Brine Diffusers and Shear Mortality: Application to Huntington Beach

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Final Report

Prepared for
Eastern Research Group

April 18, 2018

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EXECUTIVE SUMMARY

A brine diffuser proposed by Poseidon Water (Poseidon) for the Huntington Beach Desalination Project (Project) is evaluated in light of the recent recommendations for brine diffusers of Roberts (2018) (R2018). The proposed diffuser consists of three ports atop an existing cooling water discharge tower in about 28 ft of water depth. The discharge dynamics were modeled by CORMIX.

As implemented by Poseidon (Jenkins 2017a), the CORMIX analysis is unrealistic and does not represent modern understanding of dense jet hydrodynamics. The diffuser is modeled as a horizontal slot jet. A stability analysis is then performed that predicts the flow will mix over the water column a short distance from the diffuser. Beyond this point, the discharge is assumed to behave as if emitted from a vertical slot jet with full mixing over depth that persists for almost one kilometer from the diffuser. This distance is interpreted as the zone of initial dilution. These are not realistic estimates or depictions of the expected flow, which should rapidly stratify into two layers with a bottom density current in which initial mixing persists for only a few tens of meters.

According to Jenkins (2018), the diffuser was designed to produce a submerged wastefield that does not disturb the water surface. A new analysis is presented using dense jet theory that contradicts this assertion and predicts that the jets will surface and create a strong surface boil.

Shear-induced mortality was predicted (Jenkins 2017b) using the CORMIX predictions and assuming that mortality effects in the jet persist until the Taylor scale of the turbulence exceeds one mm. This assumption contradicts experimental evidence in R2018 that shows the controlling influence of the smaller Kolmogorov scale on planktonic organism mortality. Use of the Taylor scale results in a much smaller estimate of harmful shear entrainment than obtained by use of the Kolmogorov scale. The potentially harmful entrained flows were re-estimated for the Poseidon design and new proposed alternate designs using the methods suggested in R2018 which prescribe using the mathematical model UM3.

The modified diffuser designs that are proposed using the procedures suggested in R2018 meet the criteria of a submerged wastefield and an increase in salinity no greater than 2 ppt above natural background in the Brine Mixing Zone (BMZ), which shall not exceed 100 m laterally from the points of discharge and throughout the water column. Two diffuser configurations were considered: A single multiport “rosette” diffuser on the

existing riser structure, as in the Project's proposal, and a linear diffuser at the same depth.

The diffusers can minimize jet velocity, the size of the BMZ, or entrained volume, but not all simultaneously. The final design choice will depend on a relative weighting of these objectives.

The diffuser can be designed to meet the salinity requirement in the Water Quality Control Plan for Ocean Waters of California at the jet bottom impact point or at the end of the hydrodynamic near field. Both situations are addressed. Comparing the two, meeting at the impact point results in higher jet velocity, a smaller BMZ, and larger entrained flow. The original proposed Poseidon design and the alternate designs that minimize the area of the BMZ or the volume of potentially harmful entrained flow are summarized in Table 5. For the alternate designs, meeting the salinity requirement at the impact point results in roughly twice the harmful entrained flow compared to meeting it at the end of the near field.

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NOTATION

b	=	buoyancy flux per unit diffuser length = $g'_o q$
B	=	width of equivalent slot jet
d	=	nozzle diameter
D_m	=	dilution as defined in the Ocean Plan ($D_m = S - 1$)
g	=	acceleration due to gravity
g'_o	=	modified acceleration due to gravity = $g\left(\rho_o - \rho_a/\rho_a\right)$
F	=	jet densimetric Froude number = $u/\sqrt{g'_o d}$
H	=	water depth
q	=	flow rate per unit diffuser length for a multiport diffuser = Q_T/L
Q_j	=	flow rate from an individual jet
Q_t	=	total flow rate
L	=	diffuser length
m	=	momentum flux per unit diffuser length = uq
Re	=	jet Reynolds number = ud/ν
S	=	dilution
S_i	=	impact dilution (see Figure 3 of Roberts 2018)
S_n	=	near field dilution (see Figure 3 of Roberts 2018)
S_{ta}	=	average dilution at jet terminal rise height predicted by UM3
S_{50}	=	empirical coefficient in CORMIX
u	=	jet exit velocity
x_i	=	impact distance (see Figure 3 of Roberts 2018)
x_n	=	length of near field (see Figure 3 of Roberts 2018)
x_v	=	location of virtual jet origin in CORMIX
y_t	=	jet terminal rise height (see Figure 3 of Roberts 2018)
η_C	=	Kolmogorov scale on jet centerline
ν	=	kinematic viscosity
χ	=	distance measured along jet centerline from origin
Θ	=	angle of jet to horizontal

1. INTRODUCTION

Poseidon Water (Poseidon) has proposed to construct a seawater desalination plant at the site of the Huntington Beach Generating Station (HBGS) in California. The Huntington Beach Desalination Project (Project) would modify the existing HBGS cooling water system infrastructure for brine disposal. The cooling water disposal system of this infrastructure consists of a 14 ft diameter conduit extending approximately 1500 ft offshore. It terminates in a vertical tower discharging approximately 8.5 m (28 ft) below mean lower low water (MLLW) (Jenkins, 2017a). Poseidon has proposed to retrofit the tower by capping it with a multiport diffuser as shown in Figure 1 and Appendix A.

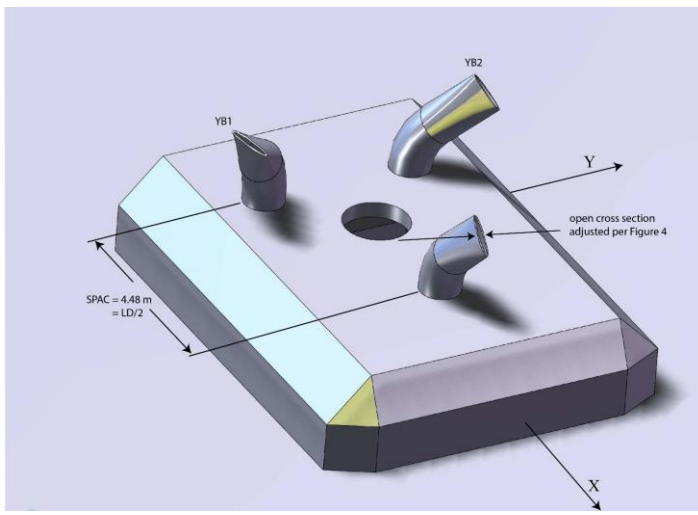


Figure 1. Proposed brine diffuser at Huntington Beach Generating Station (Jenkins 2017a)

The diffuser design (Jenkins 2018, Alden 2017) consists of three ports capped with TideFlex valves with angles between them in planform of 45°. The nozzles are oriented upwards at 47°, rather than the more common angle of 60°, to prevent the jets impacting the water surface (according to Jenkins 2018) .

The purpose of this report is to discuss the analysis leading to Poseidon's proposed diffuser, the dilution predictions, and to evaluate it in light of the new procedures for brine diffuser design and shear mortality prediction recommended in Roberts (2018), hereafter R2018. Changes are suggested to Poseidon's proposed single riser configuration and a linear diffuser is also proposed that may better meet the requirements in the Water Quality Control Plan for Ocean Waters of California (Ocean Plan). The sizes of the Brine Mixing Zone (BMZ) and the magnitudes of potentially deleterious shear entrainment (i.e., shearing-related mortality) are then predicted for the Poseidon design and the new suggested designs using the procedures of R2018.

2. PROPOSED POSEIDON DIFFUSER

2.1 Introduction

The objectives of the proposed diffuser (Alden 2017) are to maintain a submerged wastefield that does not disturb the water surface and meet the Ocean Plan's salinity receiving water limitation, which requires that discharges shall not exceed a daily maximum of 2.0 ppt above natural background salinity measured no farther than 100 m horizontally from each discharge point. The ports are spaced to ensure adequate entrained flow between the jets and to impose a net horizontal offshore momentum to the wastefield.

Dilution analyses of this proposed diffuser design were performed by Poseidon using CORMIX (Jenkins, 2017a). This analysis is discussed below. Four flow scenarios were addressed: Worst-case #1 and Worst-case #2 with temperature differences between effluent and ambient seawater of 0°C and +2°C. To illustrate the calculation procedures prescribed in R2018, we consider here only Worst-case #1 with temperature difference of 2°C (hereafter WC1). The conclusions should be similar for the other cases. The conditions for WC1 (Jenkins 2017a) are:

- Total brine flowrate, Q_T = 62.5 mgd (2.74 m^3/s)
- Brine salinity = 62.4 ppt
- Brine density ρ_o = 1046.4 kg/m^3
- Ambient oceanic salinity = 33.5 ppt
- Ambient oceanic density ρ_a = 1023.5 kg/m^3
- Equivalent nozzle diameter d = 0.496 m (19.5 inches)
- Jet exit velocity u = 4.72 m/s (15.5 ft/s).

The dilution S required to reduce the salinity increment to 2 ppt above natural background salinity, as required in chapter III.M.3 of the Ocean Plan, is therefore:

$$S = \frac{62.4 - 33.5}{2} = 14.5 \tag{1}$$

Eq. 1 is the dilution usually predicted by mathematical models such as Visual Plumes and CORMIX. As explained in R2018, Section 2.3.2, it differs from the definition of dilution, D_m, in the Ocean Plan. The relationship between the two definitions is:

$$D_m = S - 1 \tag{2}$$

So the required D_m = 13.5.

2.2 Diffuser Mixing and Dynamics

2.2.1 Project Analysis

The diffuser discharge was modeled in Jenkins (2017a) by CORMIX. The underlying methodology of the analysis and its shortcomings are discussed below.

CORMIX does not explicitly model the 3-port diffuser orientation shown in Figure 1. Jenkins therefore assumed that the diffuser was linear with ports spaced 4.48 m apart. The ports are inclined upwards at 47°. CORMIX classifies this as a unidirectional diffuser, i.e. the ports are arranged in a straight line pointing in the offshore direction, with fanning to account for the planform geometry. The assumed diffuser length, end-port to end-port, is then L = 8.96 m.

