarios with negatively buoyant effluent discharged into an ambient current, centerline dilution ratios at the impact point calculated by the UM3 model ranged from 40% lower to 7% higher than experimental data.

The UM3 model of the Visual Plumes was used in this analysis to model negatively buoyant effluent discharged into a stagnant environment. Because the study of Palomar et al. (2012a, 2012b) has shown that the centerline dilution ratios computed using the UM3 model were more than 50% lower than data from experiments with similar discharge conditions, the average dilution ratios calculated using UM3, which are nearly double the centerline dilution ratios, were used to estimate dilution of negatively buoyant plumes in this analysis. Since Visual Plumes has been more thoroughly validated for positively buoyant plumes, it alone was used for scenarios with rising plumes.

5. Dilution Results

Results for thirteen new scenarios ("Task 1" Scenarios)

For the scenarios presented in **Table C1**, several key results for the effluent plumes are reported at the edge of the ZID. As noted above, the ZID is defined as the zone immediately adjacent to a discharge where momentum and buoyancy-driven mixing produces rapid dilution of the discharge. Results for positively buoyant plumes presented in this Technical Memorandum were taken at the point where the plumes just reach the trap level, which is the depth level where the density of the diluted plume becomes the same as ambient seawater. Horizontal spreading of plumes at their trap levels was not included in this analysis because it is beyond the ZID. Results from each scenario generally include the following quantities:

- the horizontal distance from the diffuser port to the point at which the plume impacts the seafloor or reaches the trap level.
- the dilution of the plume at the point at which the plume impacts the seafloor or reaches the trap level. For the semi-empirical method of analyzing negatively buoyant plumes and for the Visual Plumes analyses of rising plumes, centerline dilution is provided. For the Visual Plumes analyses of negatively buoyant discharges, the average dilution within the plume is provided, in recognition of the conservative nature of Visual Plumes results for negatively buoyant plumes (see, e.g., Palomar et al., 2012a and 2012b).
- an estimate of the size of the plume (diameter) at the point of impact or just below the trap level (i.e., at the edge of the ZID).
- the maximum salinity at the seafloor (edge of ZID for negatively buoyant plumes).
- the percentage by which the maximum plume salinity at the seafloor (edge of ZID for negatively buoyant plumes) exceeds the ambient salinity.

Figure C5 shows a sample schematic graphic of the trajectory of a negatively buoyant plume from a horizontal discharge drawn approximately to scale. As the effluent travels away from the discharge port, it entrains ambient seawater, which increases the diameter of the plume and decreases the plume concentration.

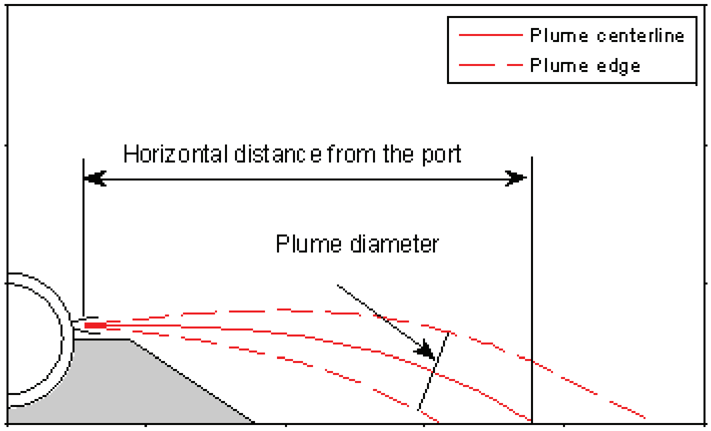

Figure C5. Sample graphic showing plume trajectory for the horizontal discharge configuration.

Table C6 presents analysis results for the 13 modeled scenarios of Task 1. The plumes were positively buoyant (i.e., had densities less than ambient seawater) for scenarios where the desalination brine was mixed with treated wastewater and for GWR Project scenarios. This is mainly because the salinity of the plumes in these scenarios was much lower than ambient seawater. The plumes were negatively buoyant (i.e., were denser than ambient seawater) for desalination brine only and for desalination brine mixed with GWR Project brine. Results in **Table C6** show that the trajectory, diameter and dilution of the negatively buoyant plumes were nearly the same across all three modeled seasons, because the trajectories of these negatively buoyant plumes were short and close to the seafloor, where the differences in salinity and temperature (hence the difference in density) between the effluent and ambient sea water changed only slightly over the modeled seasons. Therefore, for analyses of scenarios involving negatively buoyant, i.e., sinking, plumes, characteristics of the resulting plumes were similar for all seasons.

Dilution values predicted by the semi-empirical method were lower than the dilution values predicted by the Visual Plumes method. The predicted maximum plume salinity at the seafloor was 1.6 ppt above ambient ocean salinity.

Table C6 – Analysis results.

Analysis number	Effluent discharge flow rate (mgd) & component	Discharge Velocity (feet/ second)	Seasonal Condition	Effluent salinity (ppt)	Ocean bkgrd. salinity at diffuser depth (ppt)	Semi-empirical method						VP method					
						Plume diam. (d) (inch)	Center-line Dilution	Horiz. Distance from port (ft)	Max. height above port (z_{me}) (ft)	Plume salinity at calc. dilution (ppt)	Salinity increase above ambient (ppt)	Plume diam. (inch)	Average Dilution	Horiz. Distance from port (ft)	Max. height above port (z_{me}) (ft)	Plume salinity at calc. dilution (ppt)	Salinity increase above ambient (ppt)
0.0	19.78 WW	11.5	Davidson (Jan.)	0.8	33.36	--	--	--	--	--	--	246	167 [a]	27	69 [b]	--	--
5.1	8.99 BR	7.5	Upwelling (July)	58.23	33.84	31	15	10	--	35.47	1.6	36	25	8	--	34.82	1.0
6.1	8.99 BR	7.5	Davidson (Jan.)	57.40	33.36	31	15	10	--	34.98	1.6	36	26	8	--	34.30	0.9
7.1	28.77 BR+WW	13.9	Davidson (Jan.)	18.48	33.36	--	--	--	--	--	--	207	84 [a]	38	41 [b]	--	--
8.1	8.99 BR	7.5	Oceanic (Sept.)	57.64	33.50	31	15	10	--	35.11	1.6	36	25	8	--	34.47	1.0
9.1	9.72 BR+GWR	8	Upwelling (July)	54.16	33.84	34	17	11	--	35.04	1.2	39	27	8	--	34.59	0.8
10.1	9.72 BR+GWR	8	Davidson (Jan.)	53.39	33.36	34	17	11	--	34.55	1.2	40	27	8	--	34.12	0.8
11.1	25.64 BR+WW +GWR	13.1	Davidson (Jan.)	20.73	33.36	--	--	--	--	--	--	204	82 [a]	38	38 [b]	--	--
12.1	9.72 BR+GWR	8	Oceanic (Sept.)	53.61	33.50	34	17	11	--	34.68	1.2	39	27	8	--	34.24	0.7

Source: Flow Science Analysis, 2014.
BR: desalination brine. WW: wastewater. GWR: groundwater recharge.
[a] Dilution values are centerline dilution because the Visual Plumes model has been validated for positively buoyant plumes and no significant underprediction of dilution has been reported.
[b] These values are trap levels above the diffuser.

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Table C6 – Analysis results (continued).

Analysis number	Effluent discharge flow rate (mgd) & component	Discharge Velocity (feet/ second)	Seasonal Condition	Effluent salinity (ppt)	Ocean bkgrd. salinity at diffuser depth (ppt)	Semi-empirical method						VP method					
						Plume diam. (d) (inch)	Center-line Dilution	Horiz. Distance from port (ft)	Max. height above port (z_{me}) (ft)	Plume salinity at calc. dilution (ppt)	Salinity increase above ambient (ppt)	Plume diam. (inch)	Average Dilution	Horiz. Distance from port (ft)	Max. height above port (z_{me}) (ft)	Plume salinity at calc. dilution (ppt)	Salinity increase above ambient (ppt)
13.1	0.73 GWR	3.4	Upwelling (July)	4	33.84	--	--	--	--	--	--	159	777 [a]	6	48 [b]	--	--
14.1	0.73 GWR	3.4	Davidson (Jan.)	4	33.36	--	--	--	--	--	--	86	270 [a]	5	24 [b]	--	--
15.1	16.65 WW+GWR	11	Davidson (Jan.)	0.9	33.36	--	--	--	--	--	--	243	180 [a]	24	68 [b]	--	--
16.1	0.73 GWR	3.4	Oceanic (Sept.)	4	33.50	--	--	--	--	--	--	121	678 [a]	5	41 [b]	--	--

Source: Flow Science Analysis, 2014.
BR: desalination brine. WW: wastewater. GWR: groundwater recharge.
[a] Dilution values are centerline dilution because the Visual Plumes model has been validated for positively buoyant plumes and no significant underprediction of dilution has been reported.
[b] These values are trap levels above the diffuser.

Impact of Discharge Rate on Effluent Dilution and Salinity

To explore the impact of the brine discharge rate on effluent dilution ratio and to determine the desalination brine discharge rate that results in salinity at the seafloor that exceeds ambient salinity levels by no more than 2 ppt , a series of brine discharge rates were analyzed using both the Visual Plumes model and the semi-empirical method. For this analysis, the desalination brine was assumed to be the only effluent discharged from the diffuser. The dilution and salinity levels for these scenarios are summarized in **Table C7**. **Figure C6** and **Figure C7** graphically present the effluent salinity (in ppt above ambient salinity) calculated using the semi-empirical method and the Visual Plumes method, respectively, at the impact point as a function of desalination brine discharge flow rates.

Results of the semi-empirical method showed that salinity values within the plume at the impact point were predicted to increase (i.e., dilution decreased) for desalination brine discharge rates up to 8 mgd in January and September and 10 mgd in July; salinity values then decreased (dilution increased) for higher discharge rates. The highest effluent salinity at the impact point was 1.6 ppt above ambient salinity.

The highest effluent salinity calculated by the Visual Plumes method was 1.0 ppt above ambient salinity. Results of the Visual Plumes method also showed that salinity at the impact point was predicted to increase (i.e., simulated dilution decreased) for desalination brine discharge rates up to 10 mgd for January and 8 mgd for July and September. Dilution and impact point salinity values remained nearly constant for higher discharge rates. It should be noted that although effluent dilution ratio remained almost unchanged, more ambient seawater was entrained into the plume for scenarios with higher discharge rates. The increase in entrained seawater was approximately proportional to the increase in discharge rate, so the dilution ratio remained almost unchanged. The 65 mgd discharge rate, the highest discharge rate analyzed, translates to a single port flow of about 0.84 cfs. Assuming it takes 10 seconds for the effluent to reach the impact point, the volume of the brine is about 8.4 ft^3. Port spacing on one side of the diffuser is 16 ft (ports are 8 ft apart on alternating sides of the diffuser), ports are about 3.5 ft above seafloor, and the impact point is about 10 ft away from the ports. This gives a seawater volume of about 560 ft^3 around one port, which is about 67 times the brine volume. Therefore even for the highest analyzed discharge rate, there is enough seawater to dilute the brine. It should be pointed out that despite remaining nearly unchanged for discharge rates in the range of 10 to 65 mgd, the dilution ratio may change for discharge rates higher than 65 mgd. For brine discharge rates much higher than 65 mgd, effluent plumes from neighboring ports may merge and there might not be enough seawater to dilute the effluent, and as a result, the effluent dilution ratio will be lower and salinity values will be higher.

Table C7 – Analysis results for various desalination brine-only discharge rates.

Flow	Semi-empirical method						VP method					
mgd	Jan.		July		Sept.		Jan.		July		Sept.	
	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)
0.5	19	1.3	19	1.3	19	1.3	48	0.5	49	0.5	48	0.5
1	17	1.4	17	1.5	17	1.4	39	0.6	39	0.6	39	0.6
2	16	1.5	16	1.6	16	1.5	33	0.7	33	0.7	33	0.7
3	15	1.6	15	1.6	15	1.6	30	0.8	30	0.8	30	0.8
4	15	1.6	15	1.6	15	1.6	28	0.8	28	0.9	28	0.9
6	15	1.6	15	1.6	15	1.6	26	0.9	26	0.9	26	0.9
8	15	1.6	15	1.6	15	1.6	26	0.9	25	1.0	25	0.9
10	16	1.5	15	1.6	16	1.6	25	0.9	25	1.0	25	1.0
12	16	1.5	16	1.5	16	1.5	25	0.9	25	1.0	25	1.0
14	16	1.5	16	1.5	16	1.5	25	0.9	25	1.0	25	1.0
16	17	1.4	16	1.5	17	1.5	25	1.0	25	1.0	25	1.0
18	17	1.4	17	1.4	17	1.4	25	0.9	25	1.0	25	1.0
20	17	1.4	17	1.4	17	1.4	25	1.0	25	1.0	25	1.0
22	18	1.4	17	1.4	17	1.4	25	1.0	25	1.0	25	1.0
24	18	1.3	18	1.4	18	1.4	25	0.9	25	1.0	25	1.0
26	18	1.3	18	1.4	18	1.3	25	1.0	25	1.0	25	1.0
28	18	1.3	18	1.3	18	1.3	25	0.9	25	1.0	25	1.0
30	18	1.3	18	1.3	18	1.3	25	1.0	25	1.0	25	1.0
32	19	1.3	19	1.3	19	1.3	25	0.9	25	1.0	25	1.0
34	19	1.3	19	1.3	19	1.3	25	1.0	25	1.0	25	1.0
36	19	1.2	19	1.3	19	1.3	25	1.0	25	1.0	25	1.0
38	19	1.2	19	1.3	19	1.3	25	1.0	25	1.0	25	1.0
40	20	1.2	19	1.3	19	1.2	25	1.0	25	1.0	25	1.0
45	20	1.2	20	1.2	20	1.2	25	0.9	25	1.0	25	1.0
50	20	1.2	20	1.2	20	1.2	25	0.9	25	1.0	25	1.0
55	21	1.1	21	1.2	21	1.2	25	0.9	25	1.0	25	1.0
60	21	1.1	21	1.2	21	1.1	25	0.9	25	1.0	25	1.0
65	22	1.1	22	1.1	22	1.1	25	0.9	25	1.0	25	1.0

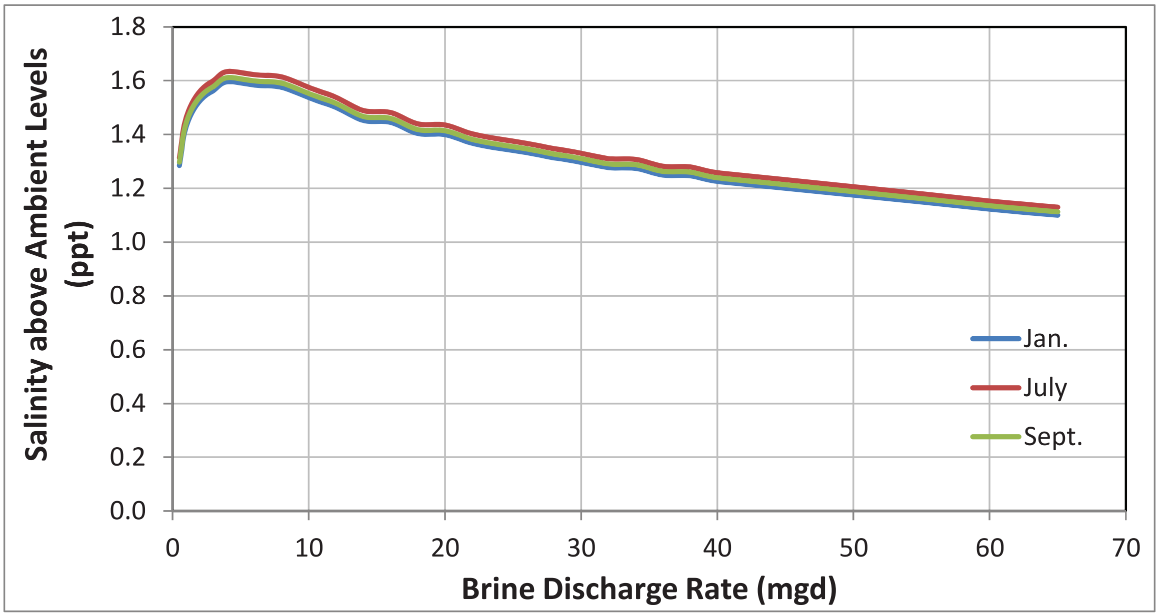

Figure C6. Simulated seafloor salinity (ppt above ambient salinity) for desalination brine calculated using the semi-empirical method.

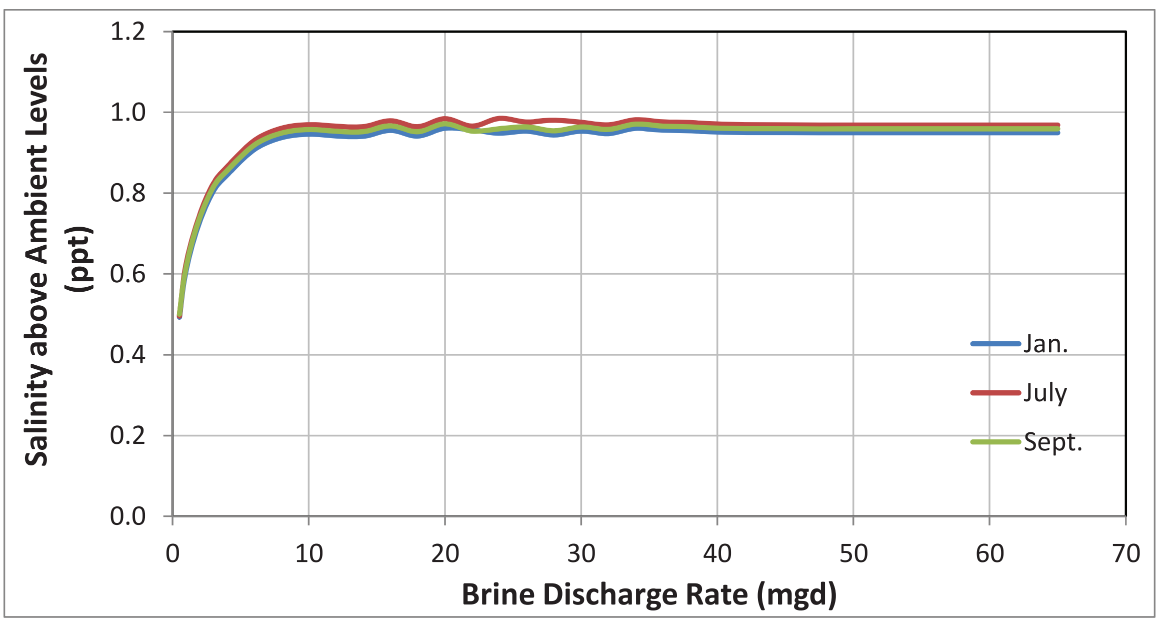

Figure C7. Simulated seafloor salinity (ppt above ambient salinity) for desalination brine calculated using the Visual Plumes method.

Impact of Seawater Pre-dilution on Effluent Dilution and Salinity

To reduce effluent salinity, seawater could be used to pre-dilute the desalination brine before discharging to the outfall pipeline. The impact of seawater pre-dilution on effluent dilution and salinity was evaluated for a series of discharge scenarios using both the Visual Plumes method and the semi-empirical method. In these scenarios, the flow rate of pre-dilution seawater was varied; the discharge rate of desalination brine was fixed at 13.98 mgd. The temperature and salinity of the desalination brine and seawater are summarized in **Table C3**, and temperature and salinity of the pre-diluted discharge was calculated as flow-weighted averages of the desalination brine and seawater. The effluent dilution and seafloor salinity for the pre-dilution scenarios are presented in **Table C8**. **Figure C8** and **Figure C9** show the salinity exceedence for the pre-dilution scenarios calculated using the semi-empirical method and the Visual Plumes method, respectively.

Results from both methods showed that the maximum seafloor salinity was simulated to decrease as the amount of seawater used to pre-dilute the desalination brine increased. Results of the semi-empirical method indicated that the highest effluent salinity at seafloor was 1.4 ppt above ambient salinity. Results from the Visual Plumes method showed that effluent salinity at seafloor was less than 0.9 ppt above ambient salinity.

Table C8 – Analysis results for seawater pre-dilution.

Flow		Semi-empirical method						VP method					
Mgd		Jan.		July		Sept.		Jan.		July		Sept.	
Sea-water	Sea-water + brine	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)
0.5	14.48	17	1.4	17	1.4	17	1.4	25	0.9	26	0.9	25	0.9
1	14.98	17	1.3	17	1.4	17	1.3	26	0.9	26	0.9	26	0.9
2	15.98	17	1.2	17	1.2	17	1.2	26	0.8	26	0.8	26	0.8
3	16.98	18	1.1	18	1.1	18	1.1	26	0.8	26	0.8	26	0.8
4	17.98	18	1.0	18	1.0	18	1.0	26	0.7	26	0.7	26	0.7
5	18.98	19	0.9	19	1.0	19	0.9	27	0.7	27	0.7	27	0.7
6	19.98	19	0.9	19	0.9	19	0.9	27	0.6	26	0.6	26	0.6
8	21.98	20	0.8	20	0.8	20	0.8	27	0.6	27	0.6	27	0.6
10	23.98	21	0.7	21	0.7	21	0.7	27	0.5	27	0.5	27	0.5
12	25.98	22	0.6	22	0.6	22	0.6	28	0.5	28	0.5	28	0.5
14	27.98	23	0.5	23	0.5	23	0.5	28	0.4	28	0.4	28	0.4
16	29.98	24	0.5	23	0.5	23	0.5	28	0.4	28	0.4	28	0.4
18	31.98	24	0.4	24	0.4	24	0.4	29	0.4	29	0.4	29	0.4

Flow		Semi-empirical method						VP method					
Mgd		Jan.		July		Sept.		Jan.		July		Sept.	
Sea-water	Sea-water + brine	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)
20	33.98	25	0.4	25	0.4	25	0.4	29	0.3	29	0.4	29	0.3
22	35.98	26	0.4	26	0.4	26	0.4	29	0.3	29	0.3	29	0.3
24	37.98	26	0.3	26	0.3	26	0.3	29	0.3	29	0.3	29	0.3
26	39.98	27	0.3	27	0.3	27	0.3	29	0.3	29	0.3	29	0.3
28	41.98	28	0.3	28	0.3	28	0.3	29	0.3	29	0.3	29	0.3
30	43.98	29	0.3	28	0.3	29	0.3	29	0.3	29	0.3	29	0.3
35	48.98	30	0.2	30	0.2	30	0.2	30	0.2	30	0.2	30	0.2
40	53.98	32	0.2	32	0.2	32	0.2	30	0.2	30	0.2	30	0.2

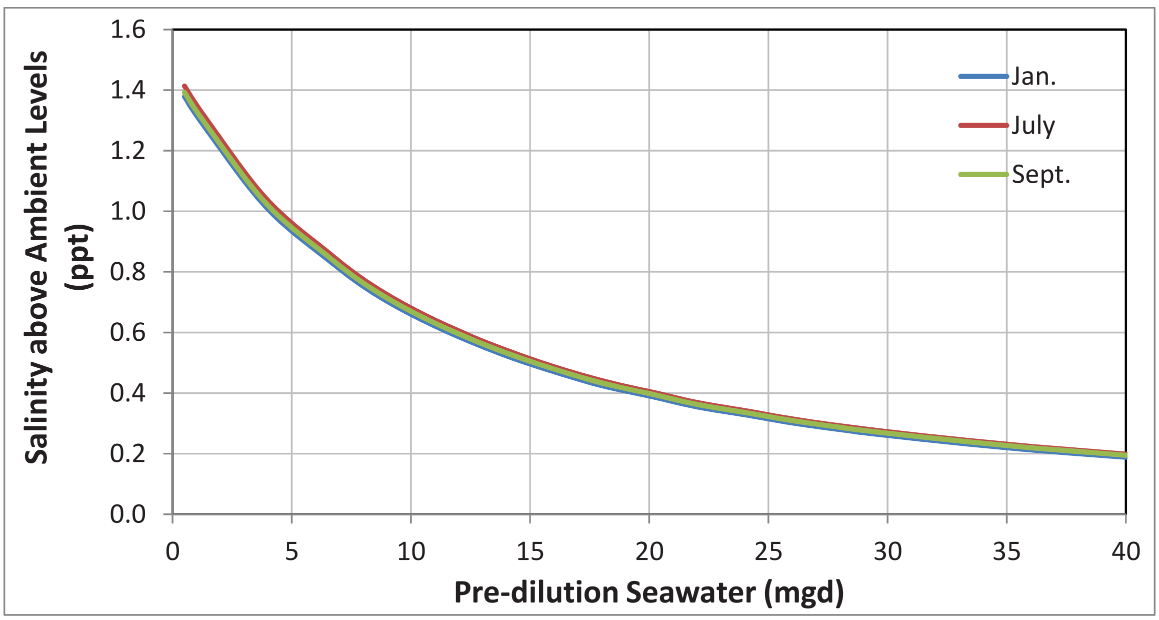

Figure C8. Simulated seafloor salinity (ppt above ambient salinity) for desalination brine (13.98 mgd) as a function of the flow rate of pre-dilution seawater; results calculated using the semi-empirical method.

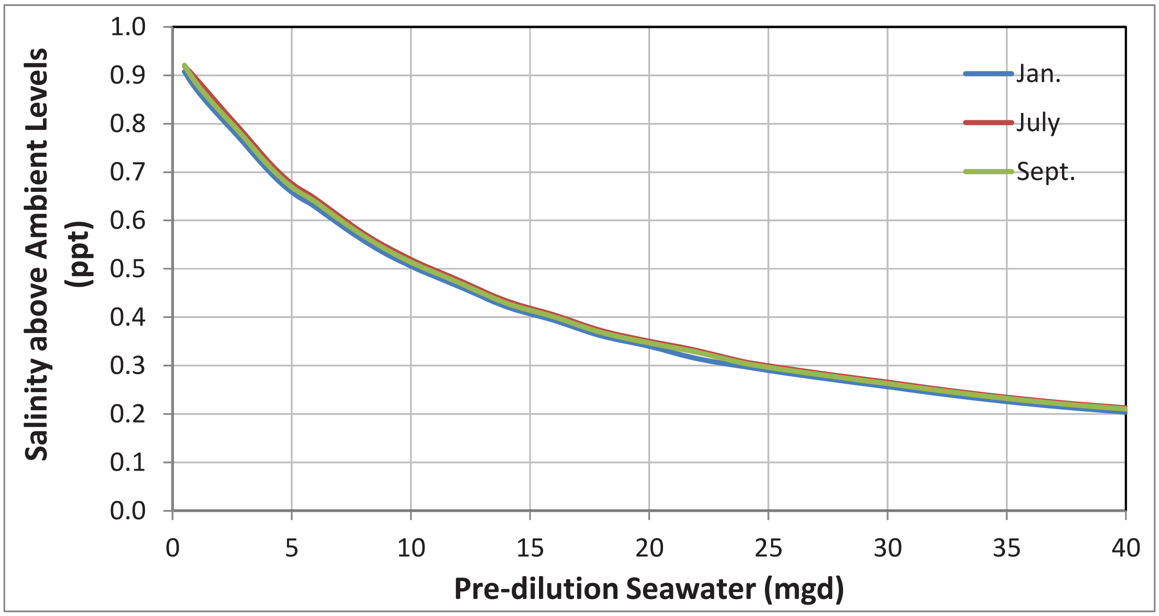

Figure C9. Simulated seafloor salinity (ppt above ambient salinity) for desalination brine (13.84 mgd) as a function of the flow rate of pre-dilution seawater; results calculated using the Visual Plumes method.

Impact of Treated Wastewater Pre-dilution on Effluent Dilution and Salinity

Instead of seawater, treated wastewater could also be used to pre-dilute the desalination brine before discharging to the outfall pipeline. The impact of treated wastewater pre-dilution on effluent dilution and salinity was evaluated for a number of discharge scenarios using both the Visual Plumes method and the semi-empirical method. In these scenarios, the flow rate of pre-dilution wastewater was varied; the discharge rate of desalination brine was fixed at 13.98 mgd. The temperature and salinity of the desalination brine and wastewater are summarized in **Table C3**, and temperature and salinity of the pre-diluted discharge was calculated as flow-weighted averages of the desalination brine and wastewater. The effluent dilution and seafloor salinity for the pre-dilution scenarios are presented in **Table C9**.

Results from both methods showed that the maximum seafloor salinity was simulated to decrease as the amount of treated wastewater used to pre-dilute the desalination brine increased. Results of both the semi-empirical method and the Visual Plumes method indicated that effluent salinity at seafloor was less than 2 ppt above ambient salinity for all three seasonal conditions.

Table C9 – Analysis results for treated wastewater pre-dilution.

Flow		Semi-empirical method						VP method					
mgd		Jan.		July		Sept.		Jan.		July		Sept.	
Waste water	Waste water + brine	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilutio n	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)	Dilution	Salinity increase above ambient (ppt)
0.25	14.23	17	1.4	17	1.4	17	1.4	26	0.9	26	0.9	26	0.9
0.5	14.48	17	1.3	17	1.3	17	1.3	26	0.9	26	0.9	26	0.9
1	14.98	18	1.2	17	1.2	18	1.2	26	0.8	26	0.8	26	0.8
2	15.98	19	0.9	19	0.9	19	0.9	27	0.6	27	0.6	27	0.6

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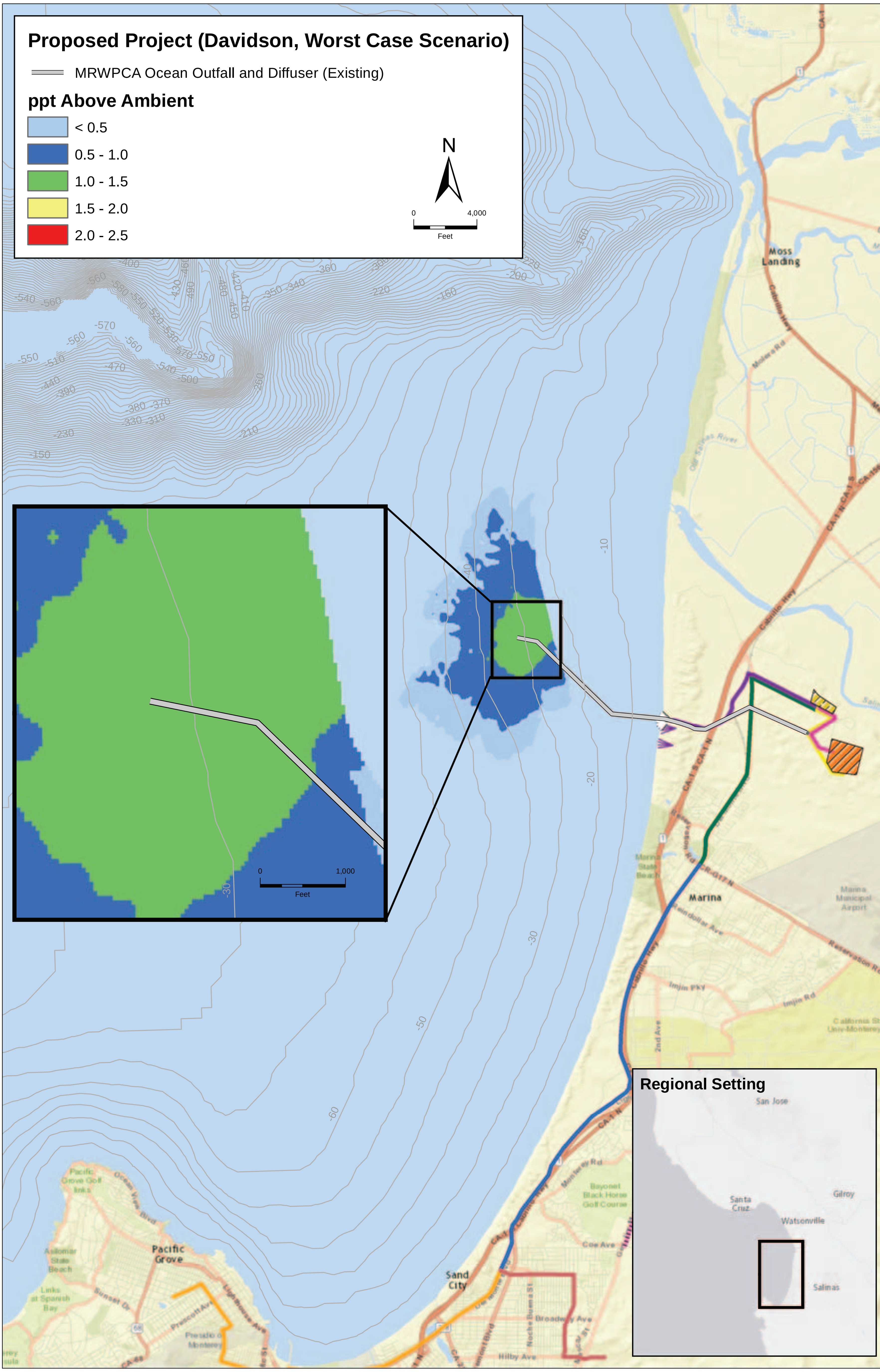
Appendix B

Proposed Project - Seasonal Plume Behavior

Figure	Ocean Season	Condition/Scenario	Parameter
B-1	Davidson	Worst Case	ppt Above Ambient
B-2	Davidson	Chronic	ppt Above Ambient
B-3	Davidson	Chronic	Dilution Rate
B-4	Davidson	Chronic	Salinity (ppt)
B-5	Upwelling	Worst Case	ppt Above Ambient
B-6	Upwelling	Chronic	ppt Above Ambient
B-7	Upwelling	Chronic	Dilution Rate
B-8	Upwelling	Chronic	Salinity (ppt)
B-9	Oceanic	Worst Case	ppt Above Ambient
B-10	Oceanic	Chronic	ppt Above Ambient
B-11	Oceanic	Chronic	Dilution Rate
B-12	Oceanic	Chronic	Salinity (ppt)



Basemap Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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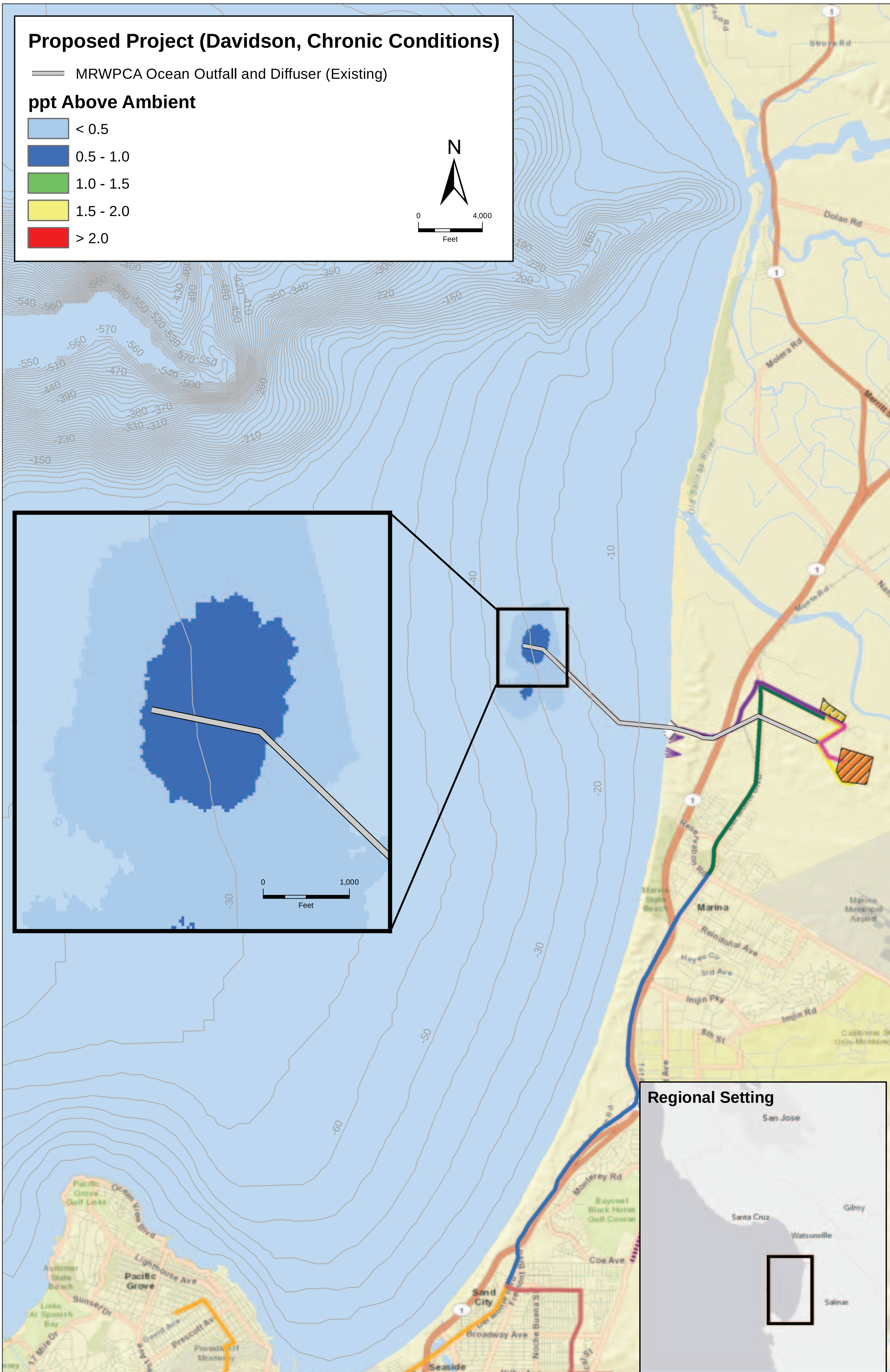
Figure B-1
Parts per Thousand Above Ambient
(Proposed Project: Davidson, Worst Case Scenario)

U:\GIS\GIS\Projects\205xxx\205335_Water\Tasks\Cal_Am_2012\Oceanography\mxds\FigureMXDs\Memo\AppendixB\B-01 + Fig19_Davidson_Acute_Ambient.mxd
4/2/2015



Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013
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Figure B-2
Parts per Thousand Above Ambient
(Proposed Project: Davidson, Chronic Conditions)

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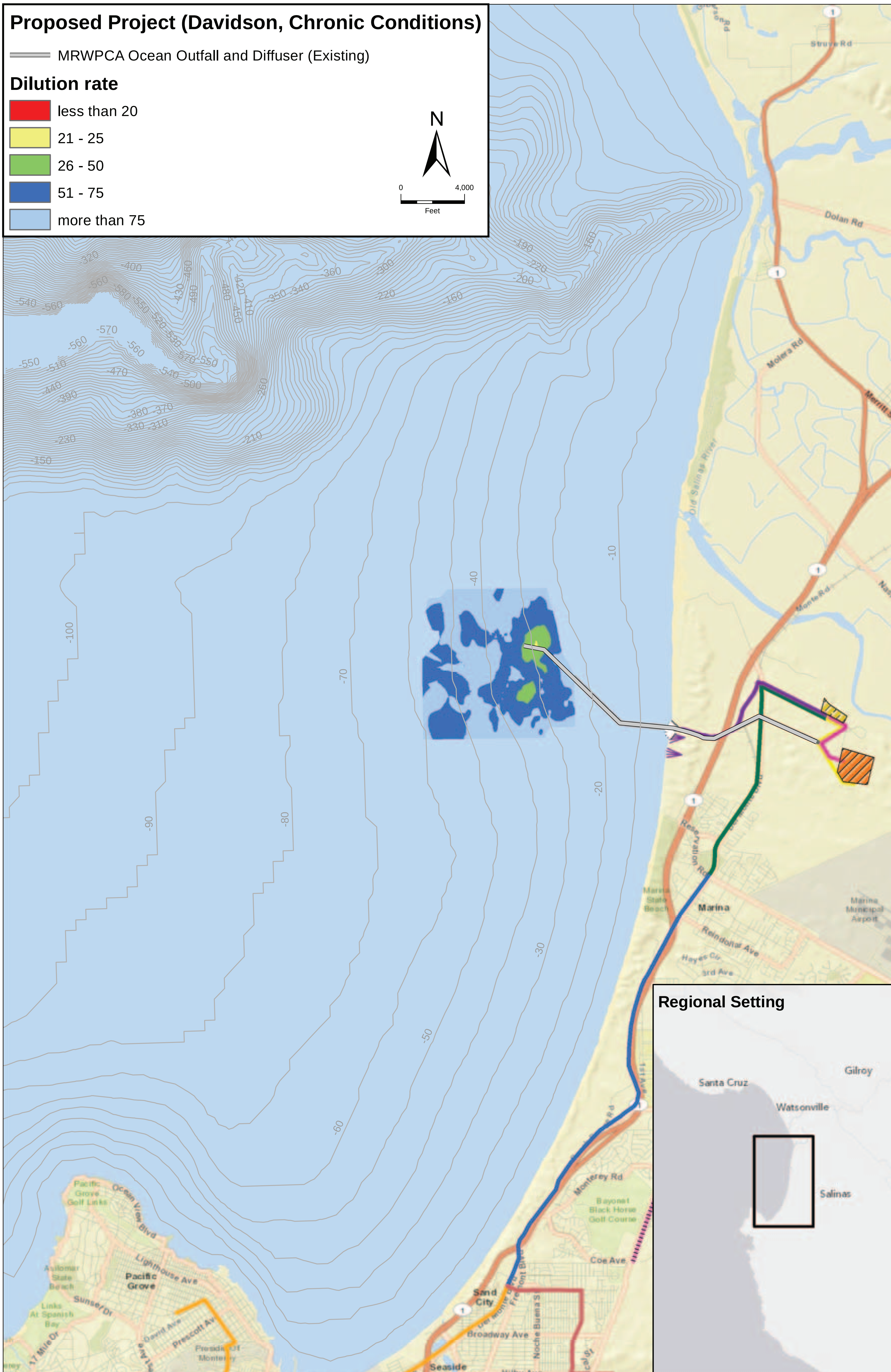
11/7/2014



Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013
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Figure B-3
Dilution Rate
(Proposed Project: Davidson, Chronic Conditions)

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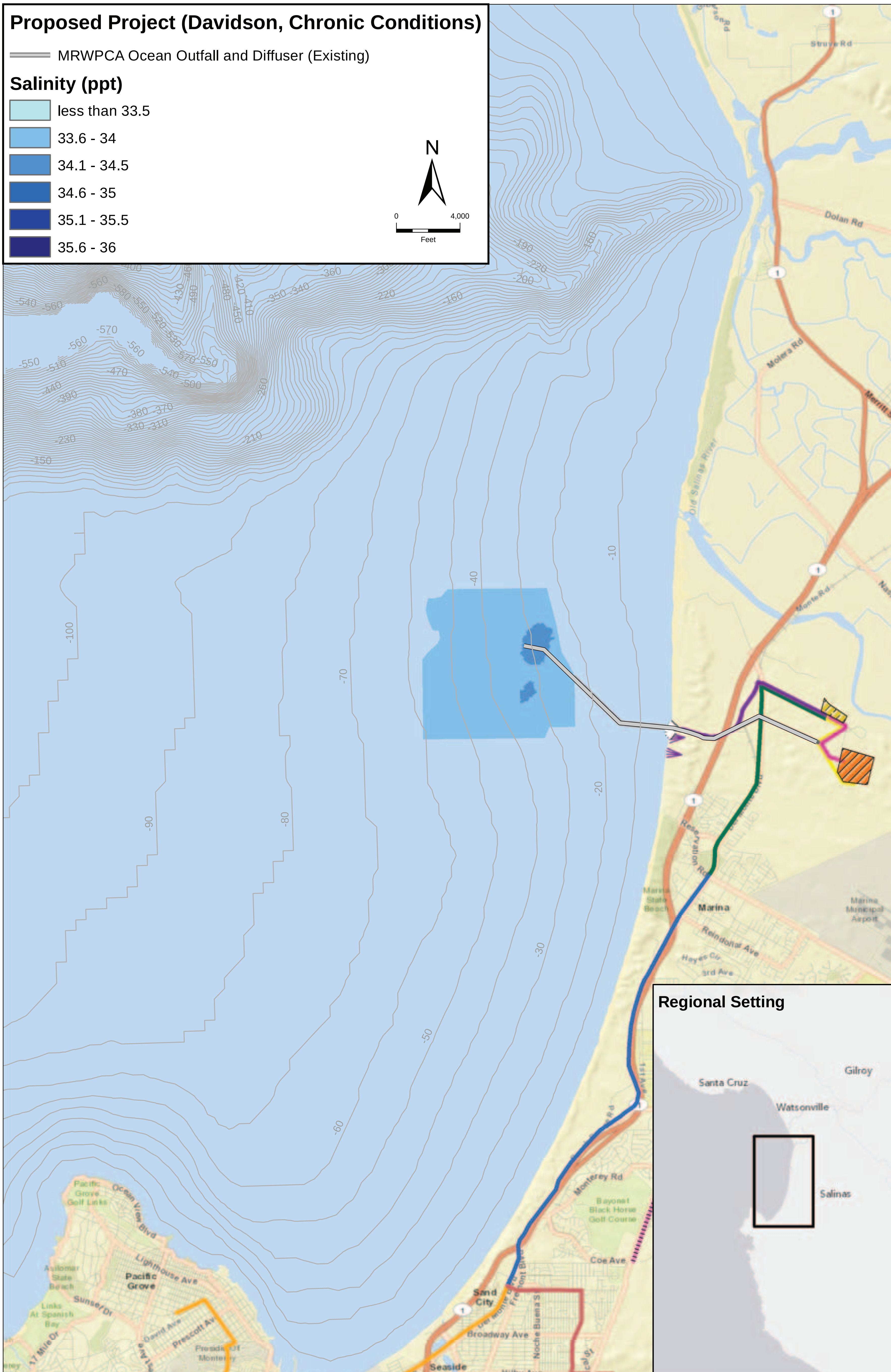

Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013
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Figure B-4
Salinity
(Proposed Project: Davidson, Chronic Conditions)