CORMIX then approximates this diffuser as a horizontal slot L = 8.96 m (29 ft) long and 0.065 m (2.6 inches) high. (The CORMIX values of momentum and buoyancy fluxes per unit diffuser length in the prediction and session files are different. This appears to be a bug in CORMIX and it is not clear which values were used in its calculations). CORMIX applies a "stability" analysis and concludes that the flow class is "MNU7" which is a layer equal to the water depth at the discharge site. This implies rapid full mixing over the water depth, an assertion repeated in Jenkins (2017a). Figure 2 is a representation of how the flow field is modeled in Jenkins' implementation of CORMIX.

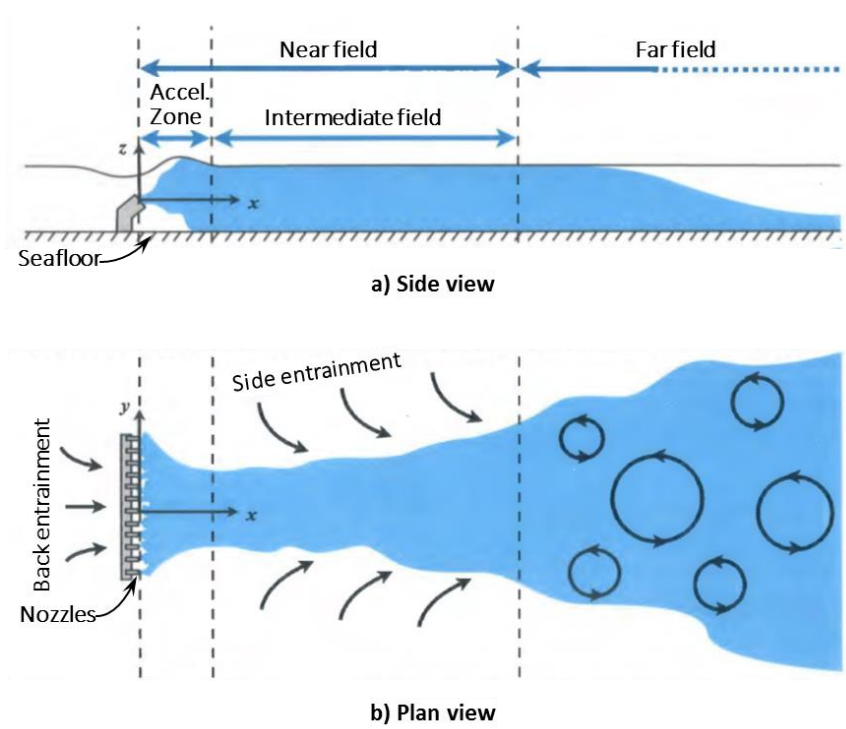


Figure 2. Diffuser flow field as modeled by CORMIX (After Cornell 2014). a) Side view; b) Plan view

CORMIX models the unstable flow field as three distinct regions as shown in Figure 2. In the CORMIX terminology, the first region is an "acceleration zone," which is followed by the second region, an "intermediate field" where the flow continues to be vertically well mixed. These two zones together constitute the "near field" and different prediction methods are used for each. The intermediate field terminates when the source momentum flux is essentially dissipated by bottom friction. Beyond this zone is the third region, the "far field" where the flow restratifies and forms a bottom density current that is diffused by ambient turbulence. The Project's CORMIX simulations terminate at the end of the intermediate field.

The flow field depicted in Figure 2 is not realistic for the Project design. The prediction that the effluent mixes over the water column and that this persists for a long distance will not occur for jets with high negative buoyancy and relatively low dilution. The assumption that the discharge behaves like a slot source is a very crude approximation to the near field dynamics of the individual round jets. The underlying theories that lead to this CORMIX analysis are discussed below.

The stability analysis traces to Jirka and Harleman (1979) and can be found in Jirka (1982). They analyzed unidirectional diffusers as a line (slot) source and proposed a stability parameter, C:

$$C = \frac{m}{b^{2/3}H}\left(1+\cos^2\Theta\right)^2 \tag{3}$$

where $m = uq$ is the source momentum flux per unit diffuser length, u is the jet velocity, $q = Q_T/L$ is the volume flux per unit length, $b = g'_o q$ is the buoyancy flux per unit length, $g'_o = g\left(\rho_o - \rho_a\right)/\rho_a$ is the modified acceleration due to gravity, H is the water depth, L is the diffuser length, and Θ is the angle of the nozzles to the horizontal. If C is greater than 0.54, the flow is designated as unstable, i.e. it mixes over the whole depth. Substituting the prediction file (Jenkins 2017a) values of $m = 0.9625$ m^3/s^2 and $b = 0.0462$ m^3/s^3 into Eq. 3 yields $C = 1.9$ which is greater than 0.54, hence the unstable flow designation.

The stability criterion, Eq. 3, was originally developed for discharges with small positive buoyancy (i.e. heated water) and large diffuser length to water depth ratios, i.e. $L/H >> 1$. There is no experimental evidence that it applies to discharges with large negative density differences with $L/H = 1.1$ as in the present case. Modern experimental data (see R2018, Section 3) suggest very different flow dynamics.

The CORMIX analysis also contradicts the assertion in the Alden (2017) report that the jets will not impact the water surface. A flow that is classified as unstable in CORMIX is well-mixed over the water column so it must reach the water surface. According to the CORMIX user's manual (Doneker and Jirka 2017), the unstable

flow classification is synonymous in CORMIX with a shallow water diffuser. An unstable flow requires the predicted jet rise height to be greater than the water depth, i.e. the source momentum flux will cause significant surface interaction and vertical mixing. The more probable hydrodynamics of Poseidon's design are discussed in Section 2.3.

For this unstable case, CORMIX then predicts a dilution at the end of the acceleration zone from:

$$S = \sqrt{\frac{mH}{2q^2}} \tag{4}$$

The analysis leading to this equation is based on propeller theory that leads to a downstream flow contraction. Eq. 4 was first derived by Adams (1982) and can be found in Jirka (1982). Eq. 4 can be written, using the definitions of $m = uq$ and $q = uB$, where B is the equivalent slot jet width as:

$$S = \sqrt{\frac{H}{2B}} \tag{5}$$

Note that Eq. 5 does not contain the jet exit velocity or density difference as variables. It predicts that dilution in the acceleration zone depends only on the ratio of water depth to equivalent slot width. The role of the source momentum and buoyancy fluxes is merely to determine stability; if it is unstable, the dilution equation then ignores them. This type of analysis is unrealistic (R2018) and does not adequately model the actual discharge scenario.

The CORMIX results for the acceleration zone that are presented in Jenkins (2017a) are based on Eqs. 4 and 5. CORMIX assumes that the zone extends a distance $x = L/2$, i.e. 4.48 m from the diffuser, the value given in the prediction file. Substituting the prediction file values of m = 0.9625 m^3/s^2 and q = 0.3056 m^2/s and H = 8.5 m into Eq. 4 yields S = 6.6. The value of 7.4 in the CORMIX prediction file may be a correction for the increase in dilution for the "fanning" effect of the nozzles or it may be due to the previously mentioned discrepancy between the CORMIX session and prediction files.

Beyond the acceleration phase is the intermediate field (Figure 2) where the jet is assumed to transition to a two-dimensional vertical momentum slot jet. Dilution is assumed to be by "side-entrainment" and can be predicted from the equation for slot jets in Fischer et al. (1979) where it is shown that dilution $S \propto x^{1/2}$ where x is the distance from the diffuser, and the jet width grows linearly with distance, $w \propto x$. The application of slot jet theory to the diffuser can be found in Lee and Jirka (1982) (where the intermediate zone is called the far field). This leads to the equation as implemented in CORMIX for dilution as a function of distance x in the intermediate region:

$$S = S_{50}\sqrt{\frac{mH\cos\Theta\left(x - x_v\right)}{q^2 L}} \tag{6}$$

where S_{50} = 0.58 (Cornell 2014) is an empirical constant. x_v is the location of a virtual jet origin that is chosen so that the dilution predicted at the end of the acceleration zone (at $x = L/2$) by Eq. 4 matches the dilution predicted by Eq. 6 at the same distance:

$$x_v = \frac{L}{2}\left(1 - \frac{1}{S_{50}^2\cos\Theta}\right) \tag{7}$$

CORMIX terminates the dilution prediction of Eq. 6 at the end of the intermediate field where the source momentum dissipates due to bottom friction. The CORMIX prediction file (Jenkins 2017a) gives this distance as 877 m from the diffuser where the dilution is 46.1. This distance is identified as the ZID (Zone of Initial Dilution). (The dilution calculated by Eq. 6 is 44.8, possibly due to the previously reported discrepancy in the CORMIX parameters). The required BMZ dilution where the salinity increment over background is 2 ppt is S = 14.5 or D_m = 13.5 (Eqs. 1 and 2). The CORMIX prediction file indicates that this dilution occurs at a distance of 69.9 m from the diffuser. Hence, this is the predicted length of the BMZ.

Although CORMIX is regularly updated, and the latest version, 10.0.3.0, was used for these simulations, these underlying analyses date back more than 40 years and have not been updated to reflect recent advances in understanding of dense jet dynamics. Modern experiments show that the effluent does not mix over the depth, even for shallow water conditions. It quickly forms a bottom density current and could remain not well-mixed for almost a kilometer from the source while continuing to entrain.

Poseidon's CORMIX analysis of the proposed discharge (Jenkins 2017a) as a multiport diffuser does not realistically depict the expected flow field, and the predictions should be viewed with considerable caution. A more realistic approach would be to analyze the discharges as individual jets using CORJET. However, this approach results in significant underestimates of dilution (Palomar, 2012). The proposed diffuser design is reanalyzed using the methods of R2018 in the next section.

2.2.2 New Analysis

The expected behavior of the dense jets from Poseidon's proposed diffuser design, such as dilution and terminal rise height, can be calculated from the theories outlined in R2018 and elsewhere.

The analysis begins with computation of the jet densimetric Froude number:

$$F = \frac{u}{\sqrt{g\left(\frac{\rho_o - \rho_a}{\rho_o}\right)d}} = 14.3 \tag{8}$$

where, for case WC1, u = 4.72 m/s, ρ_o = 1046.4 kg/m^3, ρ_a = 1023.5 kg/m^3, and d = 0.496 m (Section 2.1), yielding F = 14.3.