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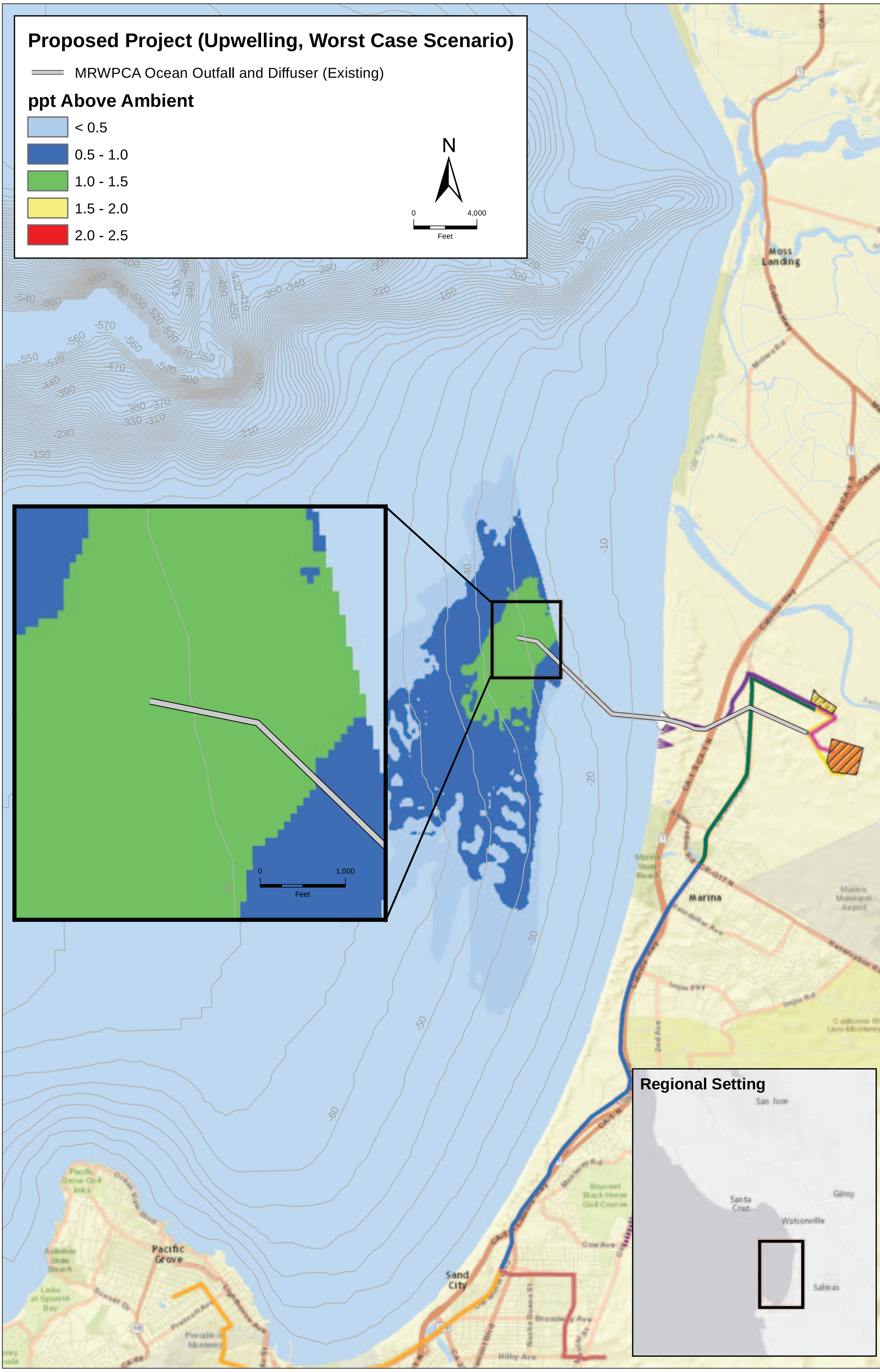

Basemap Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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Figure B-5
Parts per Thousand Above Ambient
(Proposed Project: Upwelling, Worst Case Scenario)

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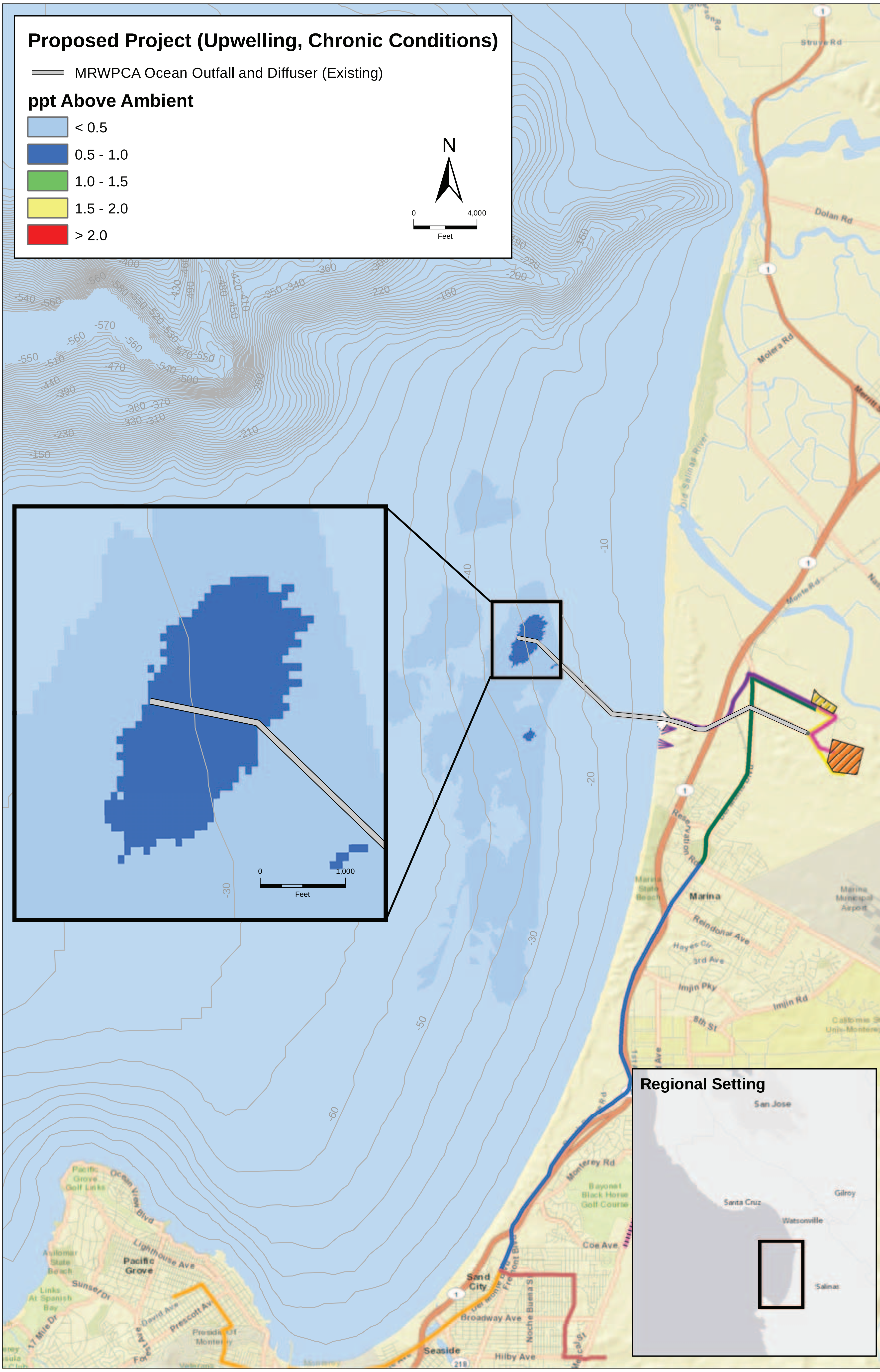

Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013
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Figure B-6
Parts per Thousand Above Ambient
(Proposed Project: Upwelling, Chronic Conditions)

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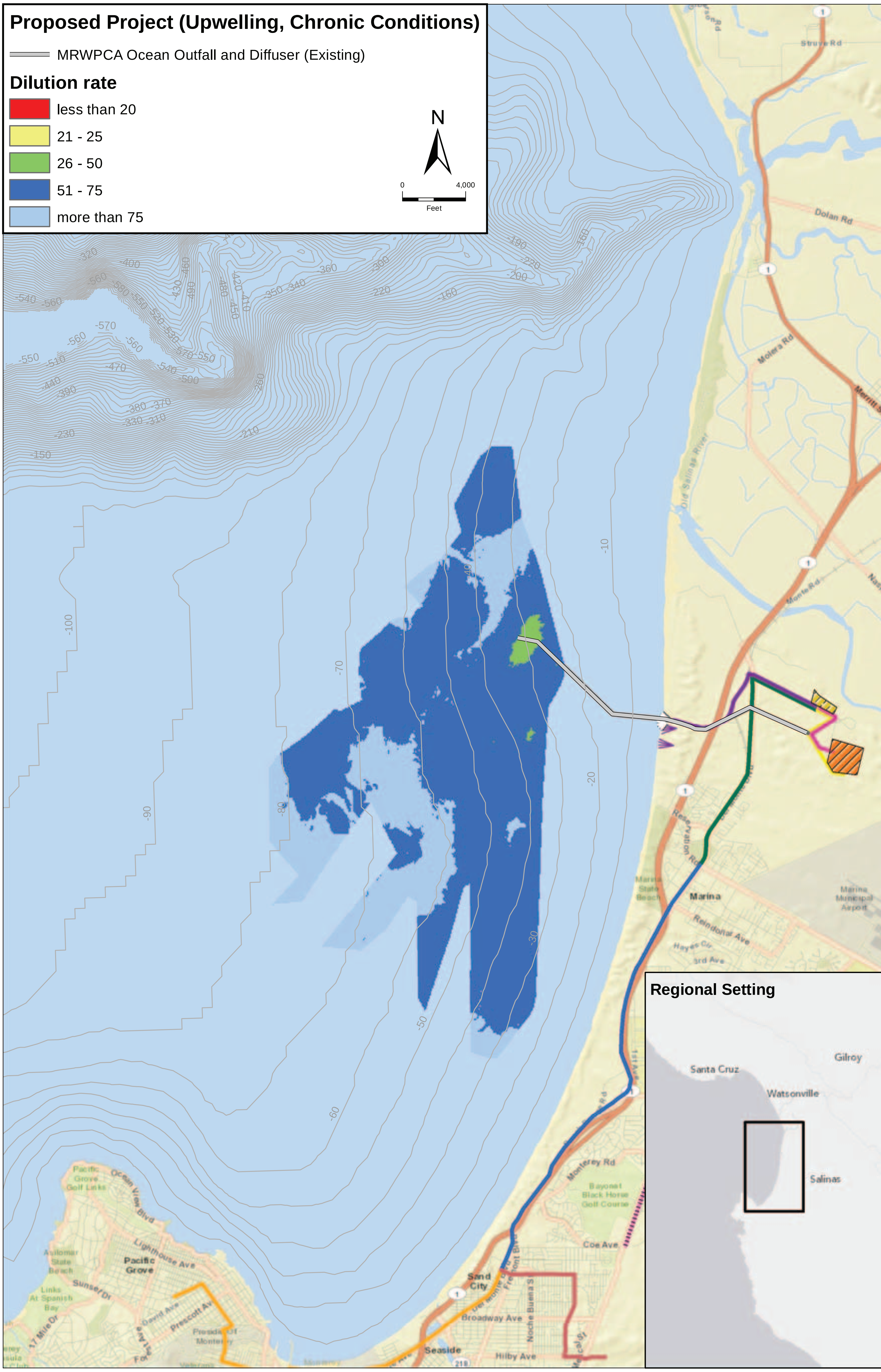

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Figure B-7
Dilution Rate
(Proposed Project: Upwelling, Chronic Conditions)

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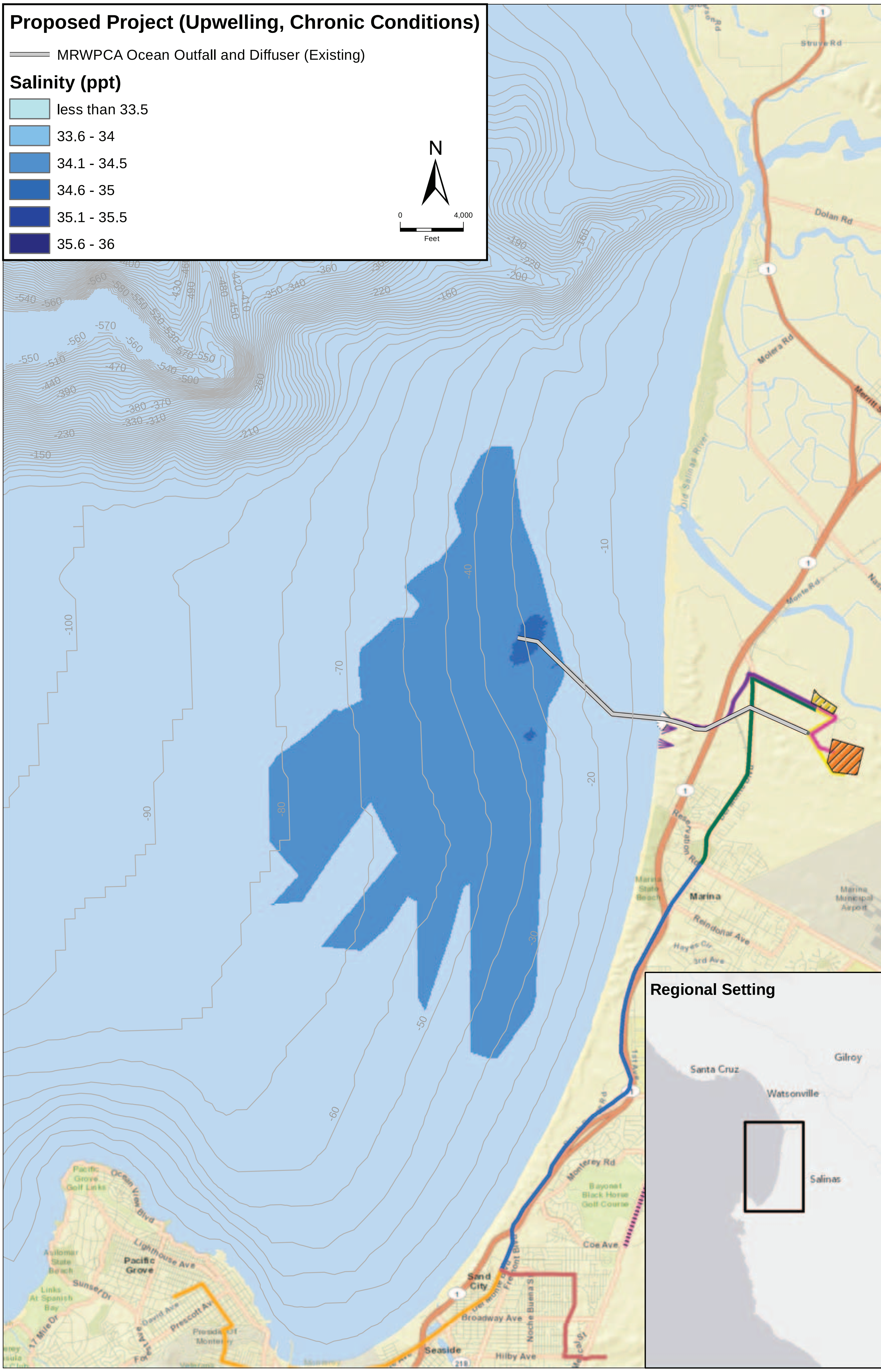

Monterey Peninsula Water Supply Project . 205335.01
Figure B-8
Salinity
(Proposed Project: Upwelling, Chronic Conditions)

Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013
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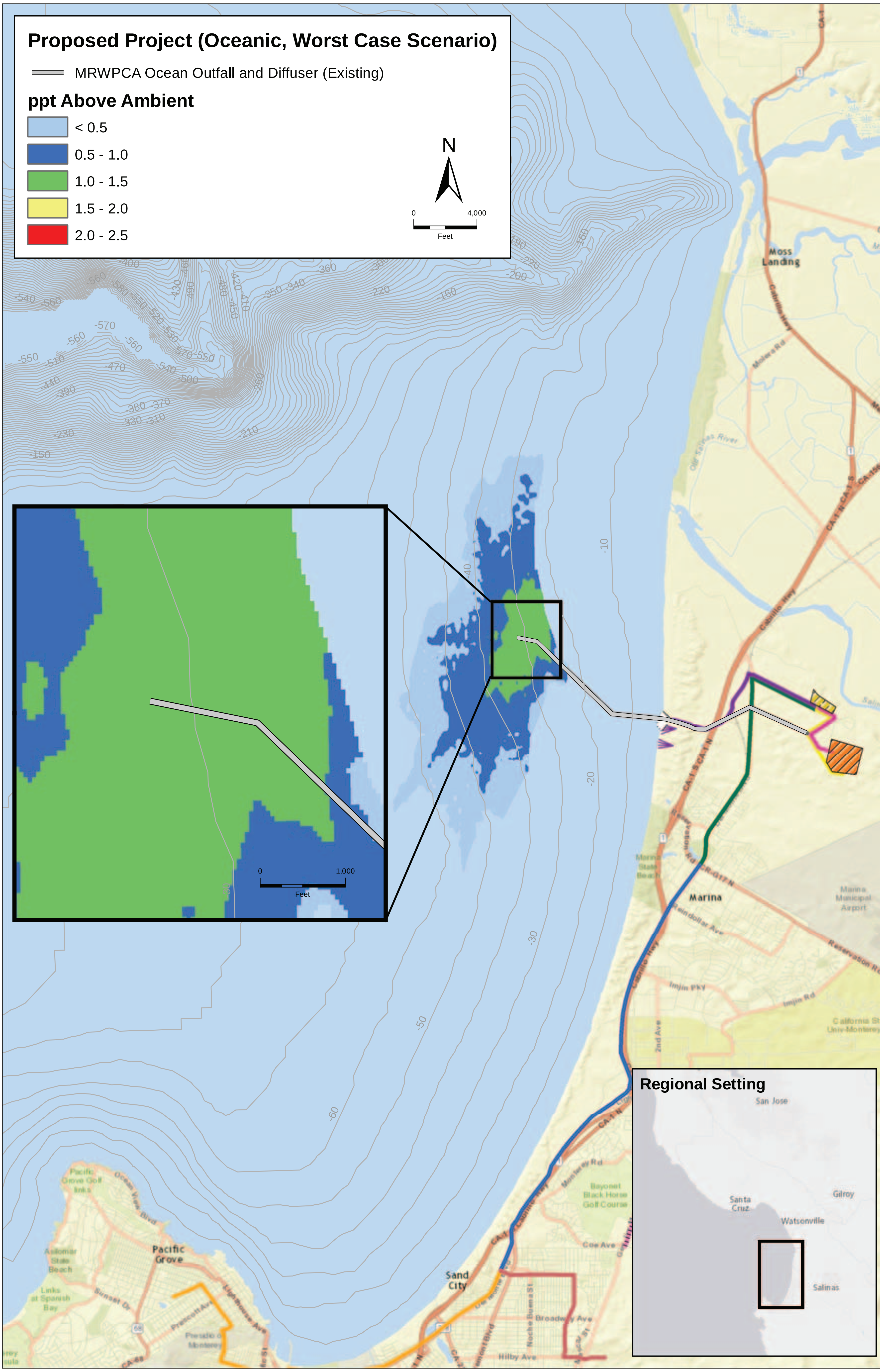

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Figure B-9
Parts per Thousand Above Ambient
(Proposed Project: Oceanic, Worst Case Scenario)

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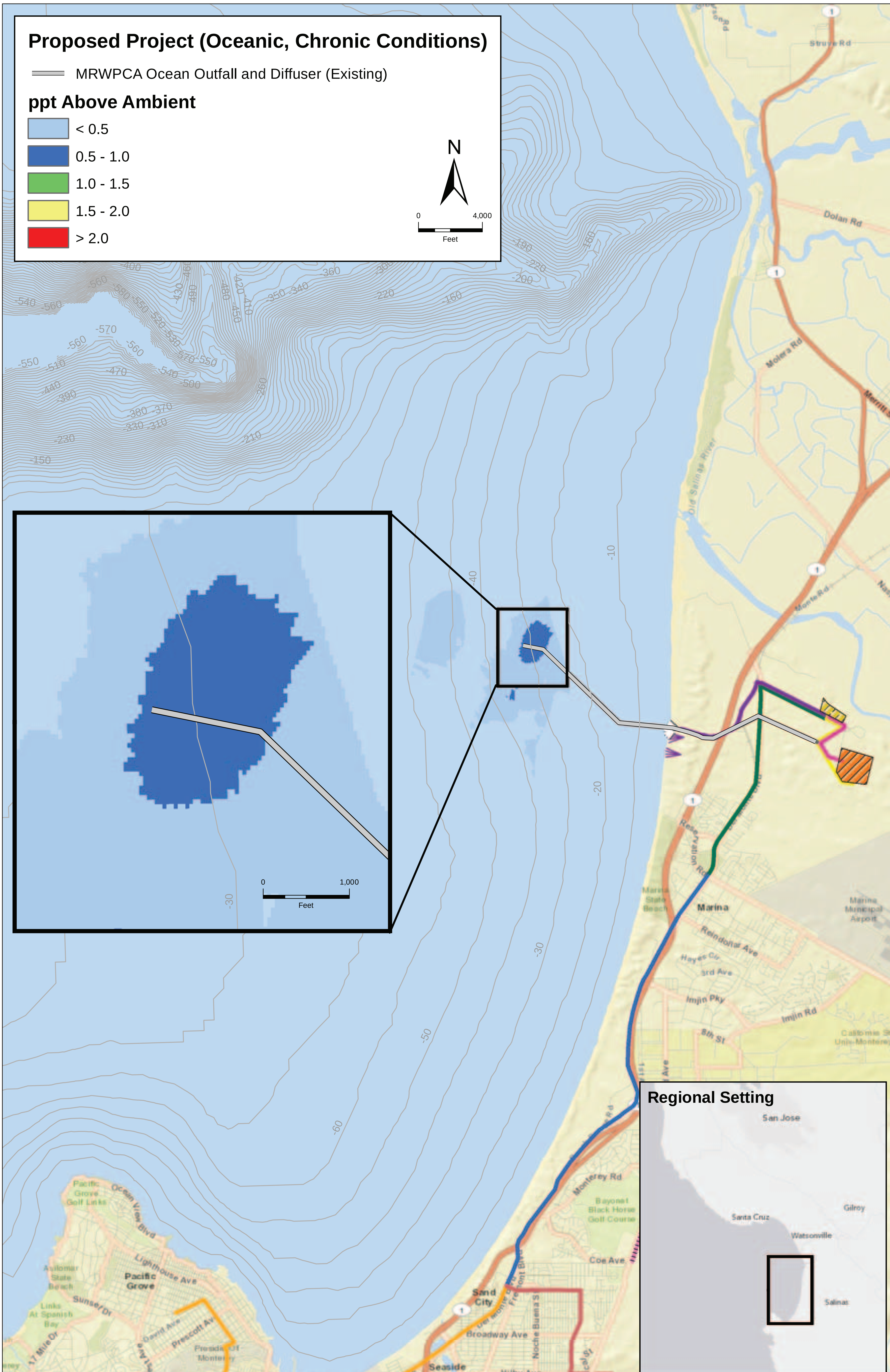

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Figure B-10
Parts per Thousand Above Ambient
(Proposed Project: Oceanic, Chronic Conditions)

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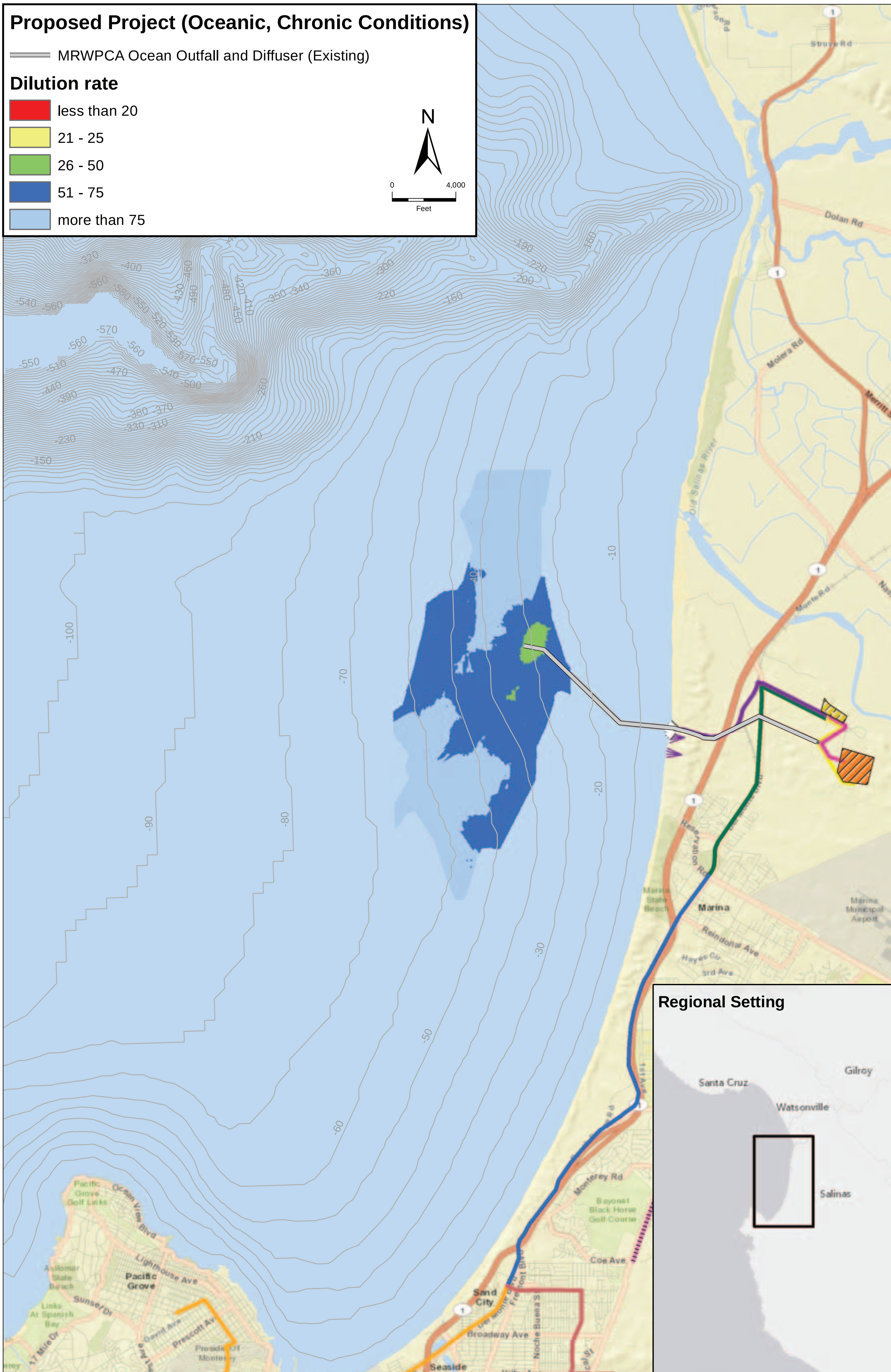

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Figure B-11
Dilution Rate
(Proposed Project: Oceanic, Chronic Conditions)

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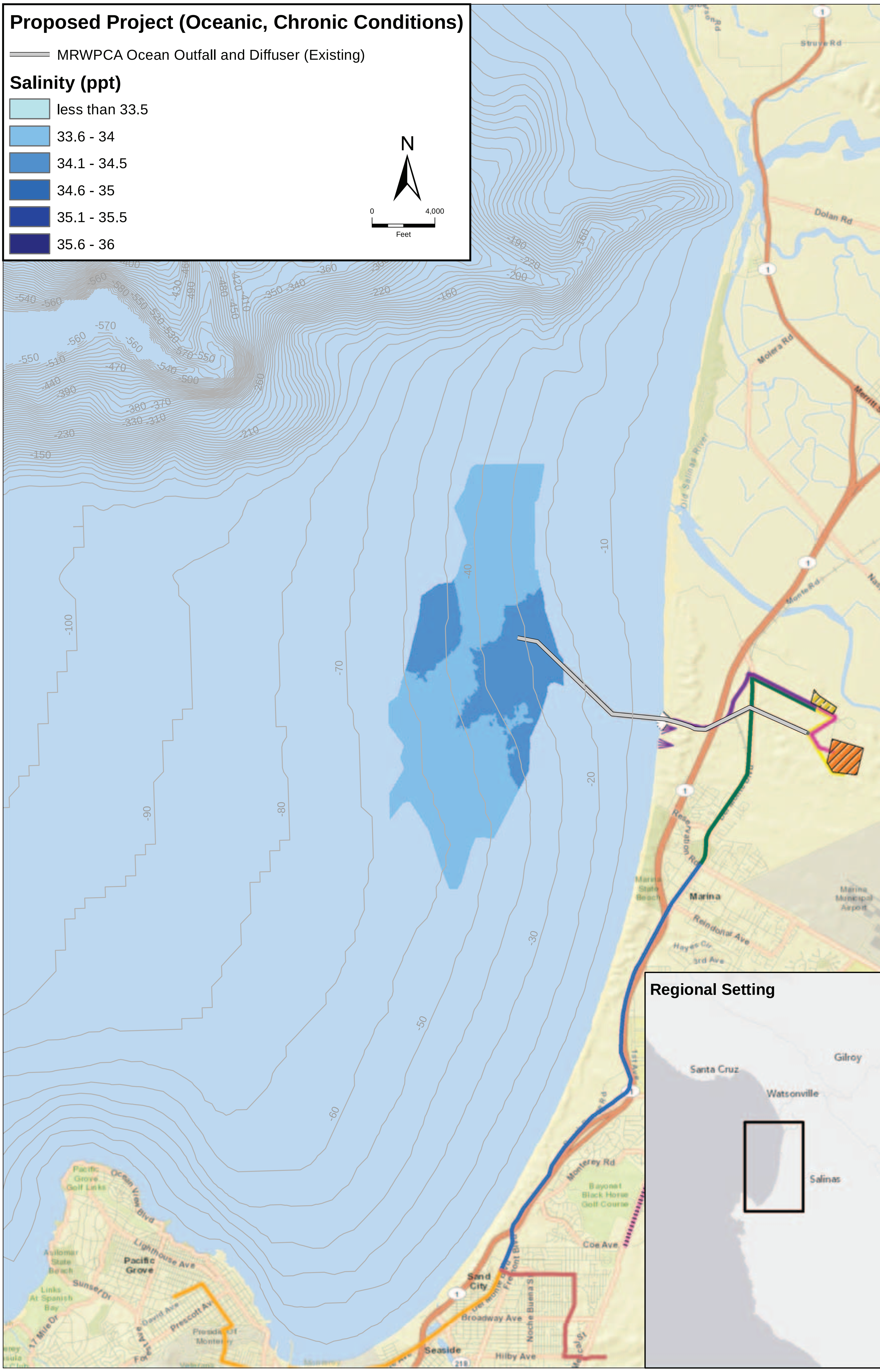

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Figure B-12
Salinity
(Proposed Project: Oceanic, Chronic Conditions)

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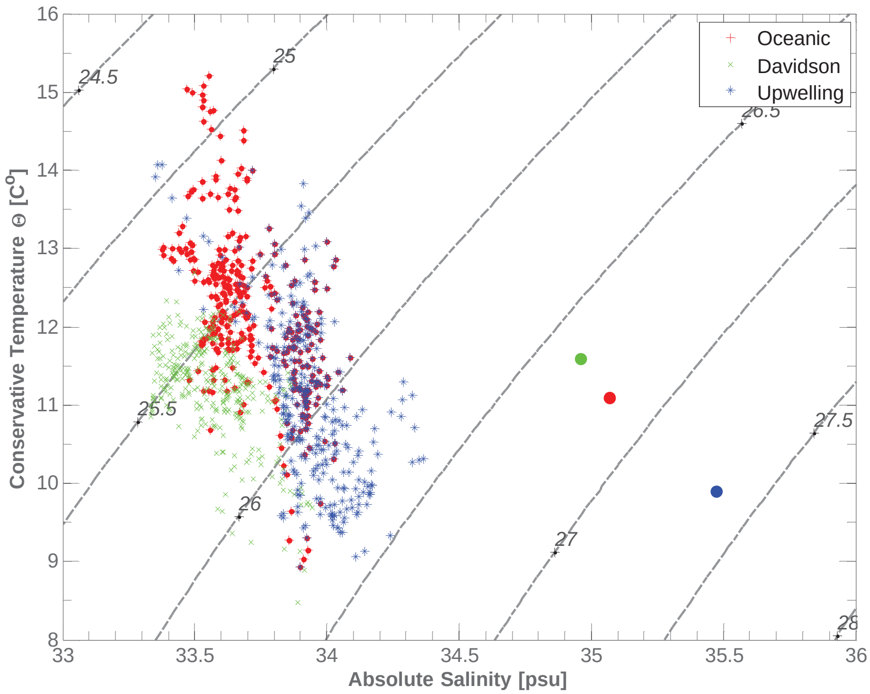
Appendix C

Project Variant T-S Diagrams



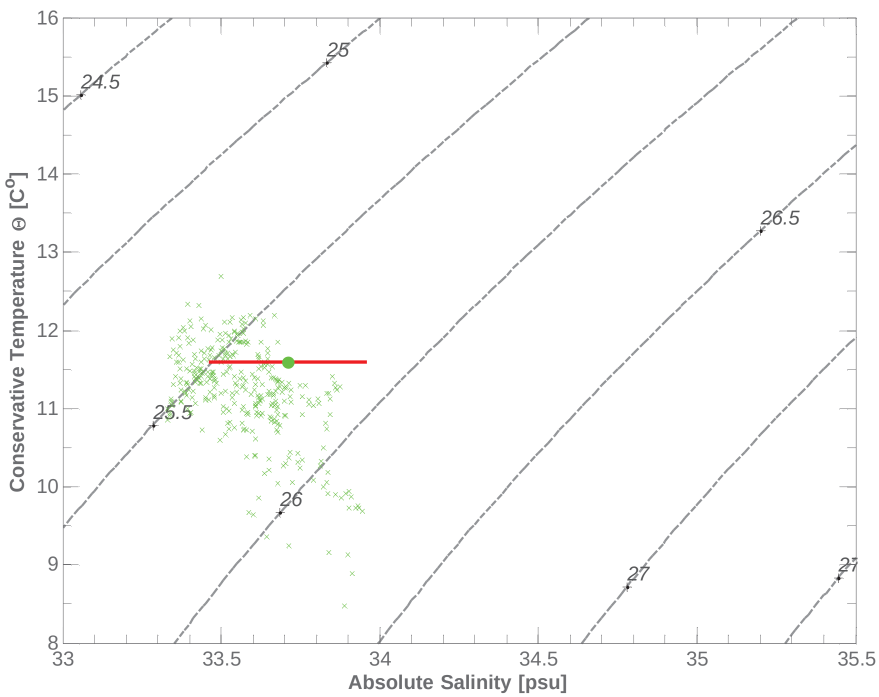


Figure 1

Temperature, salinity and density at discharge point in ROMS model during all ocean seasons after near field dilution (top) and during Davidson conditions after far-field dilution in 48 hrs (bottom). Red line is one standard deviation of diluted brine discharge.

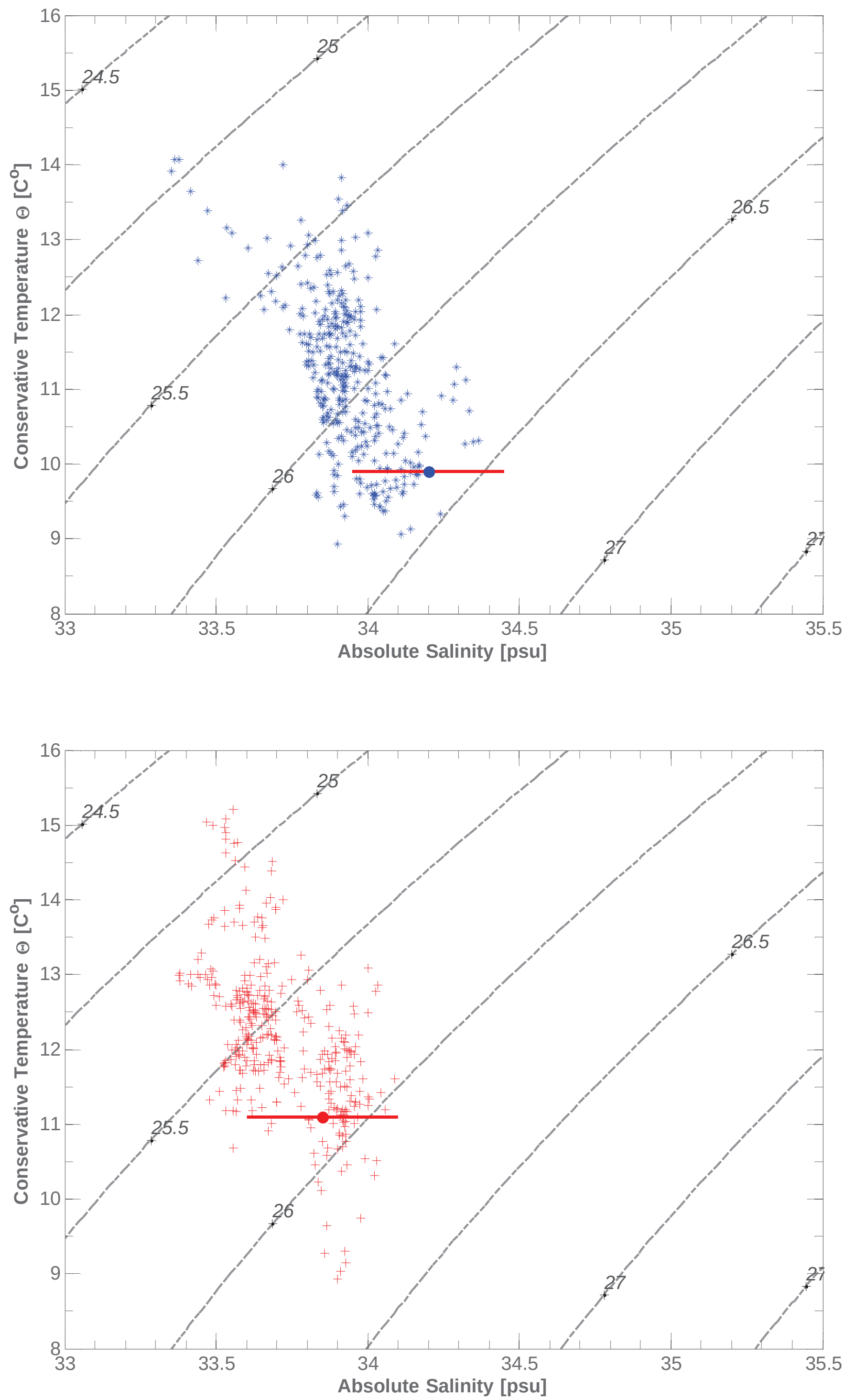


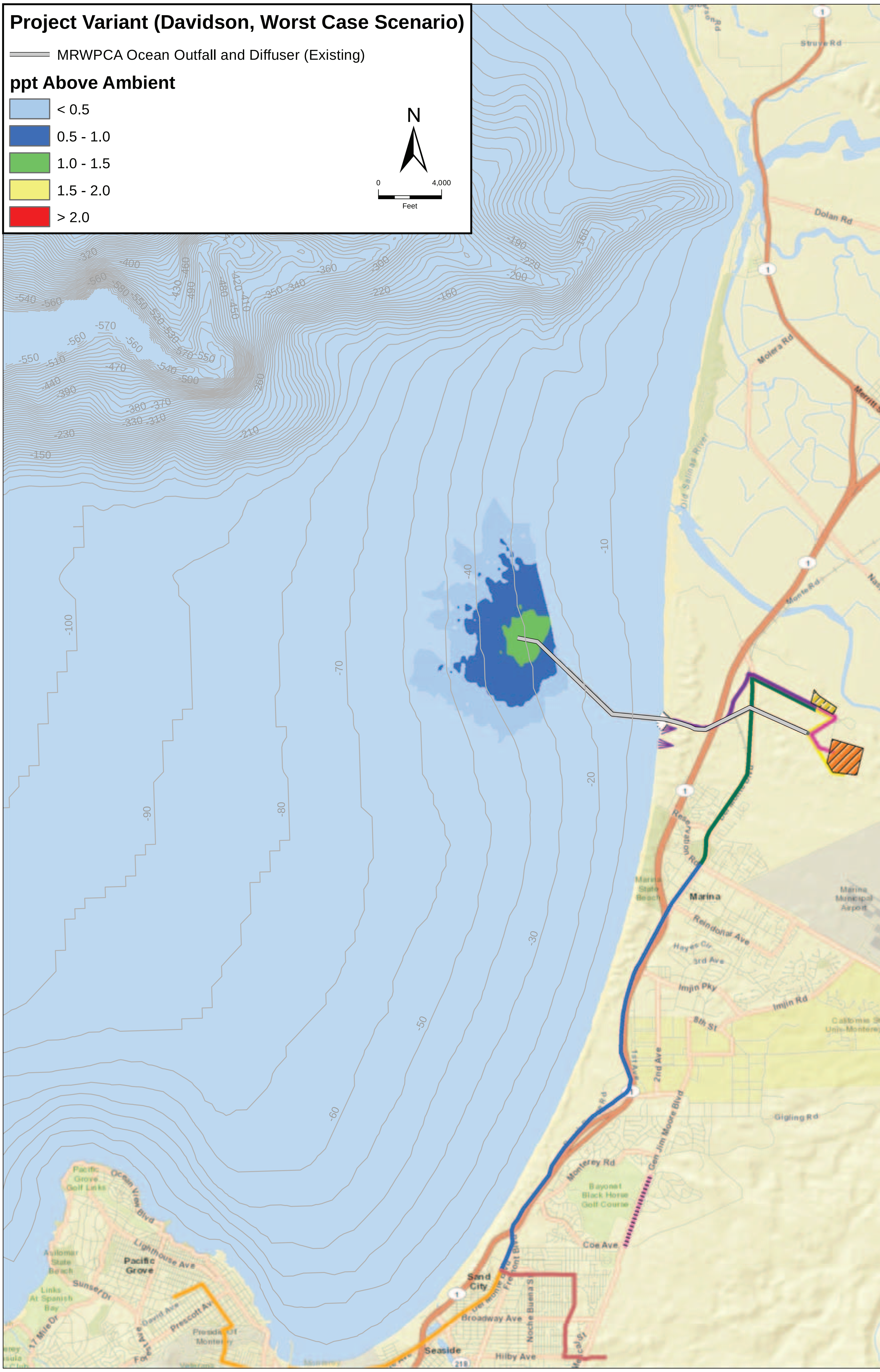
Figure 2

Temperature, salinity and density at discharge point in ROMS model during upwelling (top) and oceanic conditions (bottom) compared to brine discharge after far-field dilution in 48 hrs. Red line is one standard deviation of diluted brine discharge.

Appendix D

Project Variant - Seasonal Plume Behavior

Figure	Ocean Season	Condition/Scenario	Parameter
D-1	Davidson	Worst Case	ppt Above Ambient
D-2	Davidson	Chronic	ppt Above Ambient
D-3	Davidson	Chronic	Dilution Rate
D-4	Davidson	Chronic	Salinity (ppt)
D-5	Upwelling	Worst Case	ppt Above Ambient
D-6	Upwelling	Chronic	ppt Above Ambient
D-7	Upwelling	Chronic	Dilution Rate
D-8	Upwelling	Chronic	Salinity (ppt)
D-9	Oceanic	Worst Case	ppt Above Ambient
D-10	Oceanic	Chronic	ppt Above Ambient
D-11	Oceanic	Chronic	Dilution Rate
D-12	Oceanic	Chronic	Salinity (ppt)



Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

Monterey Peninsula Water Supply Project . 205335.01

Figure D-1
Parts per Thousand Above Ambient
(Project Variant: Davidson, Worst Case Scenario)

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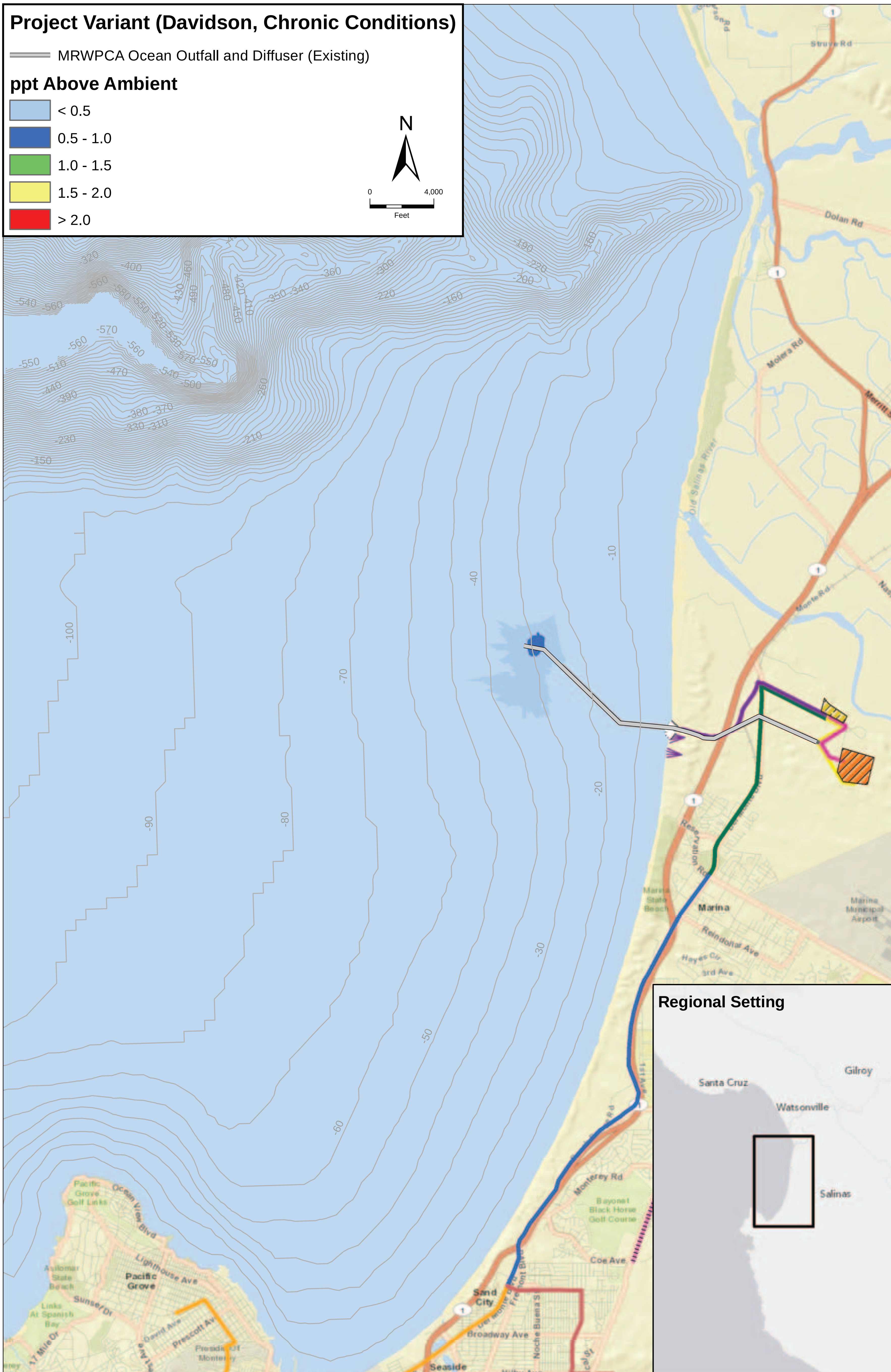

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Figure D-2
Parts per Thousand Above Ambient
(Project Variant: Davidson, Chronic Conditions)

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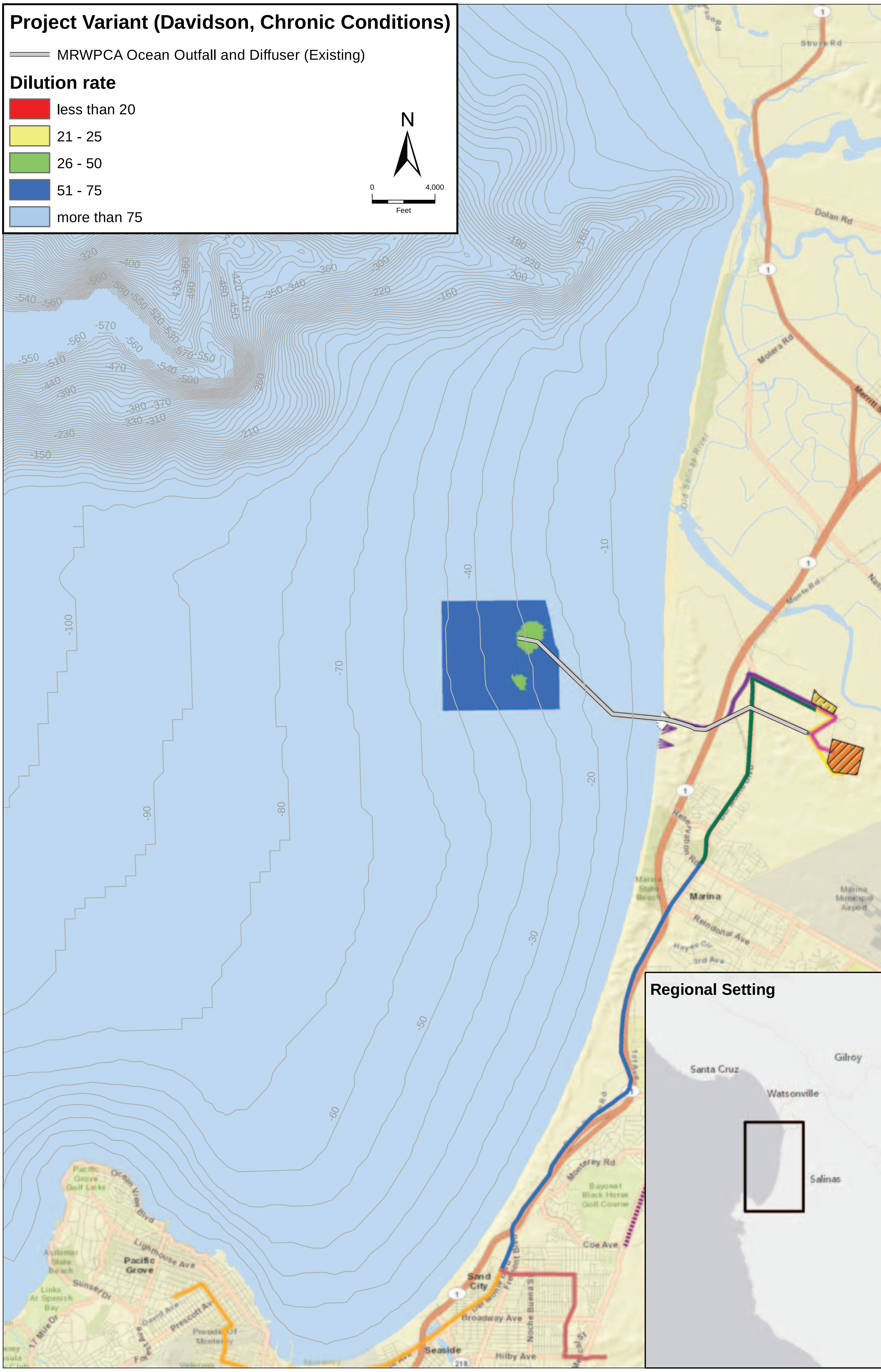

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Benthic Habitat from California Seafloor Mapping Program, CSUMB.