The rise height y_t is predicted from Eq. 11, R2018. For $\Theta = 47°$ we get y_t/Fd = 1.86, therefore:

$$y_t = 1.86Fd = 1.86 \times 14.3 \times 0.496 = 13.2 \text{ m} = 43.3 \text{ ft} \tag{9}$$

This is greater than the water depth of 8.5 m so the plume will have significant surface effects. This contradicts the assertion in the Alden (2017) report that the plume will be below the water surface.

Insights into the behavior of shallow water jets are given by the experiments of Abessi and Roberts (2015). They find that the water depth effect depends on the parameter Fd/H, where H is the local water depth, and the nozzle angle Θ. Fd/H is proportional to the ratio of the jet rise height in infinitely deep water to the actual water depth. If Fd/H is less than some critical value, the flow is fully submerged and is unaffected by the water surface; this is called the "deep water" regime. If Fd/H is larger than some critical value, the flow impacts the water surface and is strongly affected by it; this is called the "shallow water" regime. Between these two is the surface contact regime. The transition values of Fd/H where the flow regimes change for 30°, 45°, and 60° nozzles are given in Abessi and Roberts (2015).

For 45° jets (close to the 47° for the proposed Poseidon design), Abessi and Roberts find that the jet is deep water for $Fd/H <\sim 0.48$ and shallow water for $Fd/H >\sim 0.7$. For the Poseidon design case WC1:

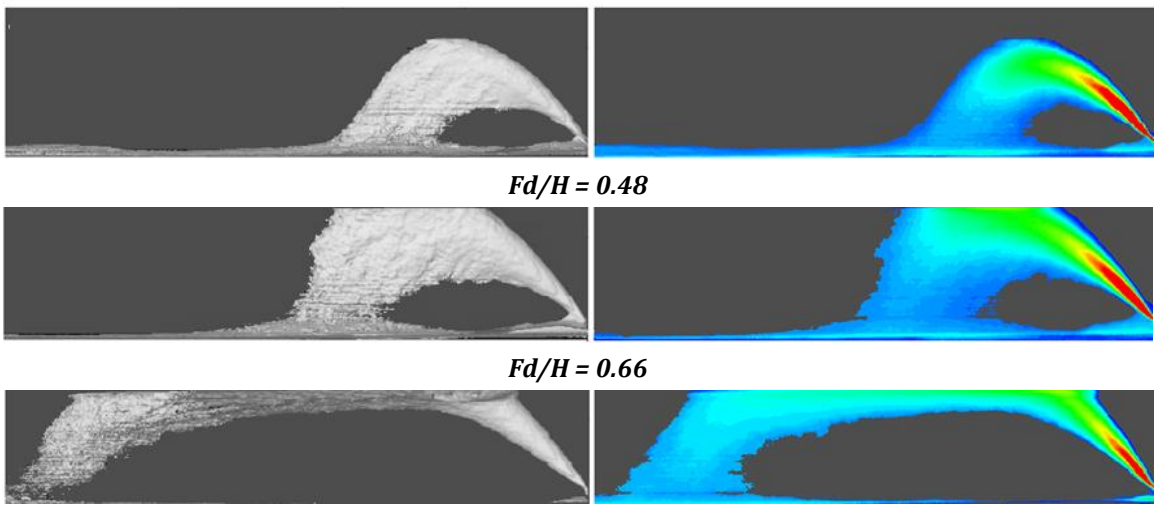
$$\frac{Fd}{H} = \frac{14.3 \times 0.496}{8.5} = 0.83$$

which corresponds to the shallow water regime so significant surface jet impaction is expected.

The dynamics of dense jets with varying degrees of surface interaction are illustrated by the laser-induced fluorescence images in Figure 3. Figure 3a shows side views of 45° jets for various values of Fd/H ranging from shallow to deep water. Figure 3b shows a three-dimensional image of a 60° jet with Fd/H = 0.9 and

illustrates its complex interaction with the water surface. The proposed diffuser design for the project case WC1 should lie between the two lower cases of Figure 3a and be similar to that in Figure 3b.

In the expected shallow water regime for case WC1, the jet centerline intersects the water surface. The vertical momentum component is destroyed and part of it converts to horizontal momentum. This, combined with the surface Coanda effect, causes the jet to cling to the surface for some distance before detaching, pushing the impact location (where the jet centerline impacts the seabed) farther from the diffuser. Impact and near field dilutions are significantly reduced compared to the deep-water condition.

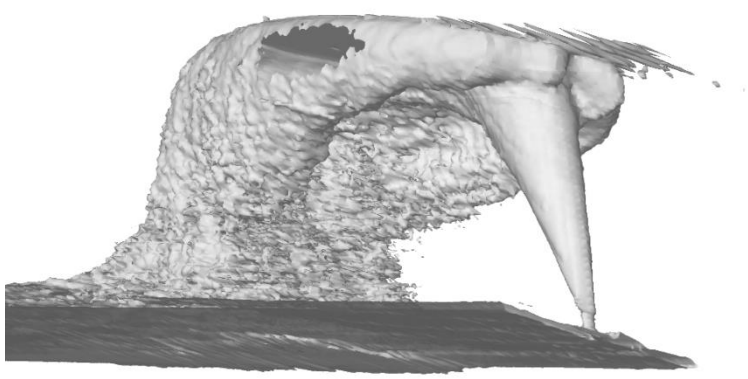


Fd/H = 0.48

Fd/H = 0.66

Fd/H = 1.2

a) Side views of jets at 45°, various *Fd/H*



b) Perspective view of jet at 60°, *Fd/H* = 0.9

Figure 3. Laser-induced fluorescence images of experimental jets with varying degrees of surface interaction. From Abessi and Roberts (2015)

Because the jets are predicted to impact the water surface, the analyses and equations of R2018 do not apply as they assume deep water with no surface interaction. Therefore, we use the results of Abessi and Roberts (2015) that include experiments in shallow water conditions. The dilution and other jet parameters are predicted from the dimensionless parameters in Figures 9, 10, 11, and 12 in Abessi and Roberts. For Poseidon's proposed design (47° jets with Fd/H = 0.83), they are:

$$S_i/F \approx 0.9,\ S_n/F \approx 1.2,\ x_i/Fd \approx 3.6, \text{ and } x_n/Fd \approx 9.0.$$

Therefore:

$$S_i \approx 0.9F = 0.9 \times 14.3 = 12.9$$
$$S_n \approx 1.2F = 1.2 \times 14.3 = 17.2$$
$$x_i \approx 3.6Fd = 3.6 \times 14.3 \times 0.496 = 25.5 \text{ m}$$
$$x_n \approx 9.0Fd = 9.0 \times 14.3 \times 0.496 = 63.8 \text{ m}$$

The dilution required to meet a salinity increment of 2 ppt is 14.5, Eq. 1. Linear interpolation between the above impact and near field dilutions indicates that Poseidon's design should meet the BMZ criterion at a distance of about 40 m from the diffuser. Assuming no further dilution between the near field and the zone of initial dilution (ZID) (at 1000 ft), the ZID dilution would be equal to the near field dilution, 17.2.

Summarizing the new analysis of the Project's results, accounting for the surface boil, in terms of the BMZ and ZID, we have:

- The BMZ dilution S = 14.5 occurs between the bottom impact point (23.5 m) and the end of the near field (63.8 m).
- The BMZ extends a distance of about 40 m from the diffuser.
- The ZID dilution at 1000 ft is S = 17.2, D_m = 16.2.

The newly predicted BMZ length of 40 m is shorter than the 69.6 m predicted by the CORMIX analysis (Jenkins 2017a), and the near field length of 63.8 m is much less than the 877 m predicted by CORMIX. The proposed Project design will result in a significant surface boil, and the receiving water limit can be better met with a multiport diffuser with lower jet velocities. Alternate designs are proposed in Chapter 3. Note also that the COSMOS/FlowWorks CFD visualizations in Jenkins (2017a) do not resemble the expected flow patterns of Figure 3 and should be viewed with considerable caution.

2.3 Shear Mortality

2.3.1 Project Analysis

In Jenkins (2017b), an estimate is given of the entrained flow that may be subject to turbulent shear that is lethal to entrained organisms. The analysis approximately follows the procedure for shearing-related mortality that is included in the Final Staff Report Including the Final Substitute Environmental Documentation for the Desalination Amendment to the Ocean Plan (SED). The main difference is that the Taylor microscale is used rather than the Kolmogorov scale as the relevant turbulent scale for organism mortality. The SED procedure is based on the assumption that shearing-related mortality occurs in the jet region between the nozzle and the terminal rise height, where the Kolmogorov scale is assumed less than one mm. In the Project analysis, (Jenkins 2017b), shearing-related mortality is assumed to occur between the nozzle and the location where the Taylor scale equals one mm. Because Taylor scales are much longer that Kolmogorov scales, this results in a much shorter entrainment distance and therefore less entrained flow.

Use of the Taylor microscale is unwarranted. Strain rates and shear stresses are highest at the Kolmogorov scale and cause the most damage; this is confirmed by the experimental literature (R2018 Section 4.2) that shows the governing importance of the Kolmogorov scale on planktonic mortality. Further shortcomings of the Project analysis (Jenkins 2017b) is that it predicts turbulence length scales from experiments that assume the discharge behaves like a plume, which is buoyancy-dominated, rather than a jet, which is momentum-dominated. Turbulent length scales for plumes are longer than for jets, so using them will underestimate the high shear zone. For these reasons, the Project analysis (Jenkins 2017b) should be viewed with considerable caution.

The results of the Project analysis for case WC1 are summarized in Table 3 of Jenkins (2017b). This table gives the critical distance for turbulence impacts, where the Taylor scale falls below one mm, as 0.77 m (2.53 ft) from the source. Jenkins assumes this to be the limit for harmful entrainment and shearing-related mortality. The CORMIX dilution at this distance is 3.67, which yields a harmful entrainment volume rate (Table 3, Jenkins 2017b):

$$(3.67-1)\times 1.4\times 62.5 = 233.6 \text{ mgd}$$

(The factor 1.4 in this equation is an error, as the dilution predicted by CORMIX in the acceleration zone is already a bulk, or average, dilution.) The critical distance over which entrainment is predicted to be harmful in Jenkins (2017b) is much smaller than if the Kolmogorov scale had been used, and, consequently, a much smaller volume of water is predicted to be exposed to lethal shear. Had the Kolmogorov scale been used, the length would have been much greater and the

corresponding entrainment much higher than 233.6 mgd. Section 2.3.2 includes a new analysis of shear mortality for the Project diffuser and for a new design, following the procedure from R2018.

2.3.2 New Analysis

Following the recommended procedure in R2018, UM3 was applied to the proposed Project diffuser design whose parameters are given in Section 2.1. The UM3 outputs are shown in Appendix C. The UM3 graphic of the jet trajectory in Appendix C clearly shows the jet intersecting the water surface, as predicted in Section 2.2.2. The graphic is similar to the experimental image for $Fd/H = 0.7$ in Figure 3a.

The dilution at the terminal rise height (local maximum rise or fall) from UM3 is $S_{ta} = 9.747$. The Poseidon design has three ports, with a flow per port = 62.5/3 = 20.83 mgd. Therefore, from Eq. 36 of R2018, the potentially harmful entrained flow Q_e up to the terminal rise height is:

$$Q_e = nQ_j\left(S_{ta} - 1\right) = 3 \times 20.83 \times \left(9.747 - 1\right) = 547 \text{ mgd}$$

This is more than twice the value (234 mgd) obtained from the Project analysis (Jenkins 2017b cited above in Section 2.3.1).

The Kolmogorov scale on the jet centerline at its terminal rise height is given by Eq. 22 of R2018:

$$\frac{\eta_c}{\chi} = 0.24\,\mathrm{Re}^{-3/4}$$

where χ is the length of jet centerline trajectory to the terminal rise height and $\mathrm{Re} = ud/\nu$ is the jet Reynolds number. For $u = 4.7$ m/s, $d = 0.496$ m (Section 2.1) and the kinematic viscosity $\nu = 1.26\times10^{-5}$ ft²/s we find $\mathrm{Re} = 2.0\times10^{6}$. The distance along the curved jet centerline up to the terminal rise height is computed by integrating along the predicted UM3 jet trajectory as explained in R2018 Section 5.4. From the UM3 output in Appendix C, this yields $\chi \approx 36$ ft. Therefore, the Kolmogorov scale at the terminal rise height is:

$$\eta_c = 0.24\chi\,\mathrm{Re}^{-3/4} = 0.24 \times 36 \times \left(2.0\times10^{6}\right)^{-3/4} = 1.6\times10^{-4}\,\mathrm{ft} = 0.05 \text{ mm}$$

This is much less than one mm, the length below which shear mortality is assumed to occur, which justifies extending the entrainment calculation to the terminal rise height. The distance over which turbulence may be harmful (36 ft) is much greater than the 2.53 ft from the Project analysis assuming the Taylor length scale (Jenkins 2017b cited above in Section 2.3.1).

2.4 Summary

The results for the Poseidon design are summarized in Table 1.

Table 1. Comparisons of Different Analyses of the Proposed Poseidon Diffuser

Parameter	Jenkins' (2017b) analysis	New analysis
Length of BMZ	69.9 m (229 ft)	40.0 m (131 ft)
Size of BMZ	15,350 m^2 (3.8 acres)	5,030 m^2 (1.2 acres)
Dilution at BMZ	S = 14.5, D_m = 13.5	S = 14.5, D_m = 13.5
Length of ZID	877 m (2880 ft)	304 m (1000 ft assumed)
Dilution at ZID	S = 46.1, D_m = 45.1	S = 17.2, D_m = 16.2
Entrained volume subject to shear mortality	234 mgd	547 mgd

3. ALTERNATE DIFFUSERS

3.1 Introduction

Alternative diffuser designs are presented in this chapter for the parameters of case WC1 (given in Section 2.1) using the suggested procedures in R2018. The following diffuser designs are intended to comply with the Ocean Plan's requirements for best available technology to minimize intake and mortality of all forms of marine life. Two configurations are considered: a single multiport "rosette" diffuser on the existing riser, similar to the Project's proposal, and a linear diffuser at the same depth. The port depths were taken as 27 ft to account for the height of the risers above the seabed. The results would be different for different port depths.

3.2 Multiport Rosette Riser

The general procedure for analyzing a rosette diffuser was presented in R2018 Section 3.2.3. The procedure to meet the Ocean Plan's salinity requirements at either the impact point or the near field is as follows:

- Choose a number of ports.
- Choose an effective port diameter.
- For various nozzle angles between 10° and 60°, compute:
    - Dilutions at the impact point (S_i) and near field (S_n) and terminal rise (y_t) height from Eqs. 7, 8, and 11 of R2018, Section 3.2. For four or more ports, account for the reduction in dilution due to merging by Eqs. 15 and 16.
    - Lengths of the impact point (x_i) and near field (x_n) from R2018 Eqs. 9 and 10.
- Vary the port diameter to find the largest diameter that simultaneously satisfies the salinity increment at the impact point less than 2 ppt and height to jet top, y_t less than 90% of the port depth = 24 ft. Note the nozzle angle at which this occurs.
- Vary the port diameter to find the largest diameter that simultaneously satisfies the salinity increment at the near field less than 2 ppt and height to jet top, y_t less than 90% of the port depth = 24 ft. Note the nozzle angle at which this occurs.
- Repeat the above procedure for three, four, etc. ports.

The reason for choosing the largest port diameter that satisfies the salinity and terminal rise height requirements is that it minimizes the jet velocity.

The above procedure results in two solutions for each number of ports, one satisfying the BMZ requirements at the impact point and one at the near field. Table 2 summarizes the results assuming the BMZ is at the impact point and Table 3 summarizes the results assuming it is at the end of the near field. These tables show the optimum port diameter and angle for each assumed number of ports.

Table 2. Optimum Port Diameters and Orientations for a Single Multiport Rosette Riser to Satisfy Plume Submergence and Salinity Increment at the Impact Point

Nozzle conditions					Impact point conditions				UM3 predictions	
No. of ports n	Diam. d (in)	Angle Θ (deg)	Jet velocity u (ft/s)	Froude no. F	Dilution S_i	Salinity increment (ppt)	BMZ Length (ft)	BMZ Area (Acres)	Average dilution S_{ta}	Deleterious entrainment Q_e (mgd)
2	20.7	16	20.7	18.6	14.5	2.0	97	0.68	8.9	494
3	20.7	28	13.8	12.4	14.5	2.0	75	0.41	7.4	400
4	19.6	34	11.5	10.6	14.5	2.0	63	0.29	6.8	363
5	18.0	38	10.9	10.5	14.5	2.0	57	0.23	6.9	369
6	16.5	40	10.9	11.0	14.6	2.0	54	0.21	7.2	388
7	15.2	42	11.0	11.5	14.7	2.0	52	0.20	7.7	419
8	14.0	42	11.3	12.3	14.5	2.0	52	0.20	8.3	456
10	11.7	40	13.0	15.5	14.7	2.0	54	0.21	10.2	575
12	9.7	36	15.7	20.6	14.6	2.0	60	0.26	13.3	769

Table 3. Optimum Port Diameters and Orientations for a Single Multiport Rosette Riser to Satisfy Plume Submergence and Salinity Increment at the Near Field

Nozzle conditions					Near field conditions				UM3 predictions	
No. of ports n	Diam. d (in)	Angle Θ (deg)	Jet velocity u (ft/s)	Froude no. F	Near field dilution, S_n	Salinity increment (ppt)	BMZ Length (ft)	BMZ Area (Acres)	Average dilution S_{ta}	Deleterious entrainment Q_e (mgd)
2	29.4	32	10.3	7.8	14.5	2.0	207	3.09	4.9	244
3	26.9	42	8.2	6.5	14.5	2.0	160	1.85	4.3	206
4	20.3	36	10.8	9.8	14.5	2.0	182	2.39	6.4	338
5	18.8	40	10.0	9.4	14.5	2.0	164	1.94	6.3	331
6	17.5	44	9.6	9.4	14.7	2.0	152	1.67	6.4	338
7	16.4	46	9.4	9.5	14.5	2.0	143	1.47	6.4	338
8	15.3	48	9.5	9.9	14.7	2.0	138	1.37	6.7	356
10	13.6	50	9.6	10.6	14.7	2.0	131	1.24	7.1	381
12	12.1	50	10.1	11.8	14.5	2.0	130	1.22	7.9	431

The BMZ areas in Tables 2 and 3 were computed as follows. If the salinity requirement is met at the impact point, the BMZ is a circle around the diffuser of radius equal to the impact point distance; if met at the near field, it is a circle of radius equal to the length of the near field.

The magnitudes of the harmful shear entrainments in Tables 2 and 3 were computed as follows. Following the suggested procedure (R2018, Section 4.4.3), UM3 was run for each port configuration. The outputs from two typical runs are given in Appendix B. The entrained volume Q_e up to the terminal rise height was calculated from Eq. 36 of R2018:

$$Q_e = n(S_{ta} - 1)Q_j$$

where n is the number of ports, S_{ta} is the average dilution computed by UM3 at the terminal rise height, and Q_j is the flow per jet.

To confirm that the entrainment calculation should extend to the terminal rise height, the Kolmogorov scales at the top were computed. These depend on the jet Reynolds number and the length of the jet trajectory. The jet Reynolds numbers $\mathrm{Re} = ud/\nu$ are of order 10^6. The jet path length χ up to the terminal rise height was calculated from the UM3 trajectory results as discussed in Section 2.3.2. They are of order 20 ft. The Kolmogorov scales at the top were then calculated from R2018 Eq. 22:

$$\frac{\eta_c}{\chi} = 0.24\,\mathrm{Re}^{-3/4}$$

They are of order 0.05 mm. Organisms that are entrained into the jet are subject to potentially harmful turbulence for times of the order of 10 seconds.