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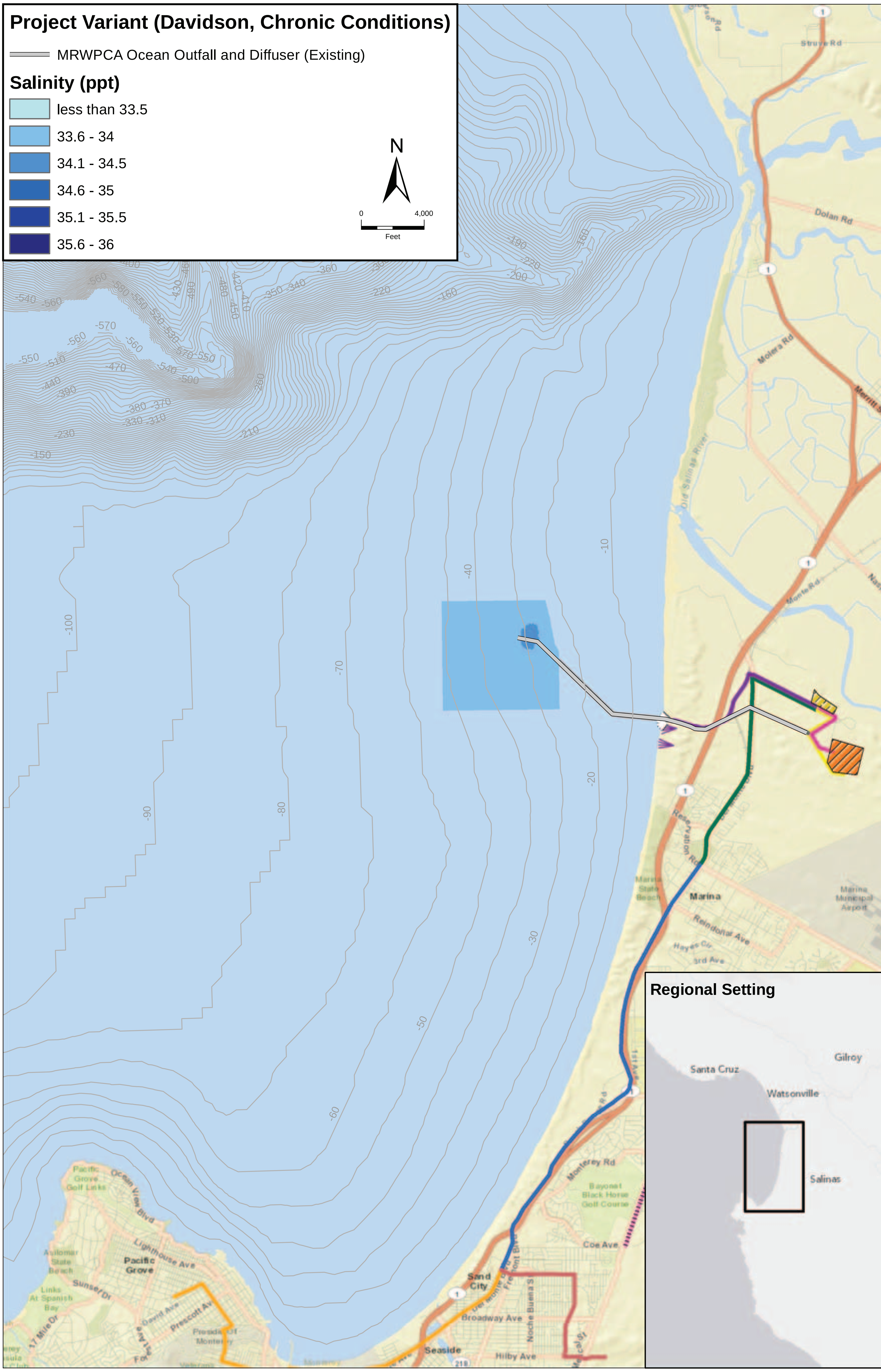
Monterey Peninsula Water Supply Project . 205335.01

Figure D-3
Dilution Rate
(Project Variant Davidson, Chronic Conditions)



Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013
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Figure D-4
Salinity
(Project Variant: Davidson, Chronic Conditions)

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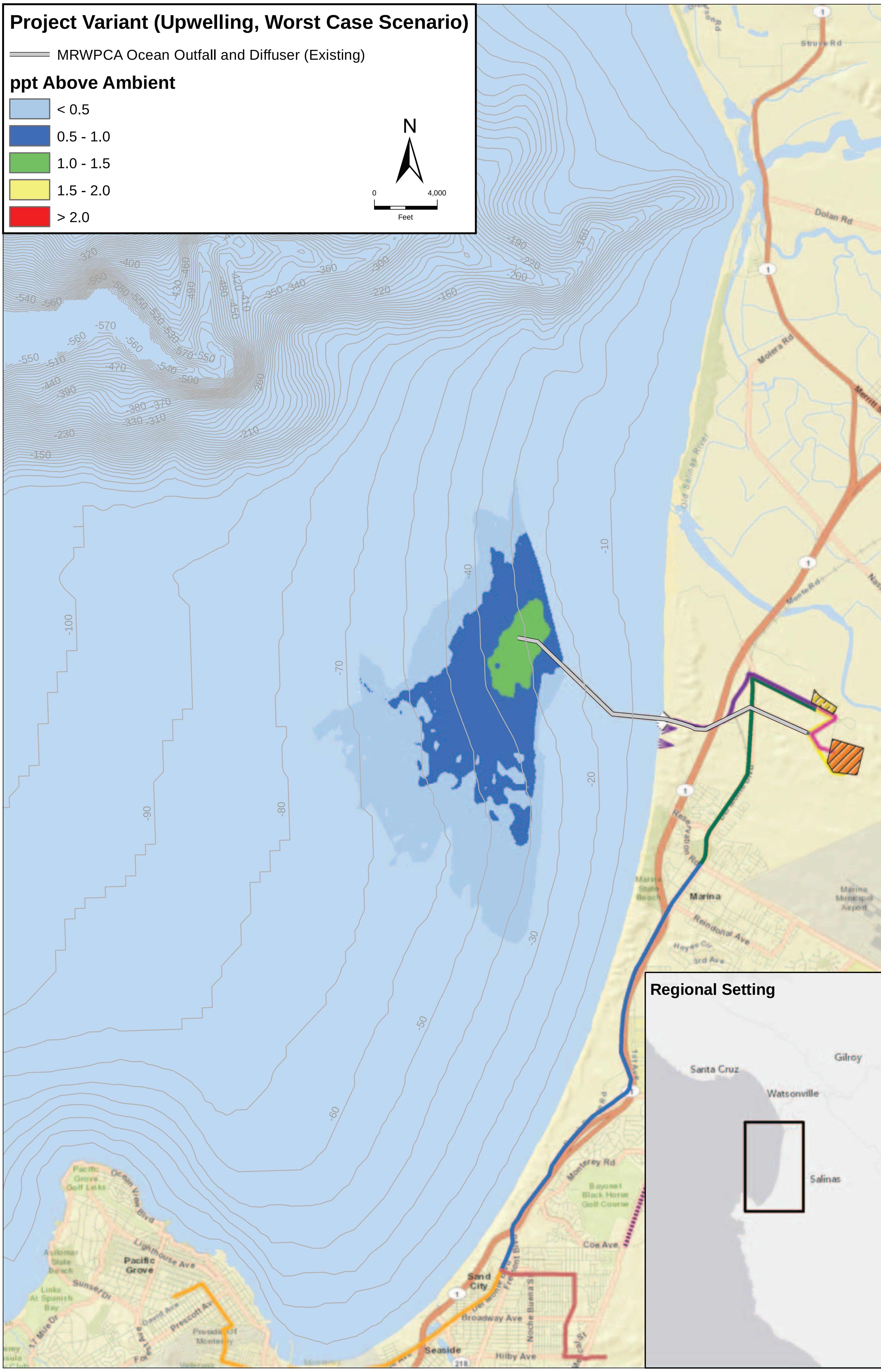

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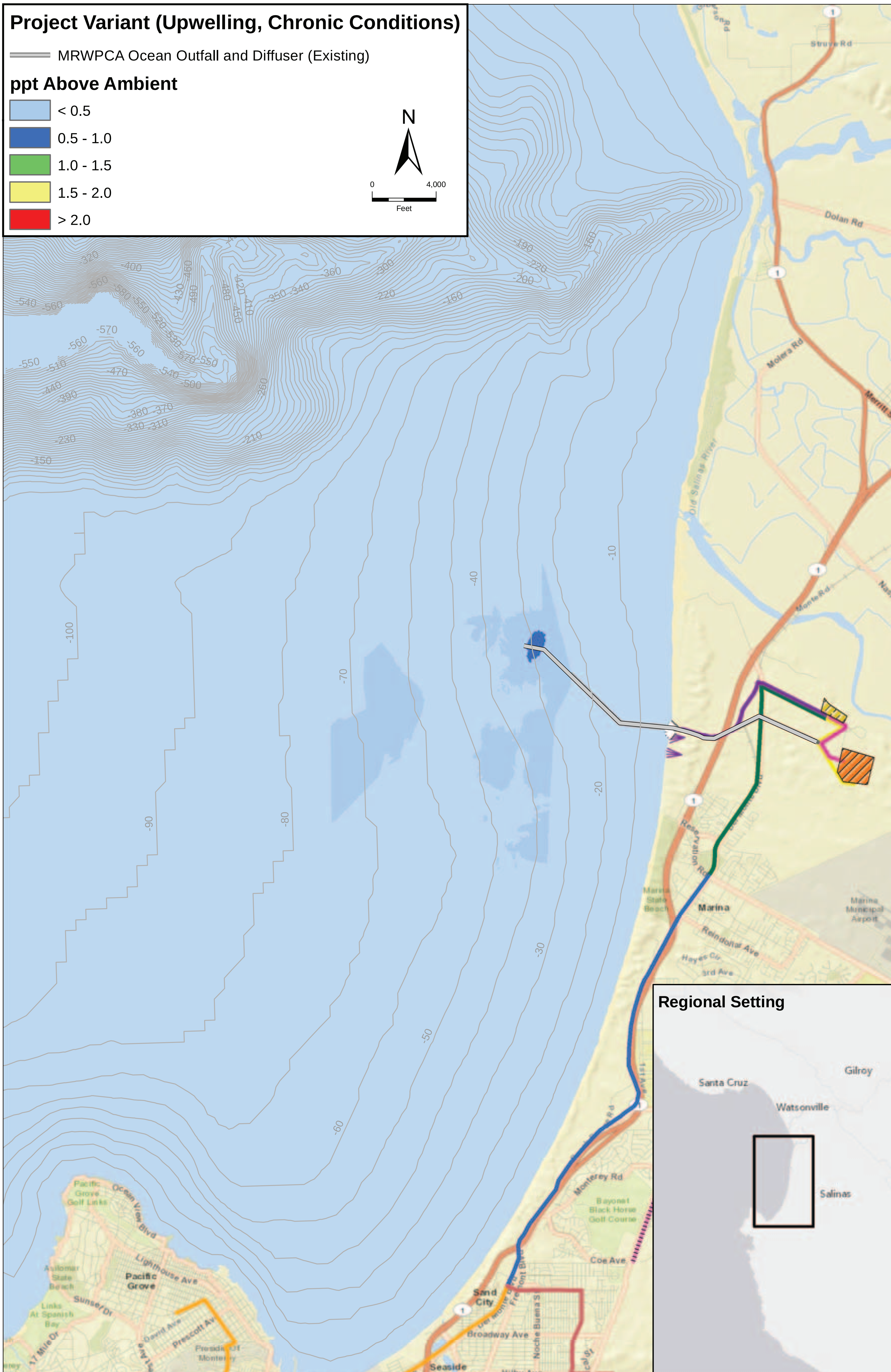
Figure D-5
Parts per Thousand Above Ambient
(Project Variant: Upwelling, Worst Case Scenario)

U:\GIS\GIS\Projects\205xxx\205335_Water\Tasks\Cal_Am_2012\Oceanography\mxds\FigureMXDs\Memo\AppendixD\D-05 PV_Upwelling_Acute_Ambient.mxd
11/6/2014



Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

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Figure D-6
Parts per Thousand Above Ambient
(Project Variant: Upwelling, Chronic Conditions)

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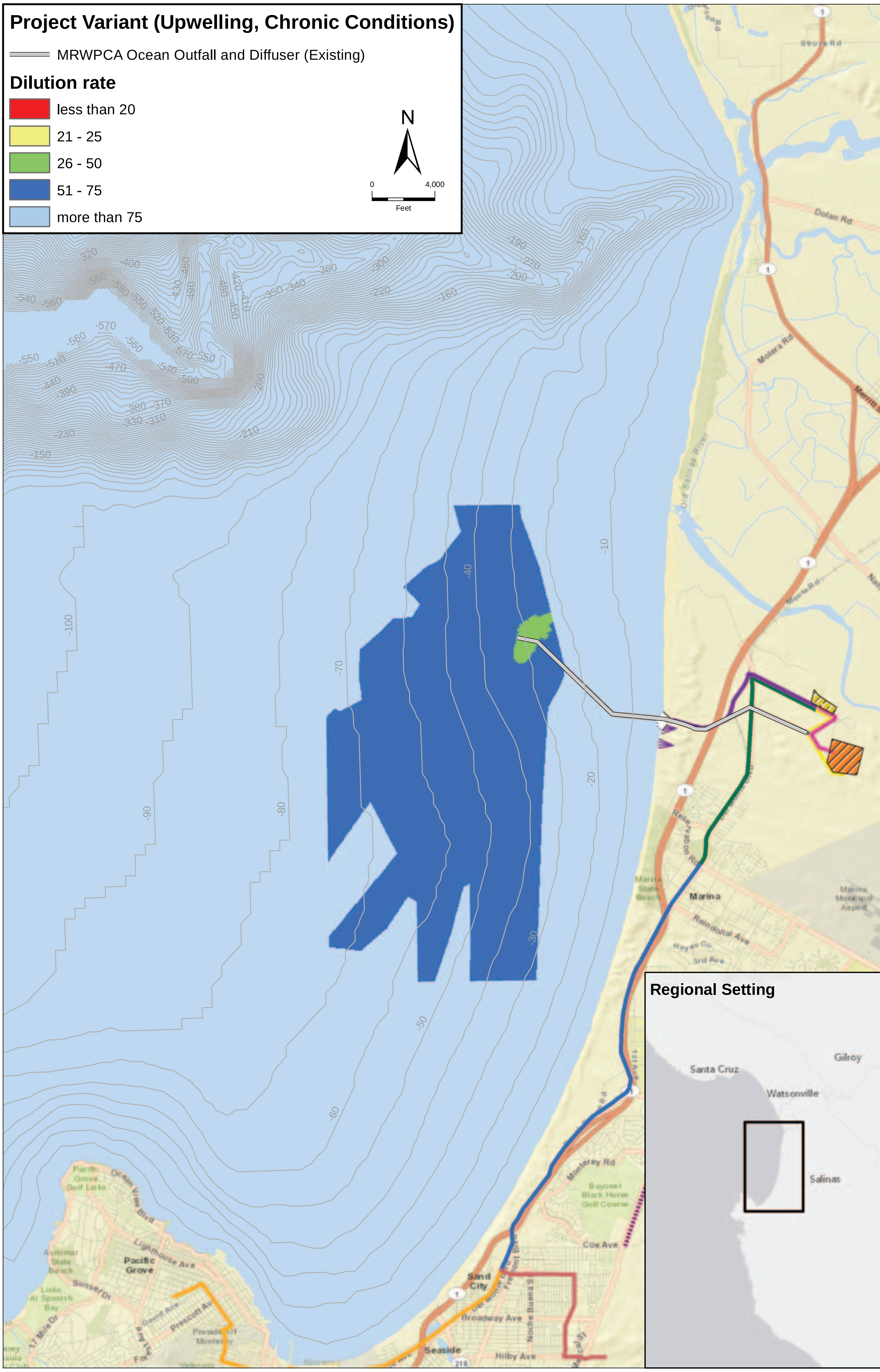
11/6/2014



Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013
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Monterey Peninsula Water Supply Project . 205335.01
Figure D-7
Dilution Rate
(Project Variant: Upwelling, Chronic Conditions)

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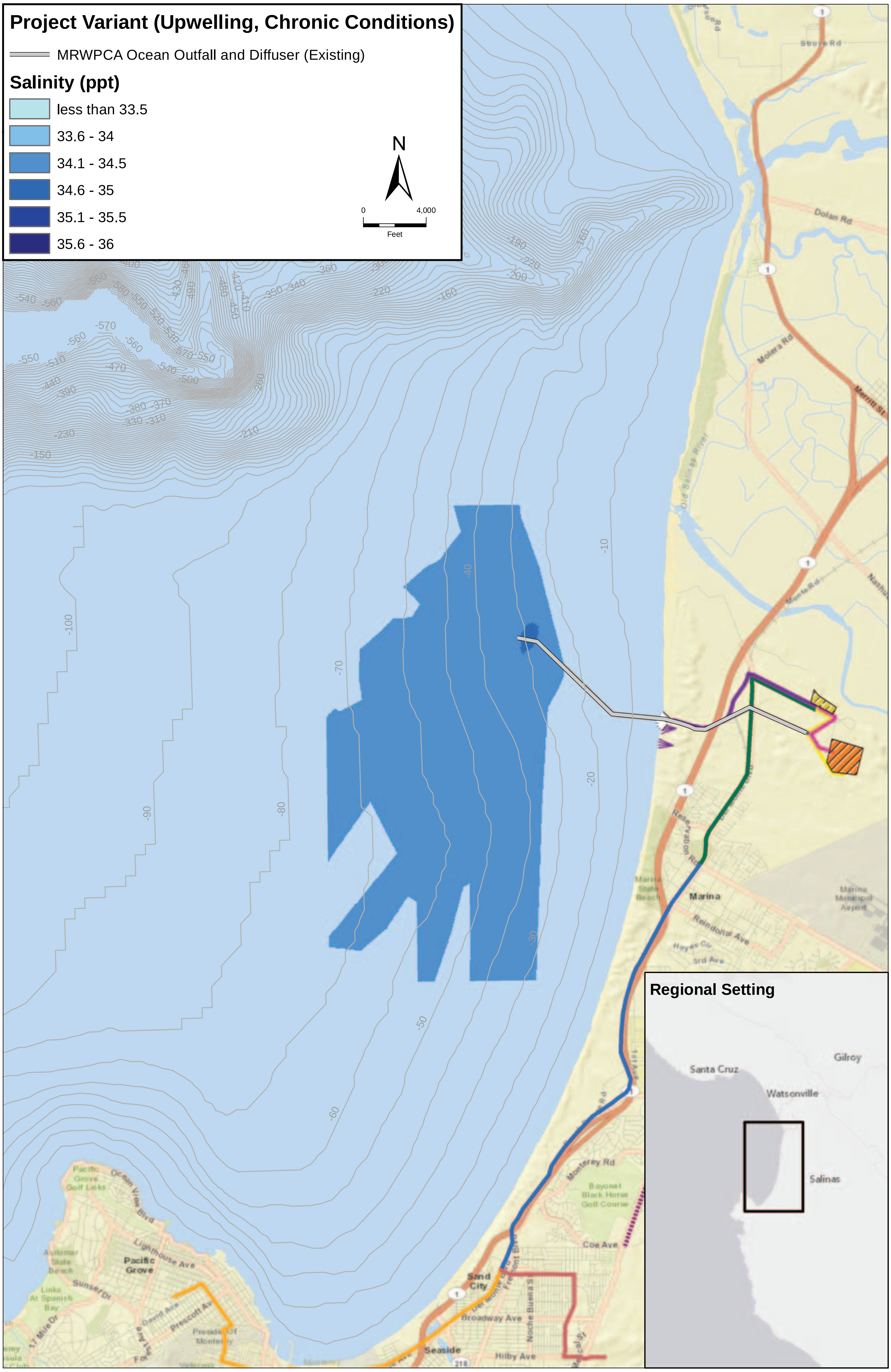

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Figure D-8
Salinity
(Project Variant: Upwelling, Chronic Conditions)