Because the Kolmogorov scale at the top is less than one mm, deleterious entrainment is assumed up to this point; beyond this point, in the jet descending region, shear is assumed to be much less and not harmful (see the discussion in R2018, Section 4.2 and 4.3). This is typical for a brine diffuser.

All of the options in Tables 2 and 3 meet the Ocean Plan's receiving water limitation for salinity. The issues involved in making a final choice among them and between a linear diffuser (that is proposed in Section 3.3) are discussed in Section 3.4.

3.3 Linear Multiport Diffuser

An example of the procedure for configuring a multiport linear diffuser, where the ports are arranged along a straight axis (Figure 8, R2018), is given in R2018, Section 5.3. This procedure was followed for case WC1, assuming the effluent and ambient characteristics of Section 2.1. The same port depth as for the rosette configuration, 27 ft (y_t = 0.9×27 = 24 ft) was assumed. Because the number of ports and the length of the diffuser are not constrained, the nozzle angle can be maintained at the optimum value of 60° (Roberts et al. 1997) with the number and diameter of the ports adjusted to avoid a surface boil. To minimize the diffuser length and size of the BMZ, the ports were assumed to discharge to both sides of the diffuser as in Figure 8a, R2018. The results of the optimization procedure for designs that meet the Ocean Plan's salinity requirements at either the impact point or the end of the near field are summarized in Table 4.

Table 4. Optimum Configurations for a Linear Diffuser to Satisfy Plume Submergence and Salinity Increment at Either the Impact or the Near Field.
Rise height y_t = 24 ft, nozzles at 60°

Nozzle conditions				Diffuser		Salinity increment		BMZ		UM3 predictions at top	
No. of ports n	Diam. d (in)	Jet velocity (ft/s)	Froude number F	Port spacing (ft)	Length (ft)	Impact point (ppt)	Near field (ppt)	Radius (ft)	Area (Acres)	Average dilution S_{ta}	Deleterious entrainment Q_e (mgd)
10	14.5	8.4	9.0	21.8	87.2	2.0	1.2	26	0.15	5.8	300
6	21.6	6.3	5.6	20.0	40.0	3.2	2.0	90	0.75	3.7	169

The BMZ for the 10-port linear diffuser (0.15 acres) is smaller than any of the rosette designs, and the harmful entrained flow for the 6-port linear diffuser (169 mgd) is smaller than any of the rosette designs.

Increasing the number of ports above those shown in Table 4 reduces the jet velocity and jet rise height, potentially allowing discharge into more shallow water. The diffuser length and area of the BMZ increase, however. Reducing the number of ports below those shown increases the jet velocity and jet rise height, necessitating discharge farther offshore into deeper water to avoid a surface boil. Table 4 assumes that the ports discharge to both sides of the diffuser. If the discharge is to one side, such as a Tee-configuration with all ports oriented offshore, the diffuser would be longer and the BMZ area larger.

4. Discussion

All options for the alternate diffusers in Tables 2, 3, and 4 meet the Ocean Plan's salinity receiving water limitation. Additionally, these alternatives do not create surface boils like the proposed design. Among these options, the final optimum design may minimize either the jet velocity (and therefore head loss), size of the BMZ, or volume of entrained flow. The three objectives cannot be satisfied simultaneously. The design choice for the Project will depend on costs, relative weighting of the objectives and their tradeoffs, and whether the salinity receiving water limitation is met at the impact point or near field. Meeting at the near field will minimize entrainment and discharge-related mortality of marine life.

Meeting the salinity receiving water limitation at the impact point versus the near field has some general implications. If the impact point dilution is used, the jet velocity is higher, the BMZ is smaller, and the entrained flow and therefore shearing-related mortality is larger. However, the salinity increment on the seabed will be everywhere less than 2 ppt, possibly reducing salinity-related mortality. If the near field dilution is used, the jet velocity is lower, the BMZ is larger, and the entrained flow is smaller.

The conclusions and observations reached here apply to the assumed fixed port depth of 27 ft. If the depth is a variable, for example by moving the diffuser to shallower or deeper water, the optimizations will be different and will need to be recalculated.

For the rosette diffuser at fixed depth, the only variables are the number of ports, their diameter, and angular orientation. The angle must be reduced below the normal optimum of 60° to avoid surface interaction. Minimizing jet velocity requires six ports at 40°or three ports at 42°; minimizing the BMZ requires 8 ports at 42° or 12 ports at 50°; minimizing deleterious entrainment (shearing-mortality) requires four ports at 34° or three ports at 42°. The optimized jet velocities for the alternative design range from 8.2 to 11.5 ft/s (2.5 to 3.5 m/s), considerably less than the original Project design, which was 15.4 ft/s (4.72 m/s, Section 2.1).

The jet velocity and entrained volume can be simultaneously minimized by meeting the salinity requirement at the near field with three ports 26.9 inches diameter at 42°. The corresponding jet velocity is 8.2 ft/s and entrained volume is 206 mgd. The length of the corresponding BMZ is 160 ft (49 m, 1.85 acres), well within the Ocean Plan's maximum allowable distance of 100 m.

For the linear diffuser at fixed depth, the nozzle angle can be maintained at the optimum value of 60°. The minimum number of ports is then found that meet the salinity and rise height criteria. Increasing the number of ports above this minimum decreases the jet velocity and rise height and may decrease the BMZ. The harmful entrainment and shear mortality remain the same, however, as they

depend only on the dilution needed to meet the salinity requirement. As for the rosette diffuser, meeting the salinity requirement at the impact point results in higher jet velocity, more harmful entrainment, and a smaller BMZ.

For the single rosette alternatives, harmful entrained flows for the optimum designs range from 206 to 456 mgd. In general, meeting the salinity requirement at the impact point (which requires more entrainment in the jet region) results in approximately twice the entrainment than if met at the near field.

A summary of the main parameters of the rosette and linear diffusers that minimize either the BMZ or harmful entrainment is shown in Table 5.

Table 5. Summary of Diffuser Options that Minimize BMZ or Harmful Entrainment

Scenario	Diffuser details					BMZ			Comments
	No. of ports	Diam. d (in)	Angle Θ (deg)	Jet velocity u (ft/s)	Froude number F	Radius (ft)	Area (acres)	Delet-erious entrain-ment (mgd)	
Single riser, original Project design	3	19.5	47	15.5	14.3	229	3.78	234	Analysis of Jenkins (2017ab)
Single riser, original Project design	7	15.2	42	11.0	11.5	52	0.20	419	New analysis, Impact dilution minimizes BMZ
Single riser, alternate design	3	26.9	42	8.2	6.5	160	1.85	206	New analysis, Near field dilution minimizes Q_e
Alternate linear diffuser	10	14.5	60	8.4	9.0	26	0.15	300	Impact dilution minimizes BMZ
Alternate linear diffuser	6	21.6	60	6.3	5.6	90	0.75	169	Near field dilution minimizes Q_e

It should be noted that these are preliminary analyses for one flow scenario assuming a port depth of 27 ft. Designing the ports so they are deeper allows a steeper nozzle angle, lower jet velocity, less entrainment and a smaller BMZ. Additional analyses would be needed to evaluate diffuser designs at different depths.

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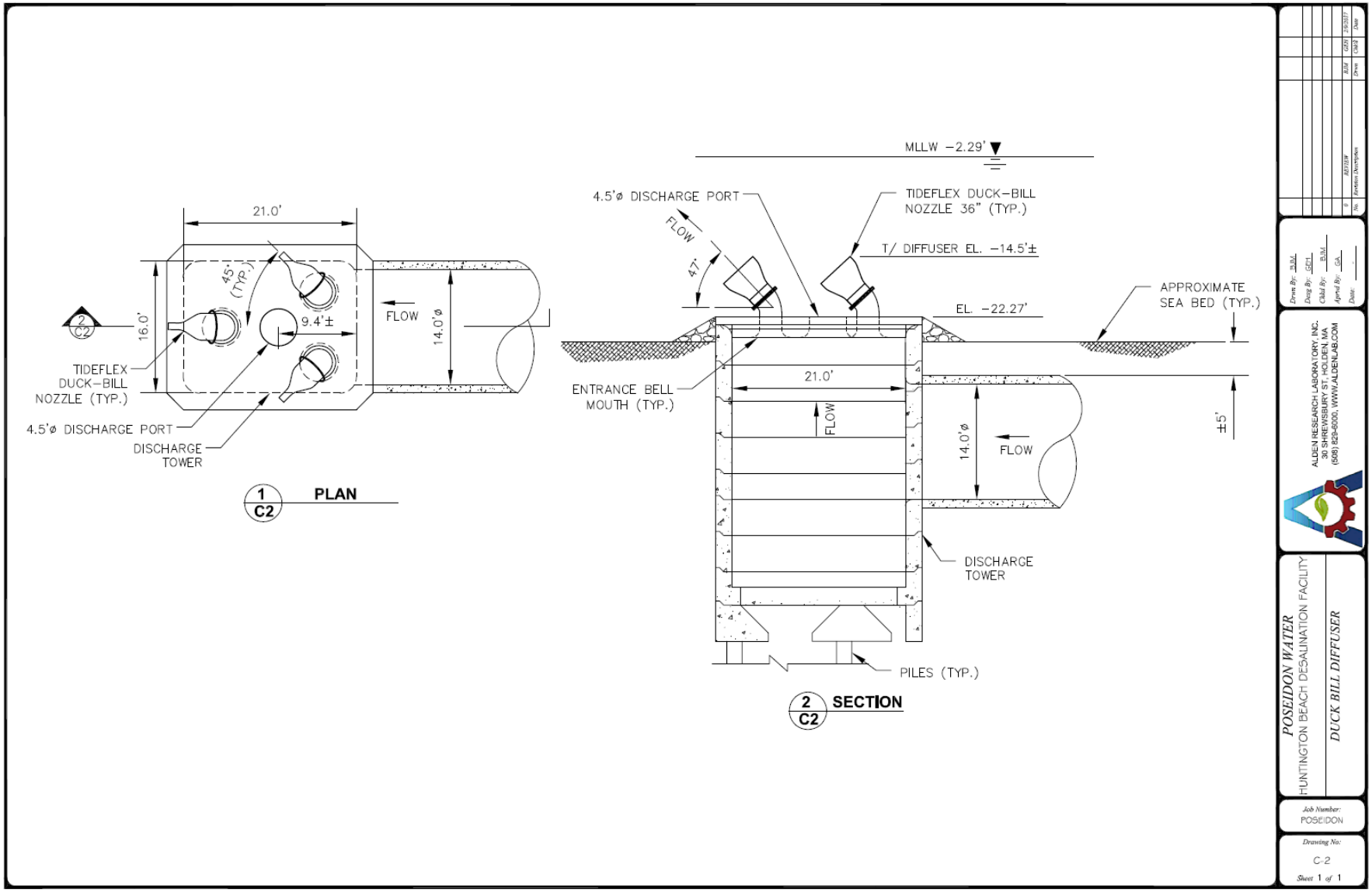
APPENDIX A. PROPOSED DIFFUSER

The proposed diffuser is shown below (Alden Laboratories, 2017)



APPENDIX B. UM3 SIMULATIONS FOR NEW SINGLE RISER DESIGNS

These are typical UM3 outputs for the three-port diffuser cases in Tables 1 and 2.

Contents of the memo box (may not be current and must be updated manually)
Project "C:\Plumes17\Huntington Beach\HB1" memo

Model configuration items checked:
  Channel width (m) 100
Start case for graphs 1
Max detailed graphs 10 (limits plots that can overflow memory)
 Elevation Projection Plane (deg) 0
Shore vector (m,deg) not checked
 Bacteria model : Mancini (1978) coliform model
 PDS sfc. model heat transfer : Medium
 Equation of State : S, T
 Similarity Profile : Default profile (k=2.0, ...)
 Diffuser port contraction coefficient 1
 Light absorption coefficient 0.16
 Farfield increment (m) 200
 UM3 aspiration coefficient 0.1
  Output file: text output tab
  Output each ?? steps 20
  Maximum dilution reported 20
 Text output format : Standard
 Max vertical reversals : to max rise or fall

/ UM3. 2/3/2018 3:39:13 PM
Case 1; ambient file C:\Plumes17\Huntington Beach\HB1.001.db; Diffuser table record 1:

Ambient Table:

Depth m	Amb-cur m/s	Amb-dir deg	Amb-den psu	Amb-tem C	Amb-pol kg/kg	Decay s-1	Far-spd m/s	Far-dir deg	Disprsn m0.67/s2	Density sigma-T
0.0	0.0	90.00	33.31	20.00	0.0	0.0	-	-	0.0	23.50000
8.535	0.0	90.00	33.31	20.00	0.0	0.0	-	-	0.0	23.50000

Diffuser table:

P-diaVer (in)	angl (deg)	H-Angle (deg)	SourceX (m)	SourceY (m)	Ports ()	Spacing (m)	MZ-dis (m)	Isoplth (concent)	P-depth (ft)	Ttl-flo (MGD)	Eff-den (kg/m3)	Temp (C)	Polutnt (ppm)
20.700	28.000	0.0	0.0	0.0	3.0000	100.00	100.00	0.0	24.000	62.500	1046.4	22.000	1000.0

Simulation:
Froude No: -12.51; Strat No: 0.0000; Spcg No: 190.2; k: 4.20E+5; eff den (sigmaT) 46.40000; eff vel 4.204(m/s);
Current is very small, flow regime may be transient.

Step	Depth (ft)	Amb-cur (m/s)	P-dia (in)	Polutnt (ppm)	Dilutn ()	x-posn (ft)	y-posn (ft)	Iso dia (m)	
0	24.00	1.000E-5	20.70	1000.0	1.000	0.0	0.0	0.5258;	
20	23.04	0.0	30.31	675.2	1.481	1.815	0.0	0.7698;	
40	21.63	0.0	45.36	452.2	2.212	4.593	0.0	1.1522;	
60	19.65	0.0	68.21	303.3	3.297	8.807	0.0	1.7325;	
80	17.46	0.0	99.06	213.1	4.692	14.46	0.0	2.5161;	
100	16.22	0.0	122.9	174.6	5.726	18.87	0.0	3.1213;	
120	15.60	0.0	141.7	153.0	6.536	22.46	0.0	3.5983;	
140	15.38	0.0	157.3	138.4	7.227	25.58	0.0	3.9958;	
145	15.37	0.0	160.9	135.4	7.388	26.31	0.0	4.0858;	local maximum rise or fall;
160	15.46	0.0	170.8	127.4	7.852	28.41	0.0	4.3374;	
180	15.81	0.0	182.6	118.4	8.446	31.07	0.0	4.6372;	
200	16.41	0.0	193.1	110.7	9.035	33.64	0.0	4.9049;	
220	17.28	0.0	202.7	103.7	9.643	36.18	0.0	5.1485;	
240	18.46	0.0	211.6	97.11	10.30	38.76	0.0	5.3756;	
260	20.02	0.0	220.2	90.67	11.03	41.43	0.0	5.5943;	
264	20.39	0.0	222.0	89.38	11.19	41.97	0.0	5.6379;	bottom hit;
280	22.08	0.0	229.0	84.16	11.88	44.25	0.0	5.8154;	
300	24.80	0.0	238.3	77.37	12.92	47.30	0.0	6.0535;	
320	28.49	0.0	249.3	70.13	14.26	50.68	0.0	6.3310;	
340	33.60	0.0	263.1	62.22	16.07	54.51	0.0	6.6838;	
360	40.97	0.0	282.4	53.47	18.70	58.98	0.0	7.1740;	
368	44.87	0.0	292.6	49.70	20.12	61.00	0.0	7.4319;	merging, stop dilution reached;

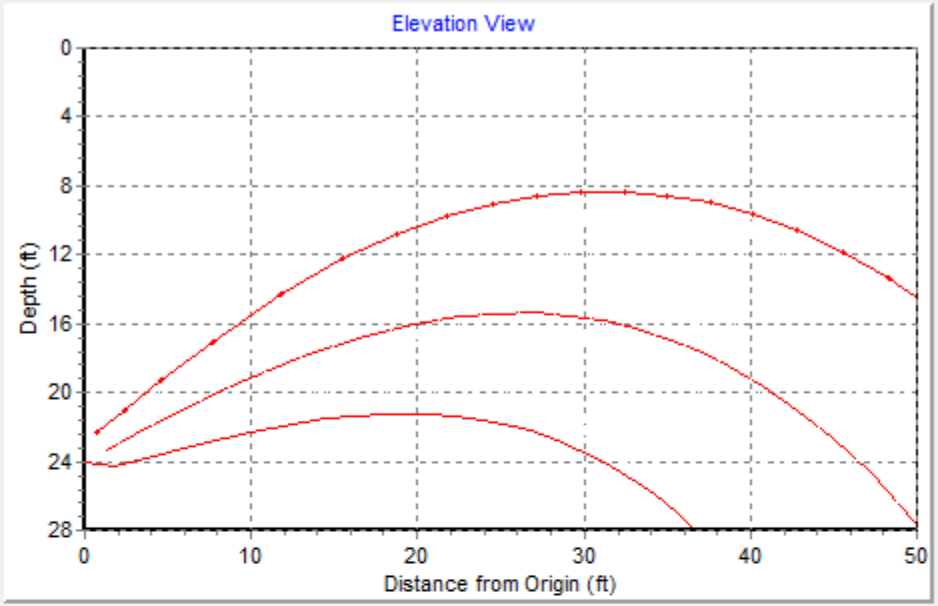
Horiz plane projections in effluent direction: radius(m): 0.0; CL(m): 18.592
Lmz(m): 18.592
forced entrain 1 0.0 -6.360 7.432 0.449
Rate sec-1 0.0 dy-1 0.0 kt: 0.0 Amb Sal 33.3122
 ;
3:39:13 PM. amb fills: 4

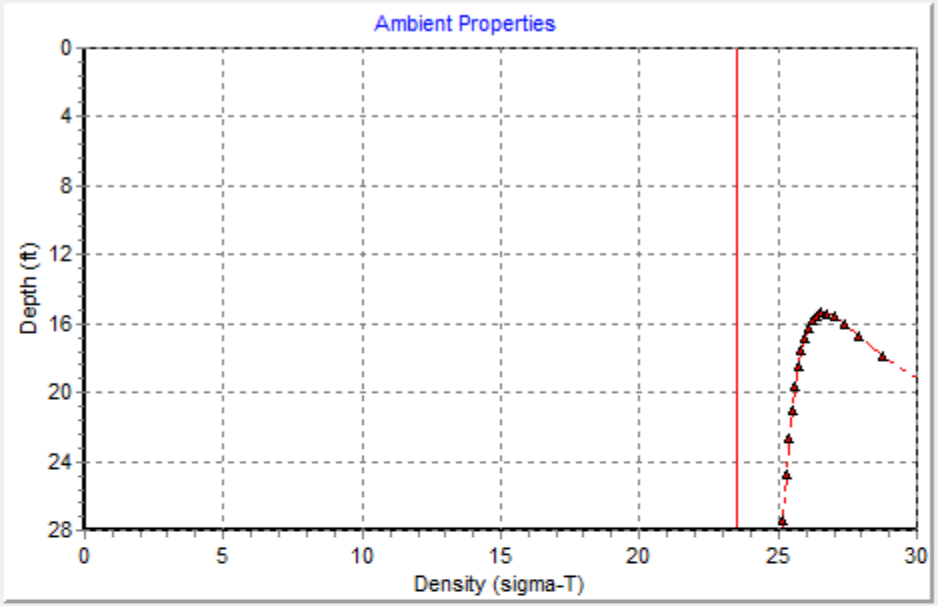
Diffuser: HB1.vpp.db | Ambient: C:\Plumes17\Huntington Beach\HB1.001.db | Special Settings | Text Output | Graphical Output