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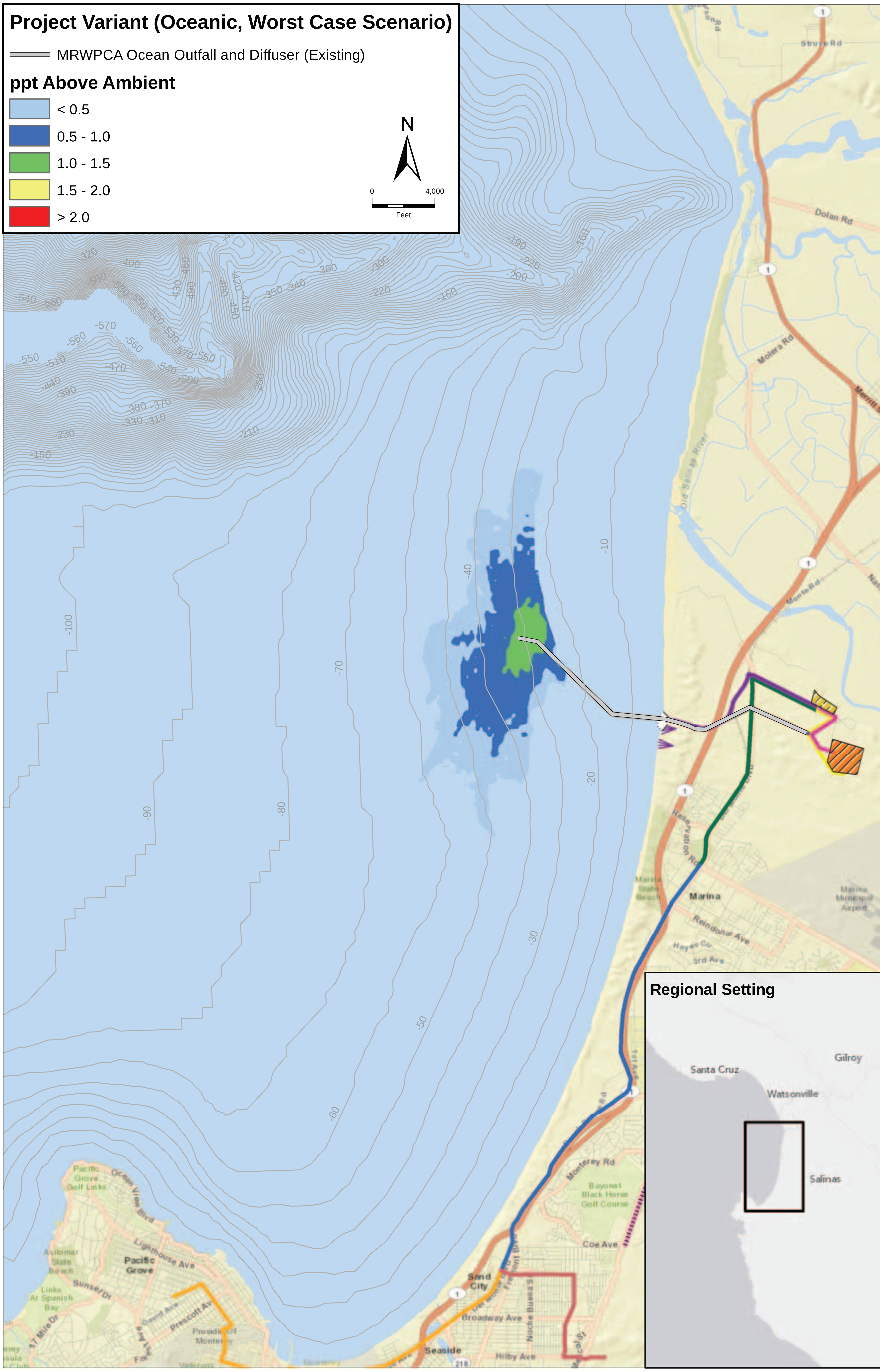

Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013
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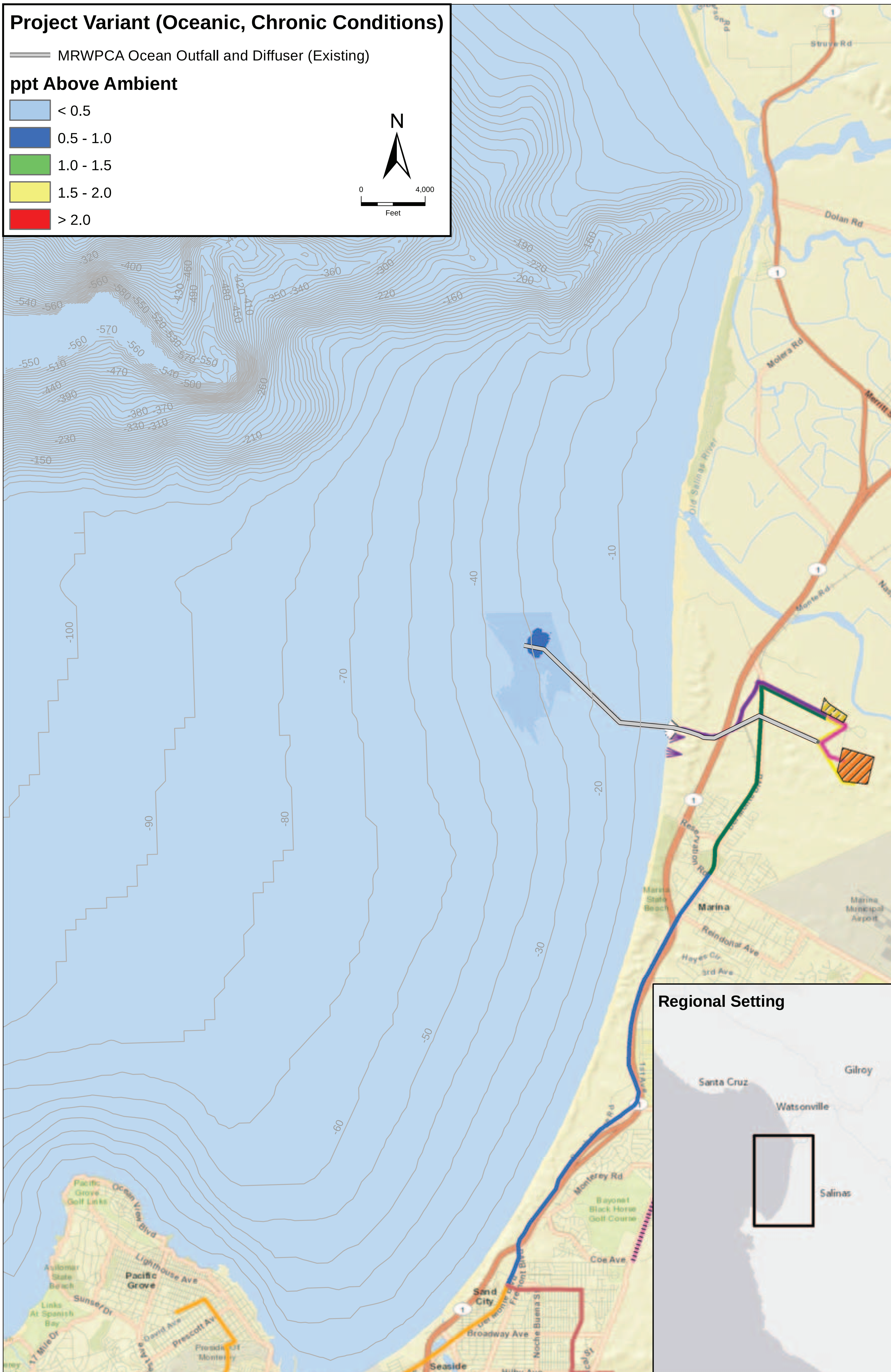
Figure D-9

Parts per Thousand Above Ambient
(Project Variant: Oceanic, Worst Case Scenario)

U:\GIS\GIS\Projects\205xxx\205335_Water\Tasks\Cal_Am_2012\Oceanography\mxds\FigureMXDs\Memo\AppendixD\D-09 PV_Oceanic_Acute_Ambient.mxd
11/6/2014



Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013
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Figure D-10

Parts per Thousand Above Ambient
(Project Variant: Oceanic, Chronic Conditions)

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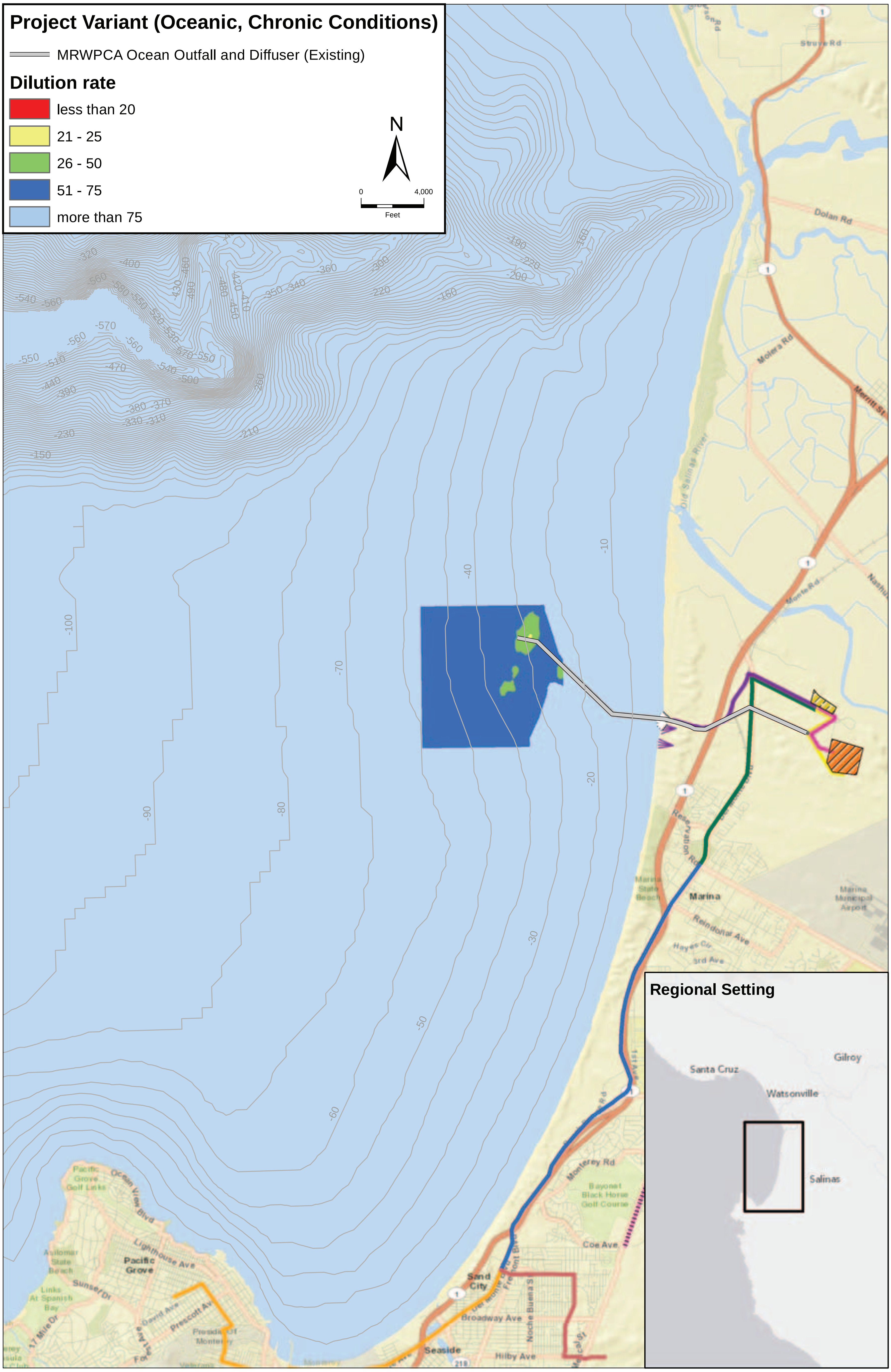
11/6/2014



Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013
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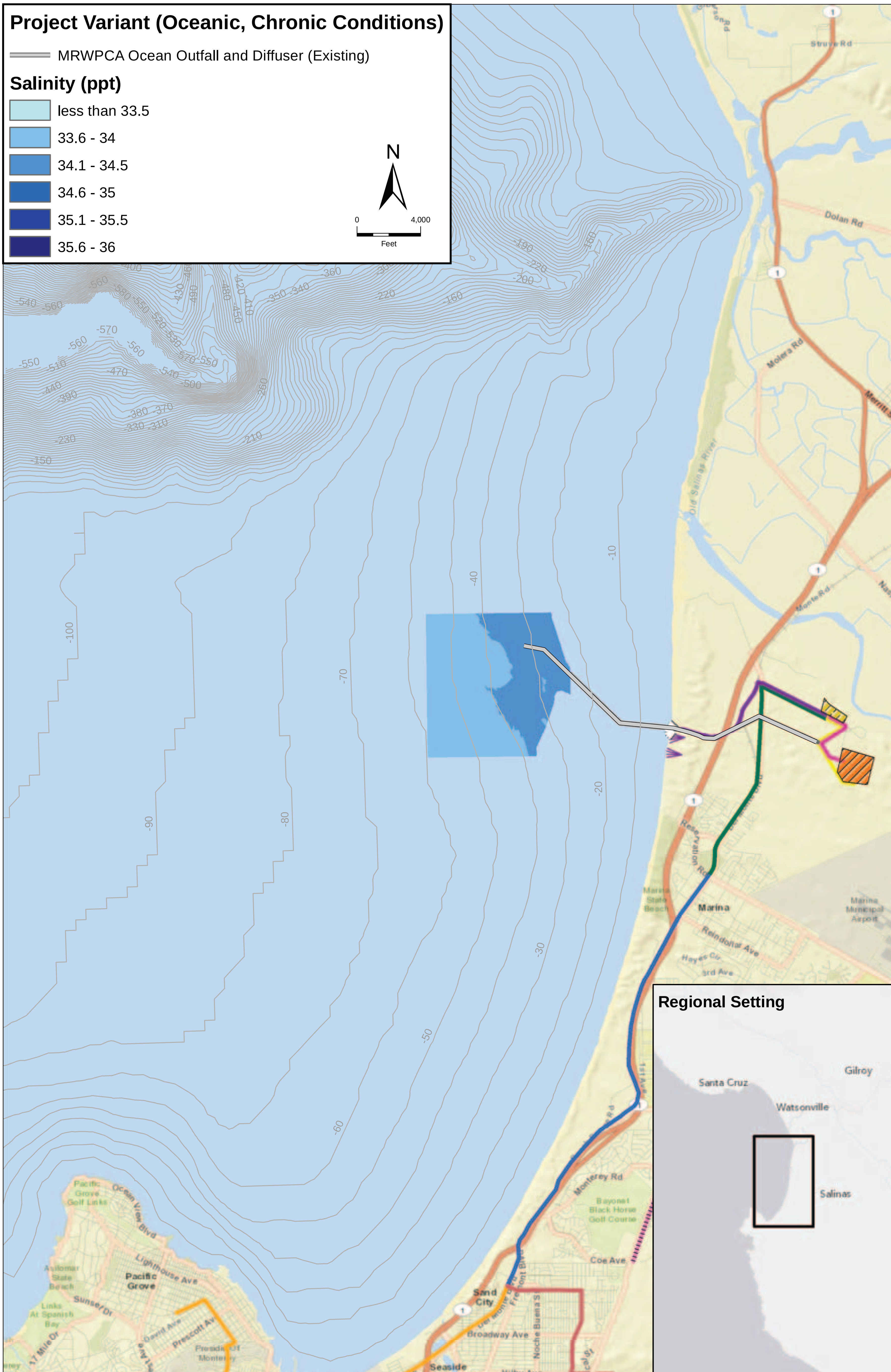
Figure D-11
Dilution Rate
(Project Variant: Oceanic, Chronic Conditions)

U:\GIS\GIS\Projects\205xxx\205335_Water\Tasks\Cal_Am_2012\Oceanography\mxds\FigureMXDs\Memo\AppendixD\D-11 PV_Oceanic_Chronic_Dilution.mxd
11/6/2014



Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

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Figure D-12
Salinity
(Project Variant: Oceanic, Chronic Conditions)

U:\GIS\GIS\Projects\205xxx\205335_Water\Tasks\Cal_Am_2012\Oceanography\mxds\FigureMXDs\Memo\AppendixD\D-12 PV_Oceanic_Chronic_Salinity.mxd
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Appendix E

Project Variant Desalination Plant Only T-S Diagrams

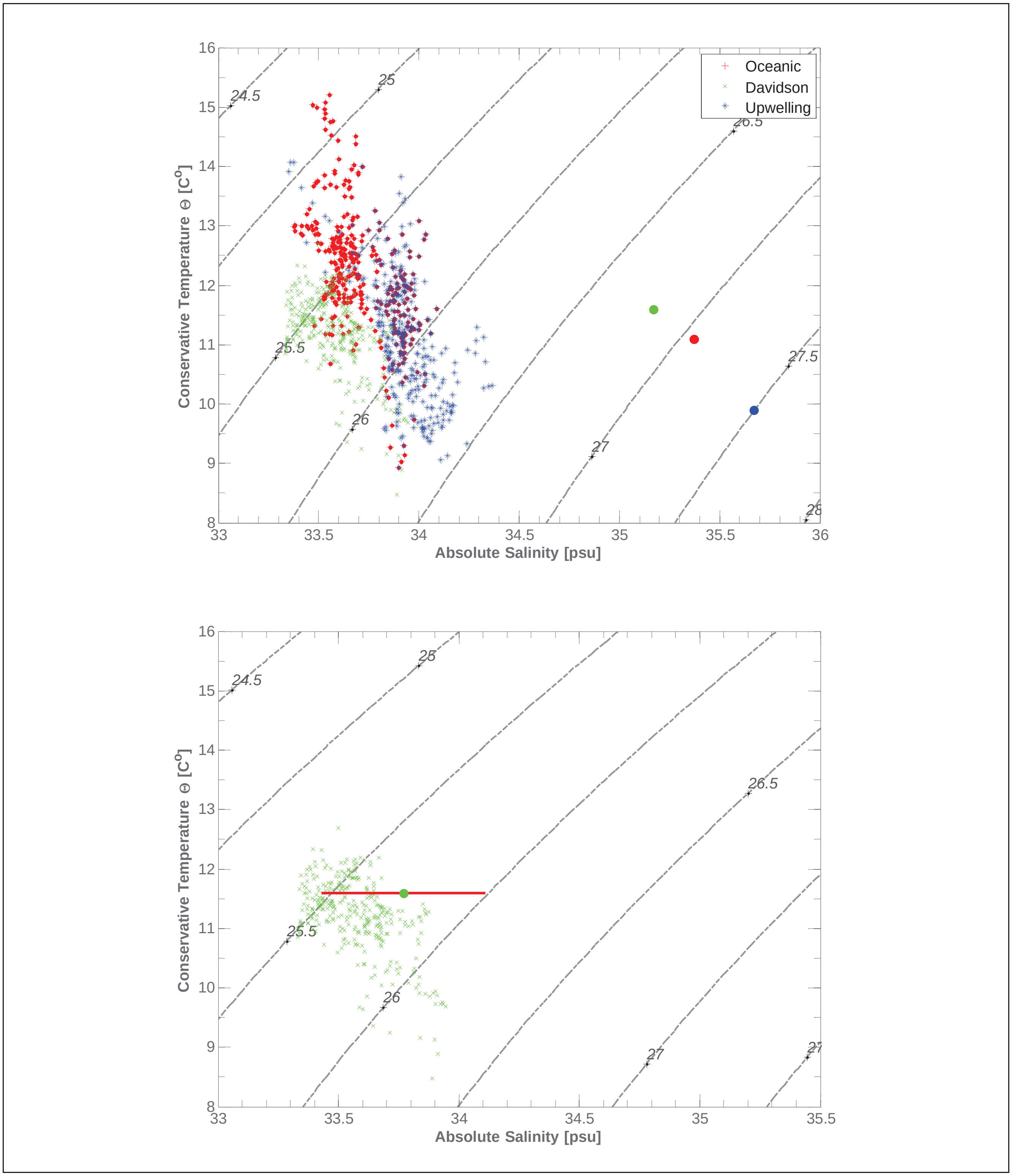

Figure 1

Temperature, salinity and density at discharge point in ROMS model during all ocean seasons after near field dilution (top) and during Davidson conditions after far-field dilution in 48 hrs (bottom). Red line is one standard deviation of diluted brine discharge.

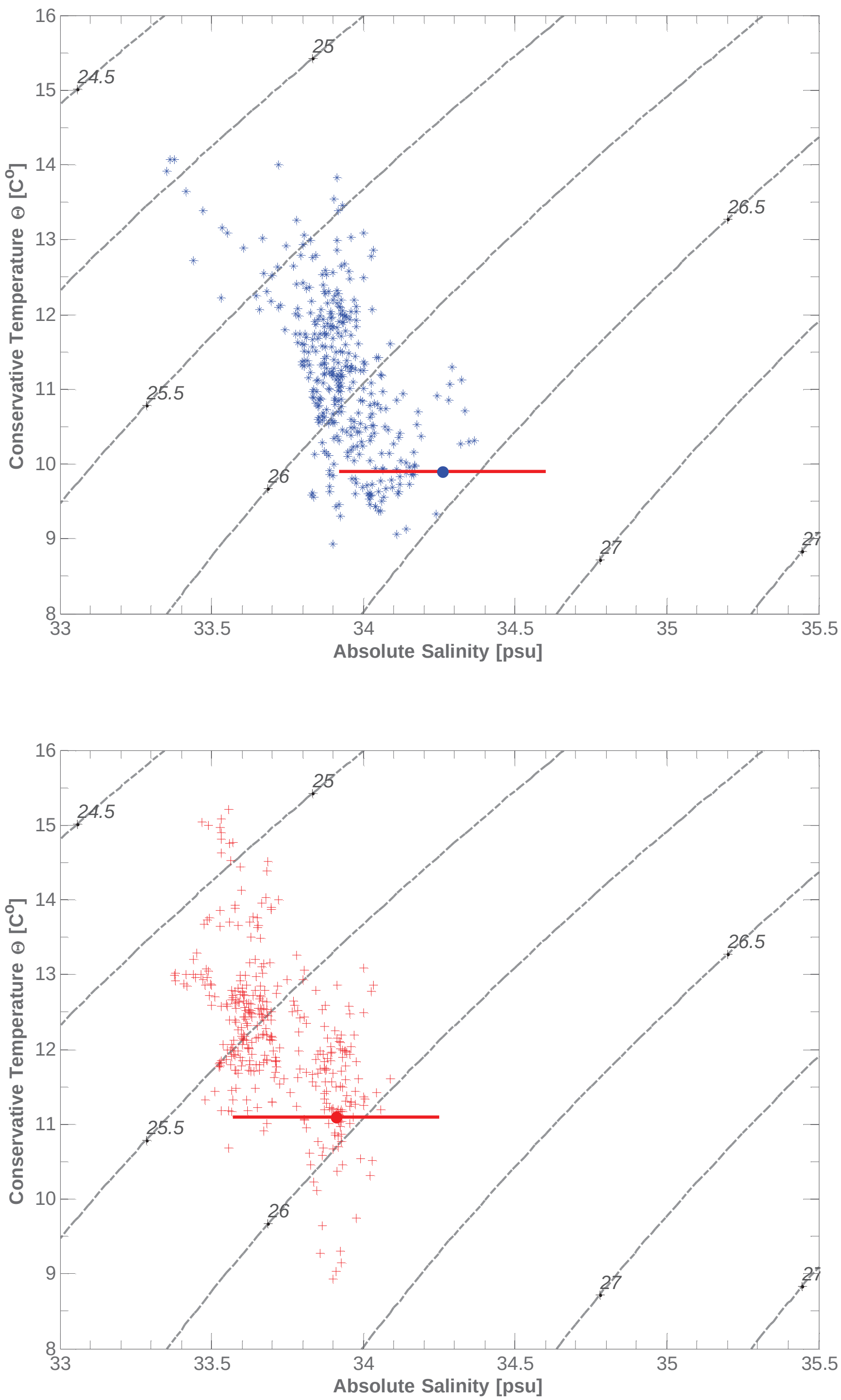

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Figure 2

Temperature, salinity and density at discharge point in ROMS model during upwelling (top) and oceanic conditions (bottom) compared to brine discharge after far-field dilution in 48 hrs. Red line is one standard deviation of diluted brine discharge.

Appendix F

Project Variant Desalination Plant Only - Seasonal Plume Behavior

Figure	Ocean Season	Condition/Scenario	Parameter
F-1	Davidson	Worst Case	ppt Above Ambient
F-2	Davidson	Chronic	ppt Above Ambient
F-3	Davidson	Chronic	Dilution Rate
F-4	Davidson	Chronic	Salinity (ppt)
F-5	Upwelling	Worst Case	ppt Above Ambient
F-6	Upwelling	Chronic	ppt Above Ambient
F-7	Upwelling	Chronic	Dilution Rate
F-8	Upwelling	Chronic	Salinity (ppt)
F-9	Oceanic	Worst Case	ppt Above Ambient
F-10	Oceanic	Chronic	ppt Above Ambient
F-11	Oceanic	Chronic	Dilution Rate
F-12	Oceanic	Chronic	Salinity (ppt)

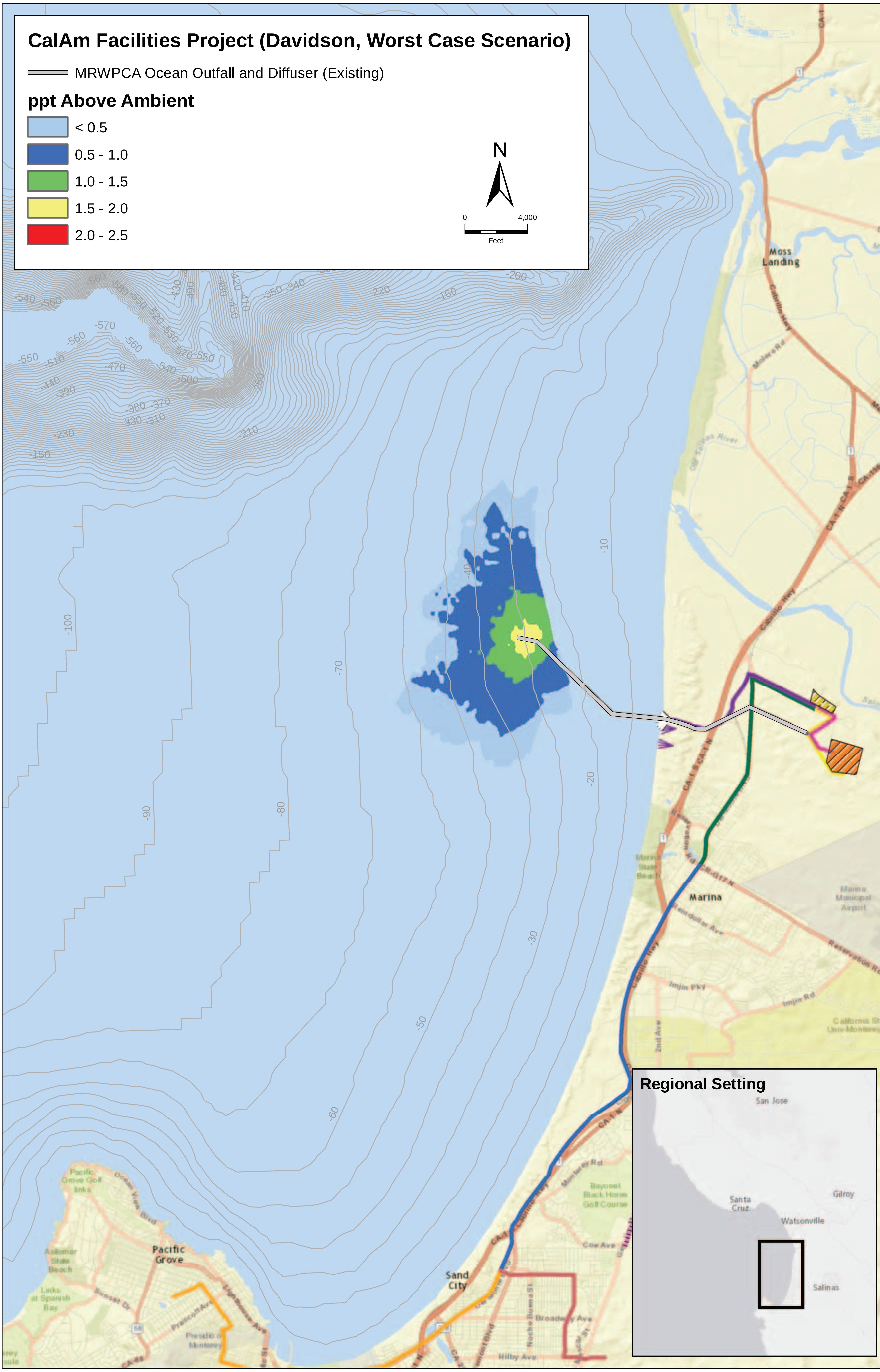

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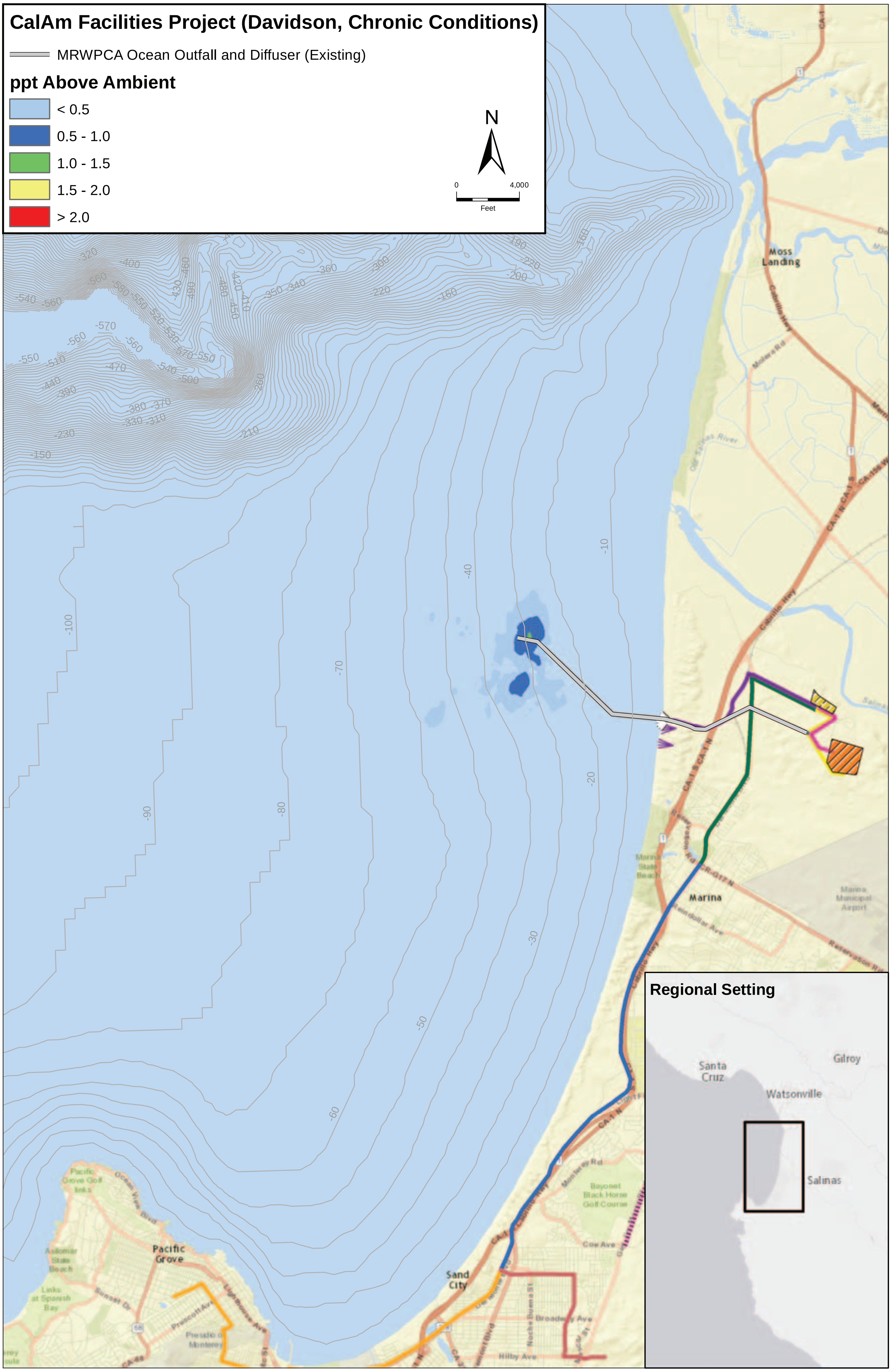
Figure F-1
Parts per Thousand Above Ambient
(CalAm Facilities Project: Davidson, Worst Case Scenario)

U:\GIS\GIS\Projects\205xxx\205335_Water\Tasks\Cal_Am_2012\Oceanography\mxds\FigureMXDs\Memo\AppendixF\F-01 SP_Davidson_Acute_Ambient.mxd
4/2/2015



Basemap Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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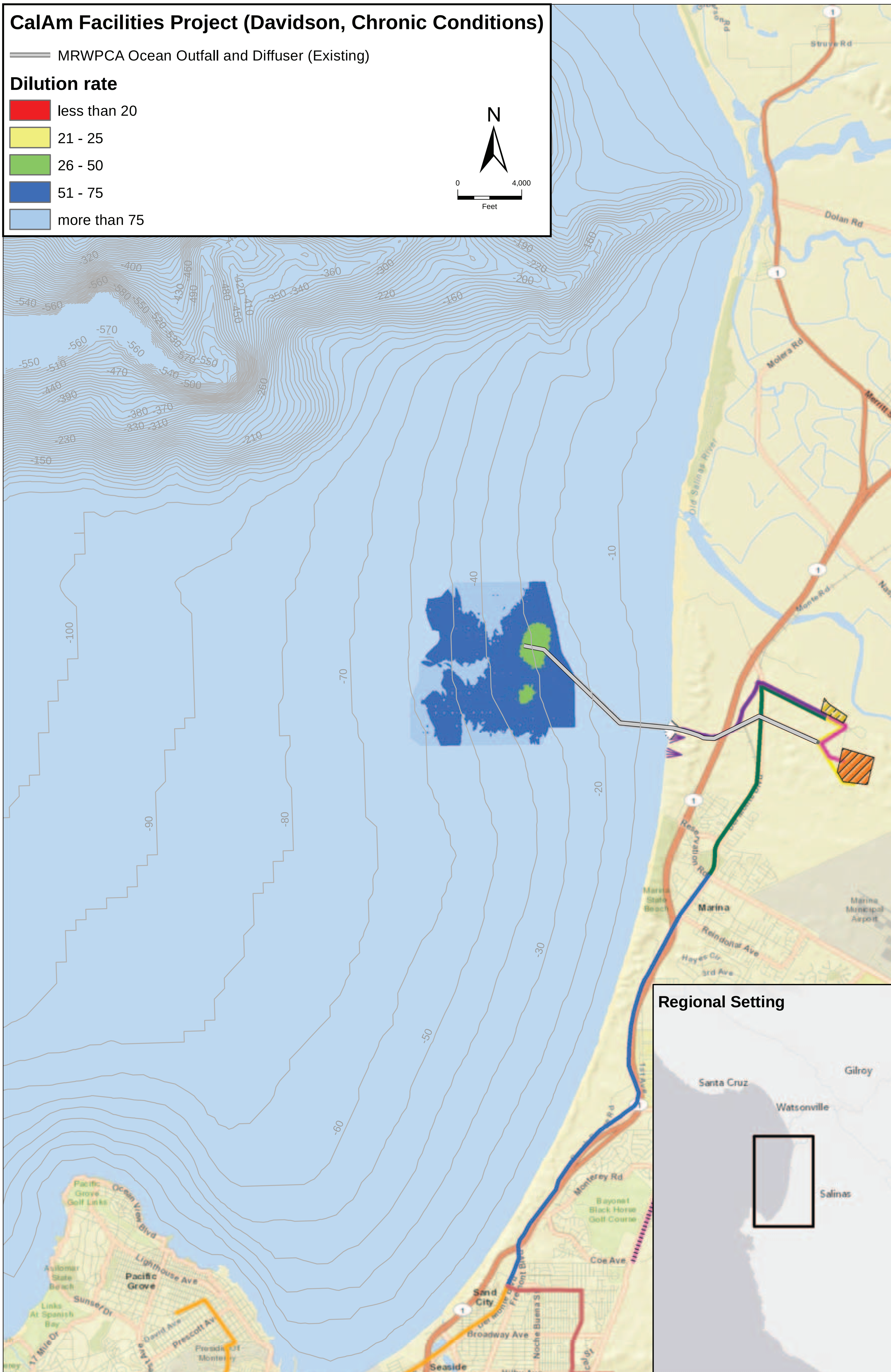
Figure F-2
Parts per Thousand Above Ambient
(CalAm Facilities Project: Davidson, Chronic Conditions)

U:\GIS\GIS\Projects\205xxx\205335_Water\Tasks\Cal_Am_2012\Oceanography\mxds\FigureMXDs\Memo\AppendixF\F-02 SP_Davidson_Chronic_Ambient.mxd
4/2/2015



Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013
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Figure F-3
Dilution Rate
(CalAm Facilities Project: Davidson, Chronic Conditions)

U:\GIS\GIS\Projects\205xxx\205335_Water\Tasks\Cal_Am_2012\Oceanography\mxds\FigureMXDs\Memo\AppendixF\F-03 SP_Davidson_Chronic_Dilution.mxd
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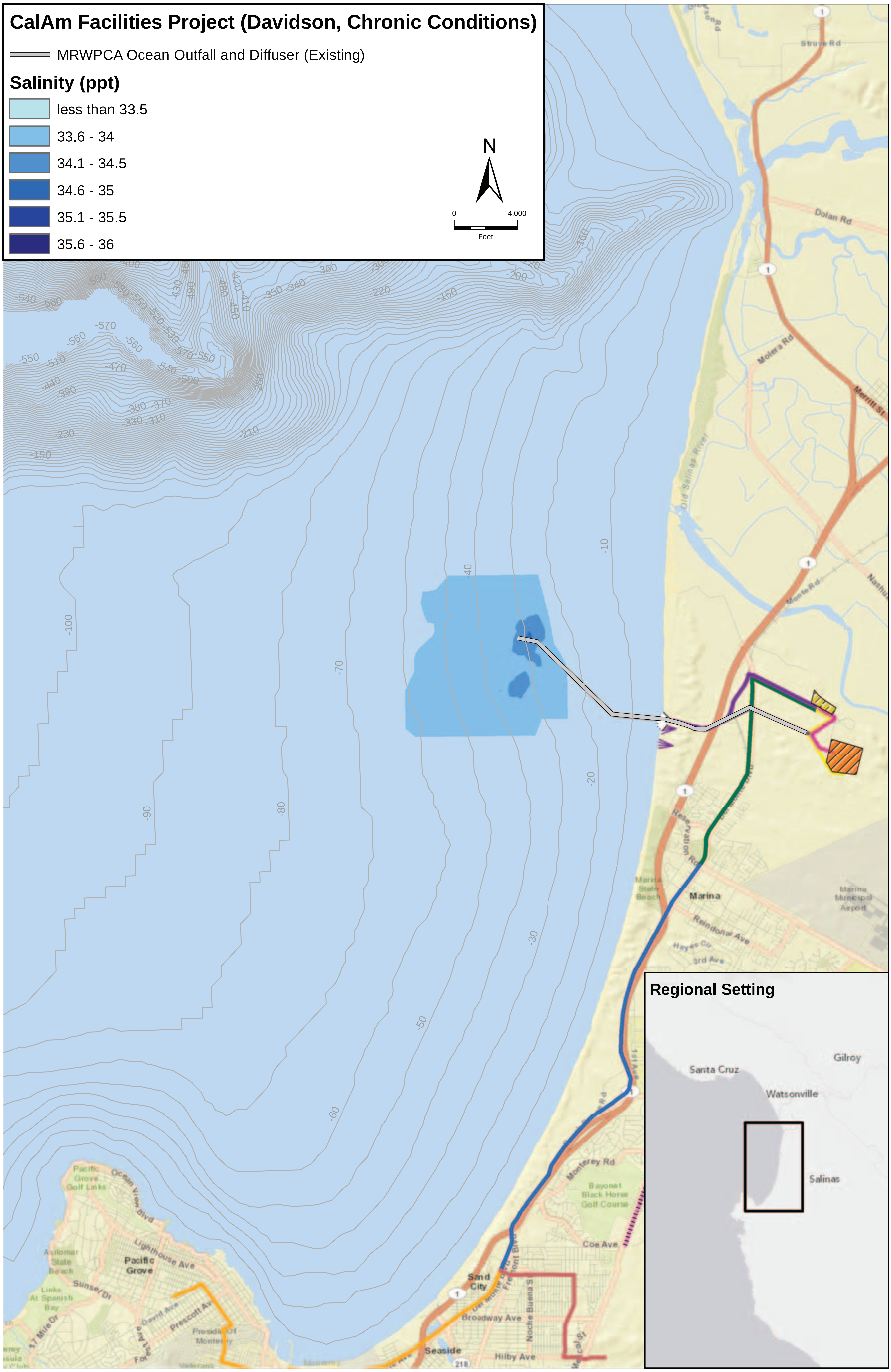

Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013
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Figure F-4
Salinity
(CalAm Facilities Project: Davidson, Chronic Conditions)

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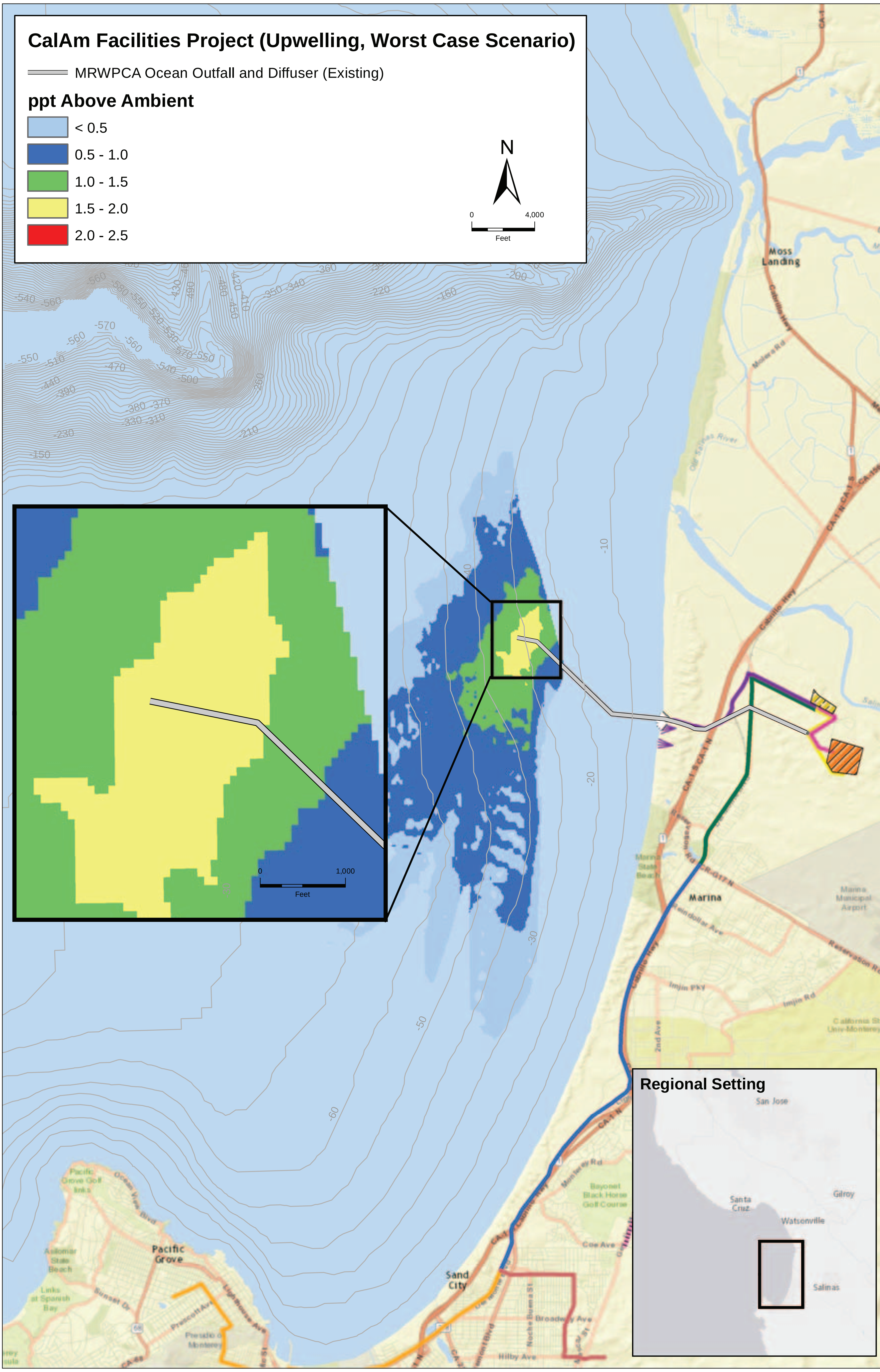

Basemap Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
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Figure F-5
Parts per Thousand Above Ambient
(CalAm Facilities Project: Upwelling, Worst Case Scenario)

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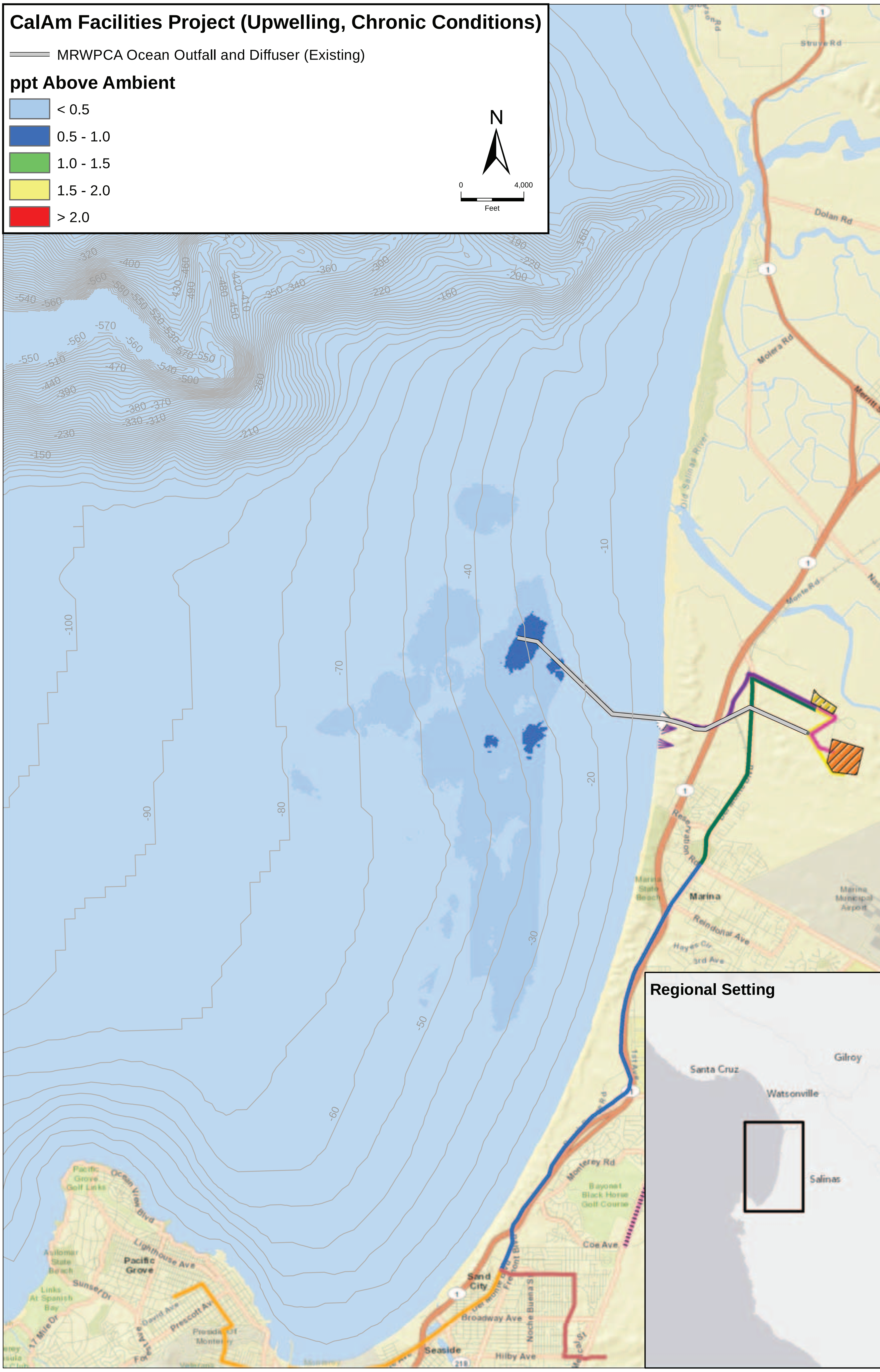