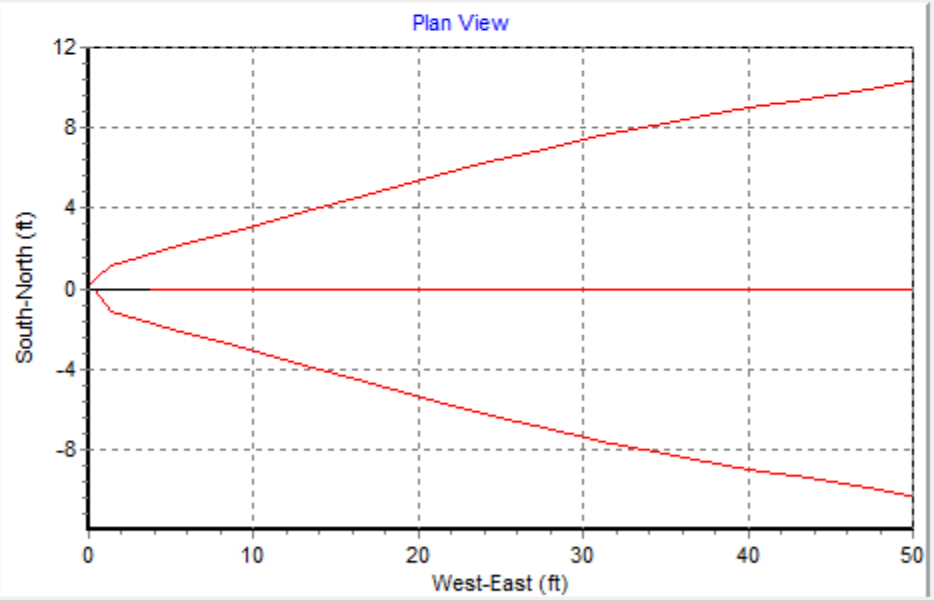
Style

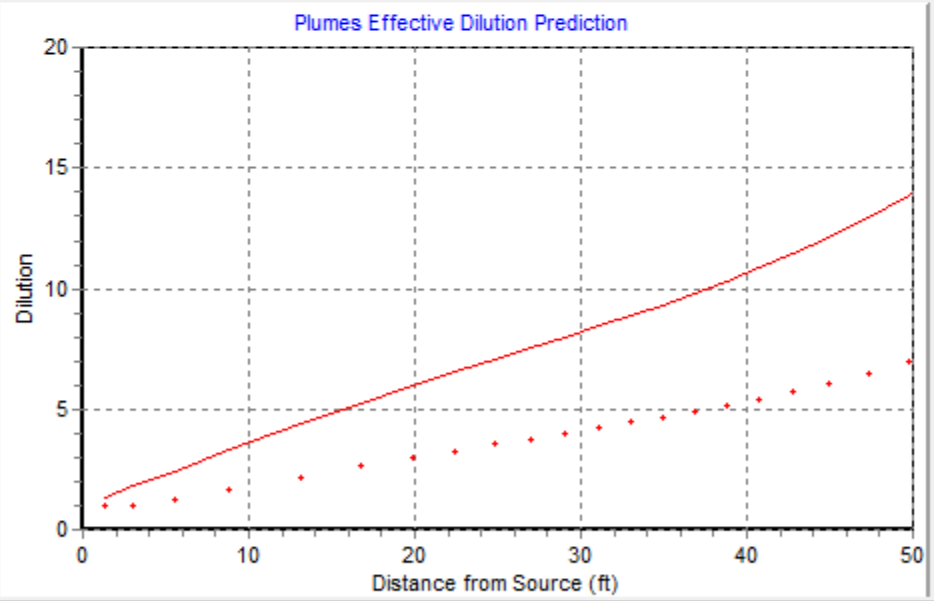
Series

Plane









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Case 1; ambient file C:\Plumes17\Huntington Beach\HB1.001.db; Diffuser table record 1:

Ambient Table:

Depth m	Amb-cur m/s	Amb-dir deg	Amb-den psu	Amb-tem C	Amb-pol kg/kg	Decay s-1	Far-spd m/s	Far-dir deg	Disprsn m0.67/s2	Density sigma-T
0.0	0.0	90.00	33.31	20.00	0.0	0.0	-	-	0.0	23.50000
8.535	0.0	90.00	33.31	20.00	0.0	0.0	-	-	0.0	23.50000

Diffuser table:

P-dia (in)	Ver angl (deg)	H-Angle (deg)	SourceX (m)	SourceY (m)	Ports ()	Spacing (m)	MZ-dis (m)	Isoplth (concent)	P-depth (ft)	Ttl-flo (MGD)	Eff-den (kg/m3)	Temp (C)	Polutnt (ppm)
26.900	42.000	0.0	0.0	0.0	3.0000	100.00	100.00	0.0	24.000	62.500	1046.4	22.000	1000.0

Simulation:
Froude No: -6.501; Strat No: 0.0000; Spcg No: 146.4; k: 2.49E+5; eff den (sigmaT) 46.40000; eff vel 2.489(m/s);
Current is very small, flow regime may be transient.

Step	Depth (ft)	Amb-cur (m/s)	P-dia (in)	Polutnt (ppm)	Dilutn ()	x-posn (ft)	y-posn (ft)	Iso dia (m)	
0	24.00	1.000E-5	26.90	1000.0	1.000	0.0	0.0	0.6833;	
20	22.26	0.0	39.53	678.7	1.473	1.979	0.0	1.0041;	
40	19.72	0.0	60.41	455.1	2.197	5.174	0.0	1.5345;	
60	17.69	0.0	80.64	354.0	2.825	8.216	0.0	2.0484;	
80	16.50	0.0	95.29	308.2	3.245	10.46	0.0	2.4203;	
100	15.76	0.0	106.9	280.7	3.563	12.27	0.0	2.7142;	
120	15.30	0.0	116.4	261.7	3.821	13.84	0.0	2.9561;	
140	15.04	0.0	124.4	247.3	4.044	15.23	0.0	3.1593;	
160	14.94	0.0	131.2	235.5	4.246	16.52	0.0	3.3318;	
168	14.93	0.0	133.6	231.3	4.323	17.02	0.0	3.3935;	local maximum rise or fall;
180	14.96	0.0	137.0	225.4	4.436	17.74	0.0	3.4791;	
200	15.10	0.0	141.9	216.4	4.622	18.93	0.0	3.6049;	
220	15.36	0.0	146.2	207.9	4.811	20.11	0.0	3.7124;	
240	15.75	0.0	149.8	199.6	5.010	21.30	0.0	3.8048;	
260	16.29	0.0	153.0	191.3	5.229	22.53	0.0	3.8853;	
280	17.03	0.0	155.8	182.6	5.477	23.83	0.0	3.9578;	
300	18.02	0.0	158.6	173.3	5.772	25.23	0.0	4.0278;	
320	19.37	0.0	161.5	162.9	6.137	26.77	0.0	4.1032;	
340	21.21	0.0	165.2	151.2	6.612	28.51	0.0	4.1960;	
360	23.83	0.0	170.3	137.6	7.266	30.52	0.0	4.3261;	
361	23.98	0.0	170.6	136.9	7.305	30.63	0.0	4.3342;	bottom hit;
380	27.66	0.0	178.3	121.6	8.227	32.91	0.0	4.5283;	
400	33.57	0.0	191.6	102.4	9.761	35.83	0.0	4.8674;	
420	43.39	0.0	215.7	80.02	12.50	39.52	0.0	5.4793;	
440	60.89	0.0	261.7	55.57	18.00	44.24	0.0	6.6471;	
446	67.48	0.0	279.6	49.33	20.27	45.65	0.0	7.1013;	stop dilution reached;

Horiz plane projections in effluent direction: radius(m): 0.0; CL(m): 13.914
Lmz(m): 13.914
forced entrain 1 0.0 -13.25 7.101 0.204
Rate sec-1 0.0 dy-1 0.0 kt: 0.0 Amb Sal 33.3122
;
3:44:45 PM. amb fills: 4

Diffuser: HB1.vpp.db | Ambient: C:\Plumes17\Huntington Beach\HB1.001.db | Special Settings | Text Output | Graphical Output

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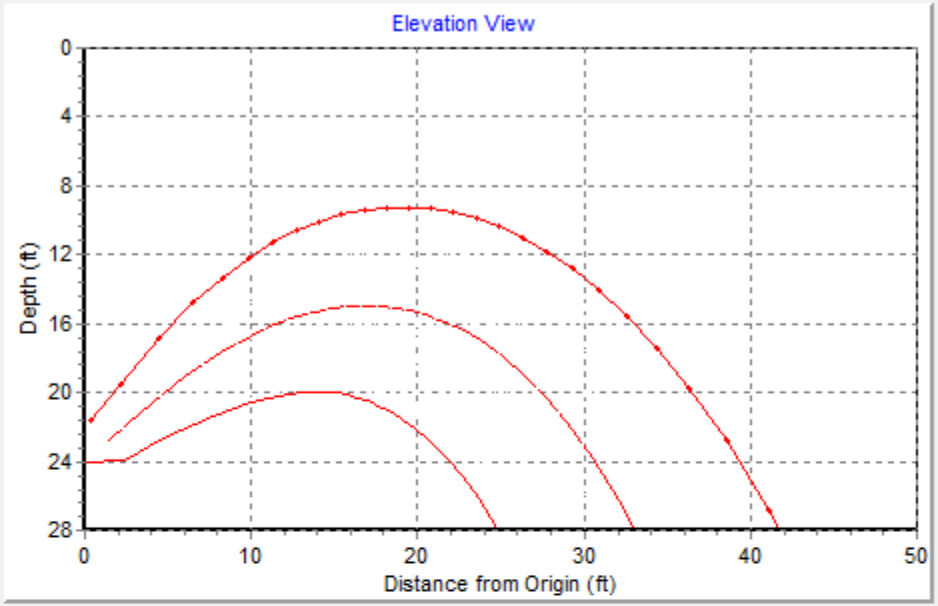