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Figure F-6

Parts per Thousand Above Ambient

(CalAm Facilities Project: Upwelling, Chronic Conditions)

Basemap Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013

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11/6/2014

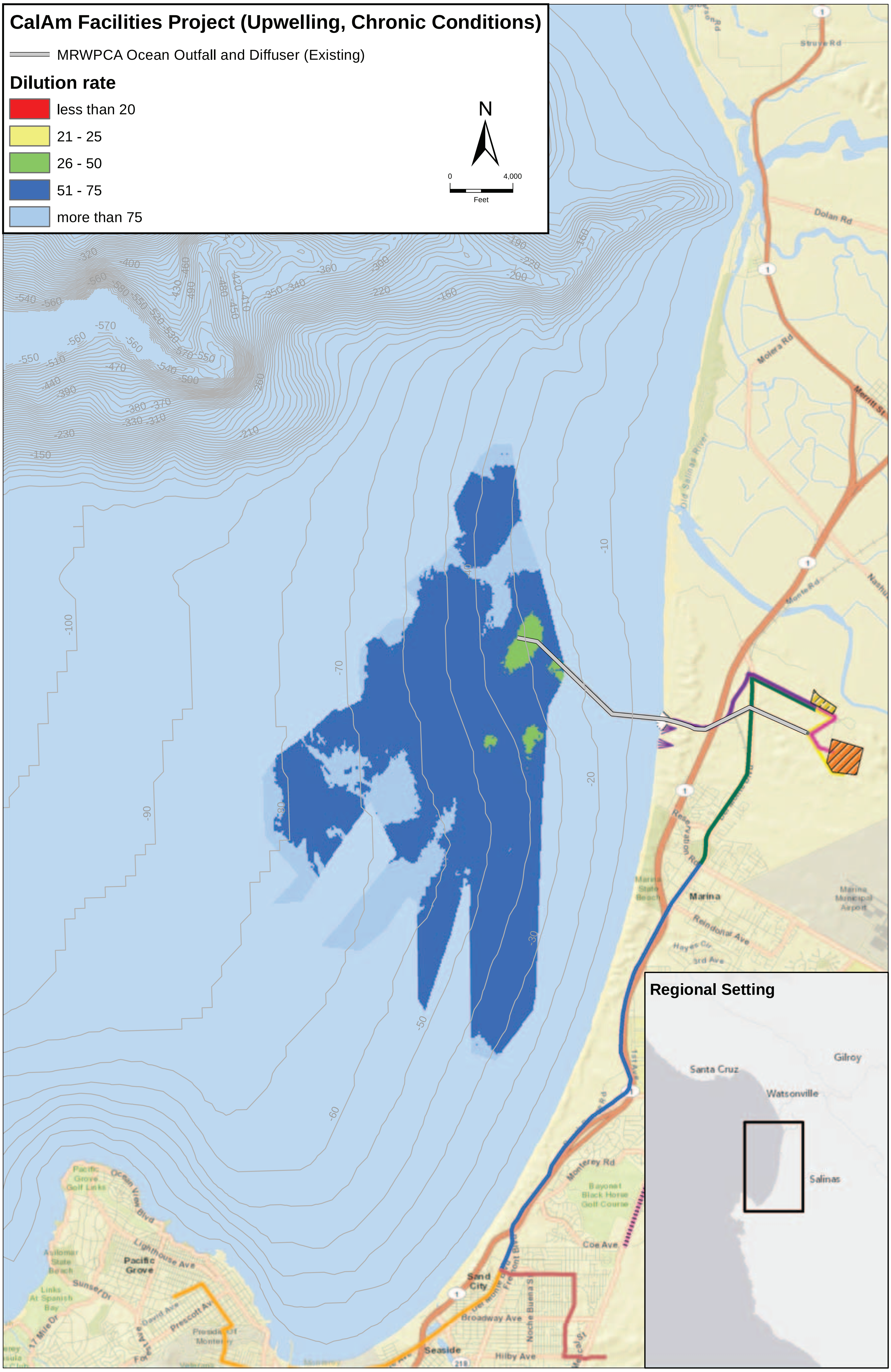

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Figure F-7
Dilution Rate
(CalAm Facilities Project: Upwelling, Chronic Conditions)

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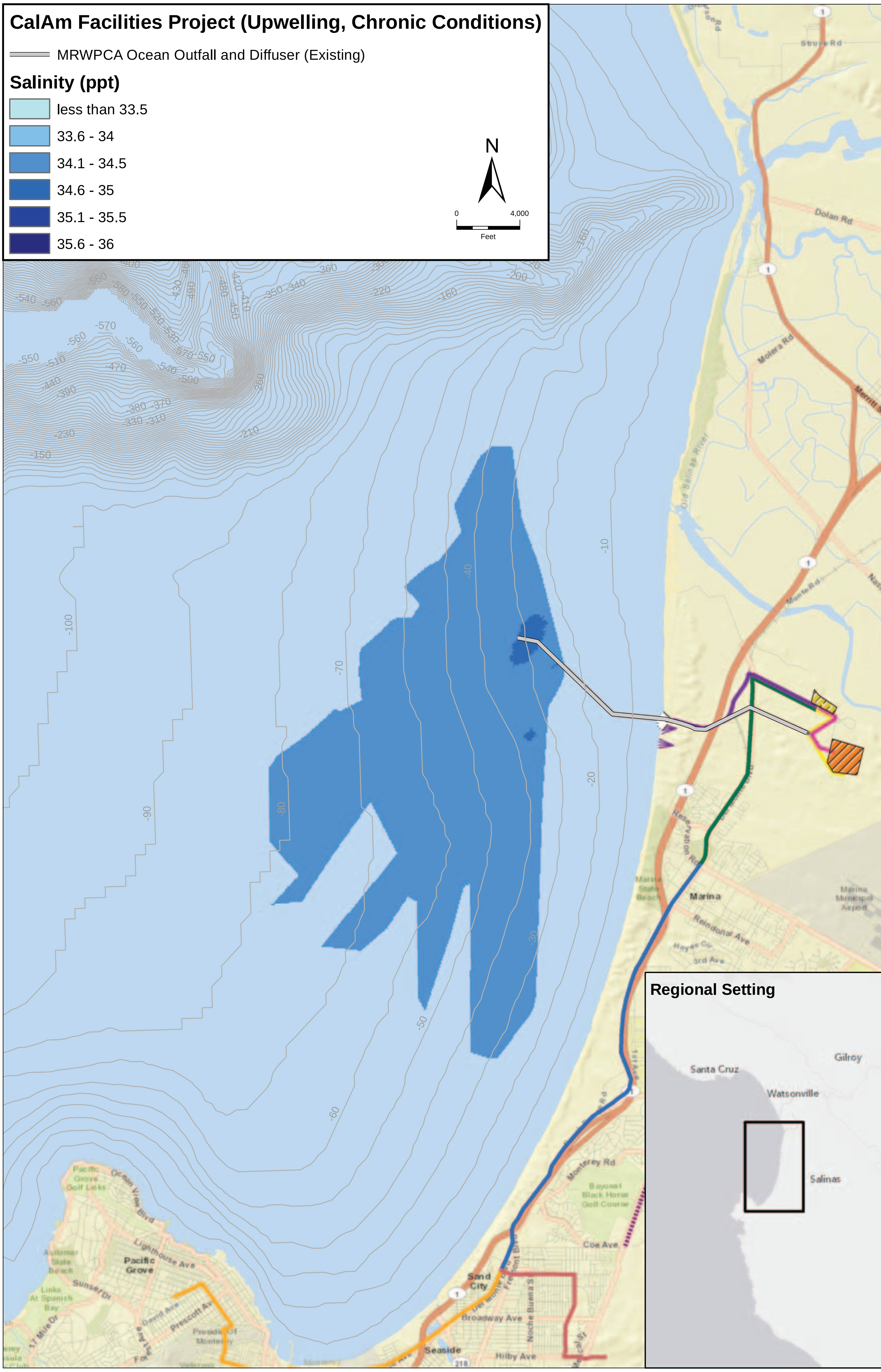

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Figure F-8
Salinity
(CalAm Facilities Project: Upwelling, Chronic Conditions)

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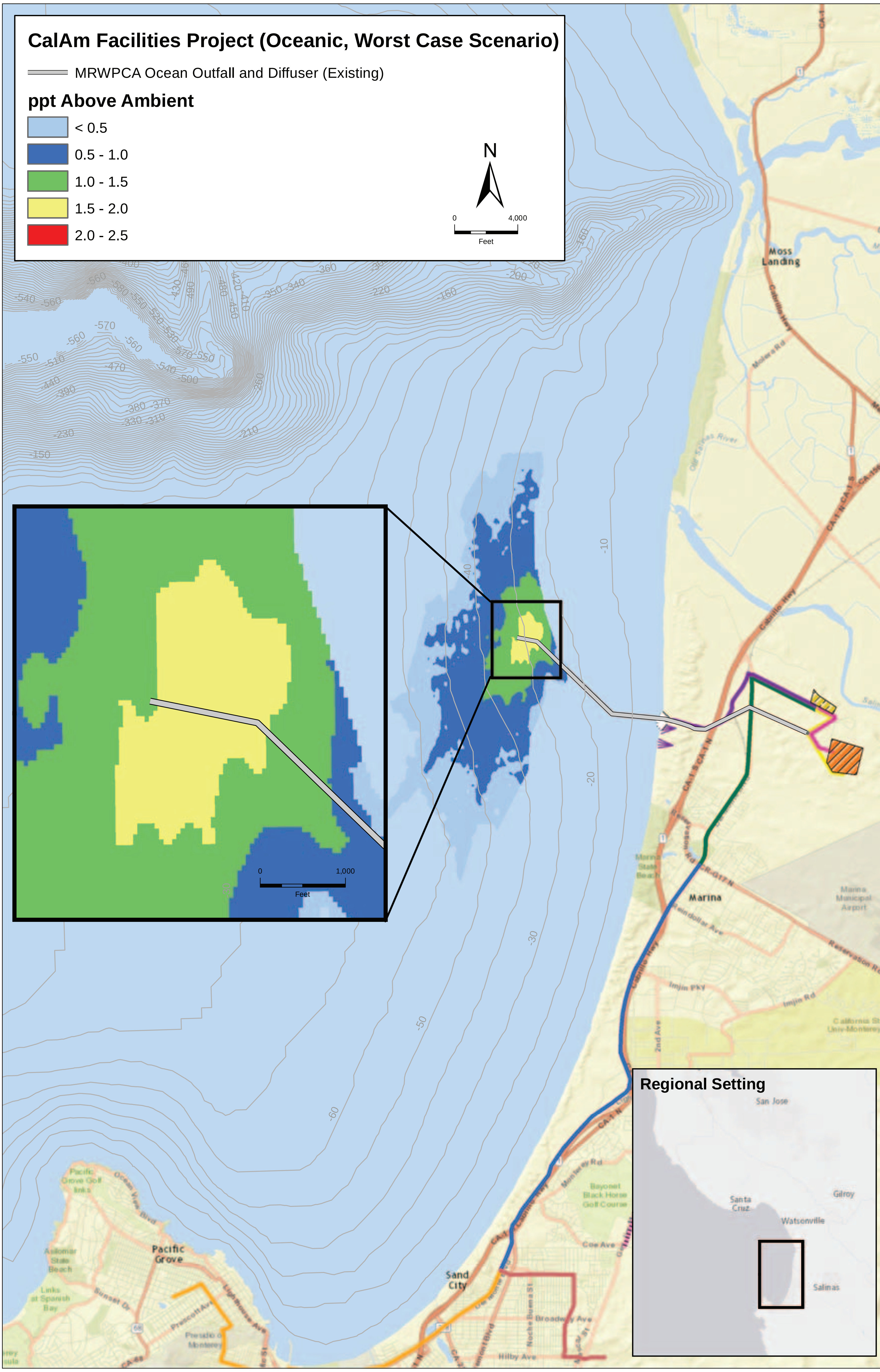

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Figure F-9

Parts per Thousand Above Ambient
(CalAm Facilities Project: Oceanic, Worst Case Scenario)

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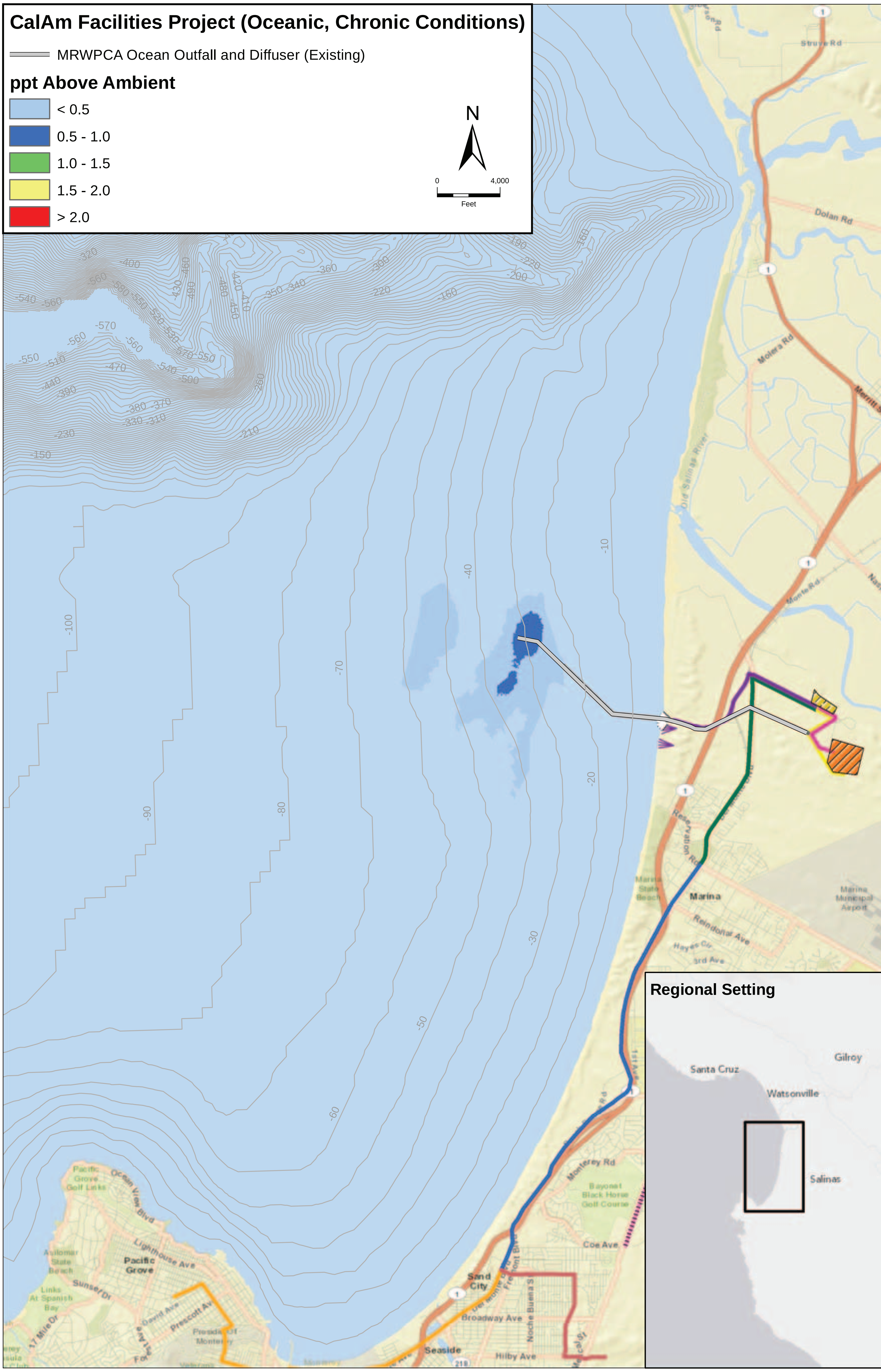

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Figure F-10
Parts per Thousand Above Ambient
(CalAm Facilities Project: Oceanic, Chronic Conditions)

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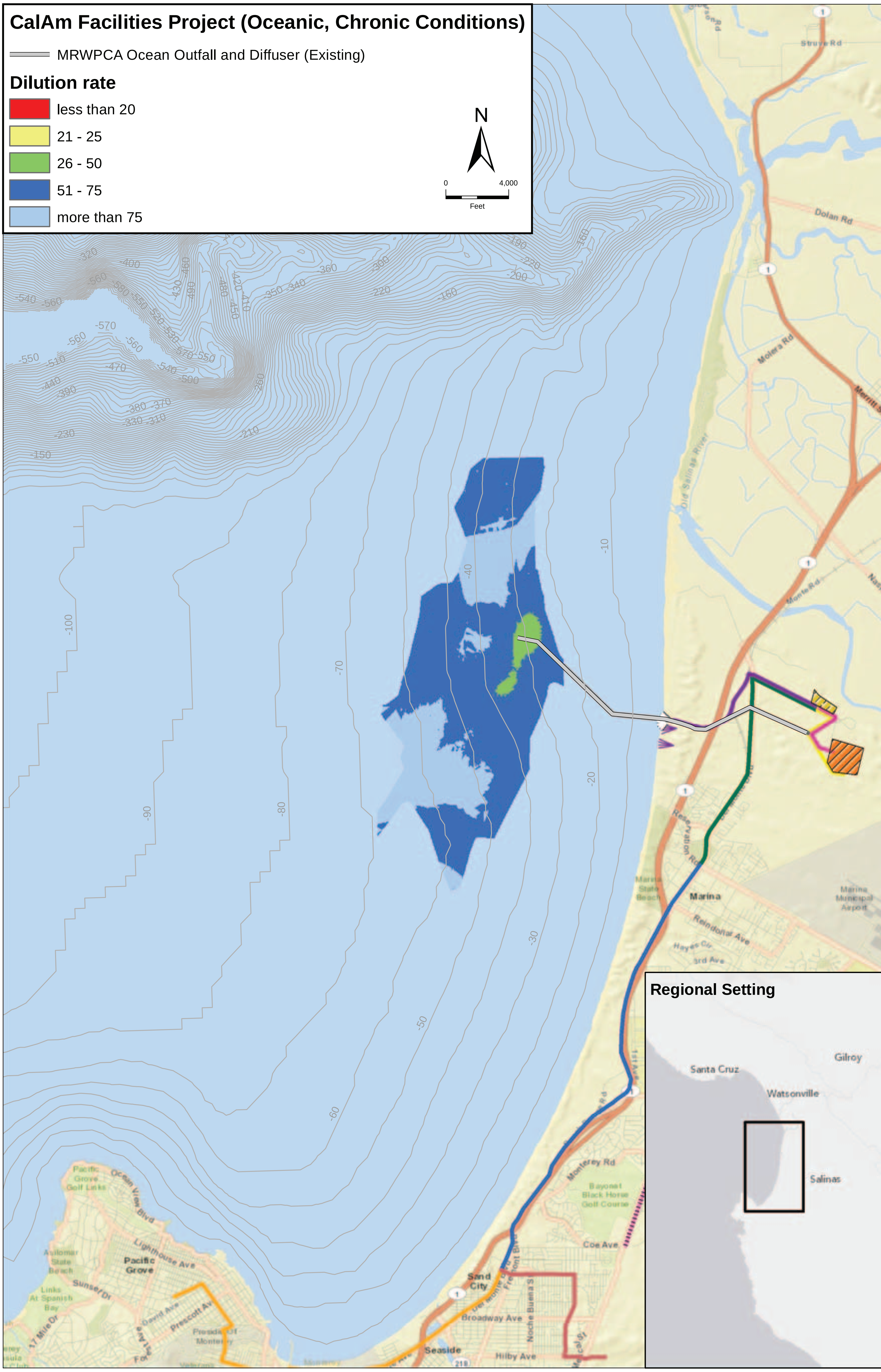

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Figure F-11
Dilution Rate
(CalAm Facilities Project: Oceanic, Chronic Conditions)

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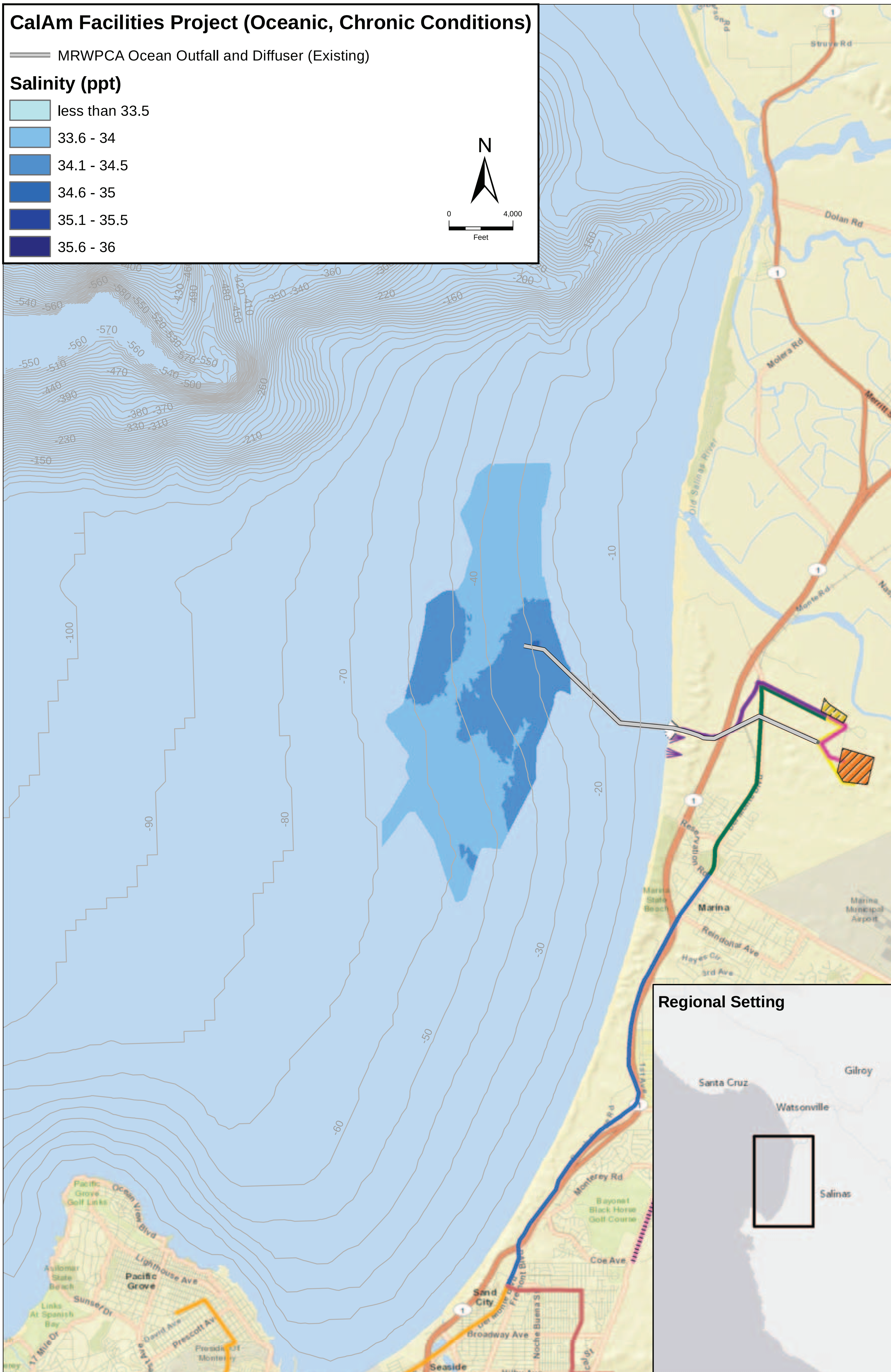

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Figure F-12
Salinity
(CalAm Facilities Project: Oceanic, Chronic Conditions)

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