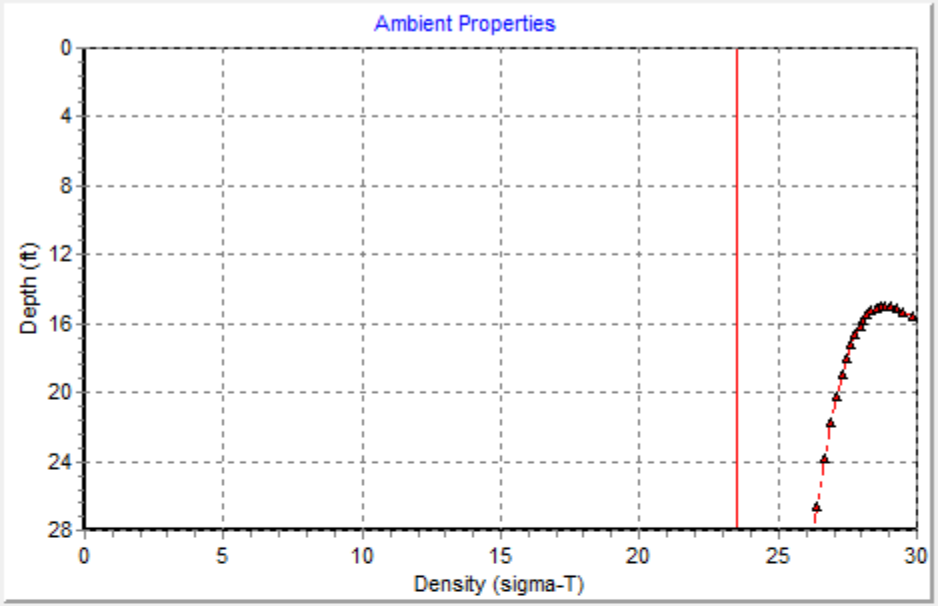

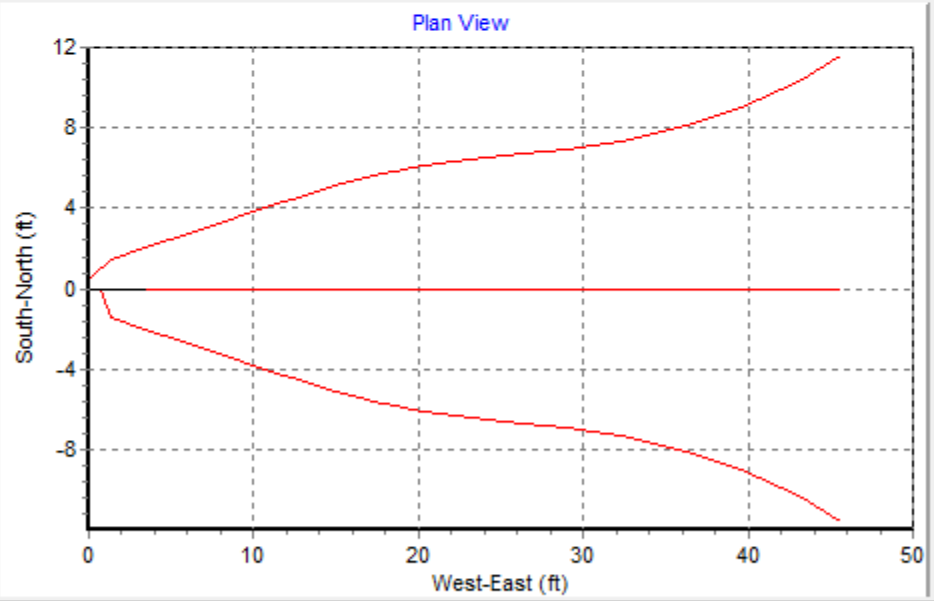

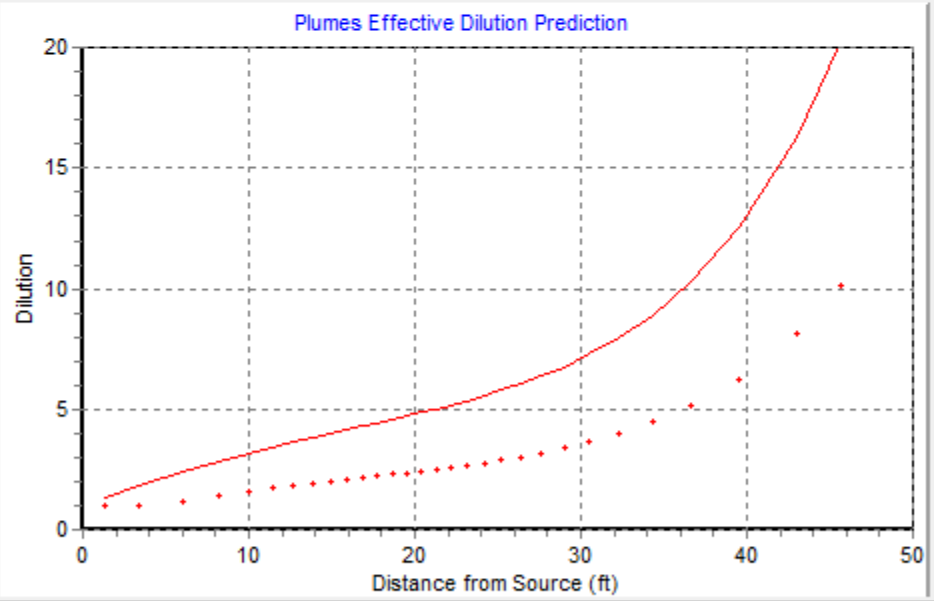

APPENDIX C. UM3 SIMULATIONS FOR PROJECT DESIGN

This the UM3 output for the Project three-port diffuser for shear entrainment calculations (Section 2.3.2).

/ UM3. 2/28/2018 2:01:51 PM
Case 1; ambient file C:\Plumes17\Huntington Beach\HB1.001.db; Diffuser table record 1:

Ambient Table:

Depth m	Amb-cur m/s	Amb-dir deg	Amb-sal psu	Amb-tem C	Amb-pol kg/kg	Decay s-1	Far-spd m/s	Far-dir deg	Disprsn m0.67/s2	Density sigma-T
0.0	0.0	90.00	33.50	20.00	0.0	0.0	-	-	0.0	23.64277
8.535	0.0	90.00	33.50	20.00	0.0	0.0	-	-	0.0	23.64277

Diffuser table:

P-dia (m)	Ver angl (deg)	H-Angle (deg)	SourceX (m)	SourceY (m)	Ports ()	Spacing (m)	MZ-dis (m)	Isoplth (concent)	P-depth (ft)	Ttl-flo (MGD)	Eff-sal (psu)	Temp (C)	Polutnt (ppm)
0.4960	47.000	0.0	0.0	0.0	3.0000	100.00	100.00	0.0	24.000	62.500	62.400	22.000	1000.0

Simulation:
Froude No: -14.85; Strat No: 0.0000; Spcg No: 201.6; k: 4.72E+5; eff den (sigmaT) 45.40553; eff vel 4.724(m/s);
Current is very small, flow regime may be transient.

Step	Depth (ft)	Amb-cur (m/s)	P-dia (m)	Polutnt (ppm)	Dilutn ()	x-posn (ft)	y-posn (ft)	Iso dia (m)	
0	24.00	1.000E-5	0.496	1000.0	1.000	0.0	0.0	0.4960;	
20	22.58	0.0	0.728	674.2	1.483	1.329	0.0	0.7276;	
40	20.45	0.0	1.090	451.6	2.214	3.359	0.0	1.0896;	
60	17.31	0.0	1.642	303.0	3.301	6.450	0.0	1.6416;	
80	12.78	0.0	2.513	203.5	4.915	11.33	0.0	2.5129;	
100	8.964	0.0	3.399	157.4	6.355	16.18	0.0	3.3985;	
120	6.759	0.0	4.027	137.4	7.280	19.66	0.0	4.0272;	
128	6.128	0.0	4.237	132.0	7.573	20.84	0.0	4.2368;	surface;
140	5.369	0.0	4.519	125.7	7.958	22.45	0.0	4.5185;	
149	4.918	0.0	4.708	121.8	8.212	23.55	0.0	4.7084;	matched energy radial vel = 0.336m/s;
160	4.476	0.0	4.919	117.7	8.494	24.80	0.0	4.9194;	
180	3.919	0.0	5.254	111.8	8.945	26.89	0.0	5.2535;	
200	3.610	0.0	5.535	107.0	9.344	28.79	0.0	5.5347;	
204	3.574	0.0	5.585	106.2	9.419	29.15	0.0	5.5854;	begin overlap;
220	3.503	0.0	5.765	103.1	9.698	30.57	0.0	5.7649;	
223	3.502	0.0	5.795	102.6	9.747	30.83	0.0	5.7946;	local maximum rise or fall;
240	3.571	0.0	5.943	99.85	10.01	32.29	0.0	5.9435;	
260	3.810	0.0	6.084	96.90	10.32	33.98	0.0	6.0842;	
280	4.228	0.0	6.198	94.00	10.64	35.69	0.0	6.1978;	
300	4.847	0.0	6.295	90.96	10.99	37.44	0.0	6.2948;	
318	5.611	0.0	6.379	87.94	11.37	39.08	0.0	6.3785;	end overlap;
320	5.710	0.0	6.388	87.58	11.42	39.27	0.0	6.3879;	
334	6.491	0.0	6.450	85.03	11.76	40.62	0.0	6.4503;	matched energy radial vel = 0.268m/s;
340	6.879	0.0	6.476	83.89	11.92	41.22	0.0	6.4759;	
360	8.458	0.0	6.560	79.84	12.53	43.34	0.0	6.5604;	
380	10.61	0.0	6.654	75.27	13.29	45.71	0.0	6.6544;	
400	13.61	0.0	6.779	69.97	14.29	48.40	0.0	6.7789;	
420	17.90	0.0	6.969	63.67	15.71	51.55	0.0	6.9686;	
435	22.43	0.0	7.189	58.11	17.21	54.32	0.0	7.1892;	bottom hit;
440	24.29	0.0	7.285	56.08	17.83	55.33	0.0	7.2854;	
454	30.81	0.0	7.643	49.83	20.07	58.50	0.0	7.6425;	merging, stop dilution reached;

Horiz plane projections in effluent direction: radius(m): 0.0; CL(m): 17.831
Lmz(m): 17.831
forced entrain 1 0.0 -2.075 7.643 0.414
Rate sec-1 0.0 dy-1 0.0 kt: 0.0 Amb Sal 33.5000
;
2:01:51 PM. amb fills: 4

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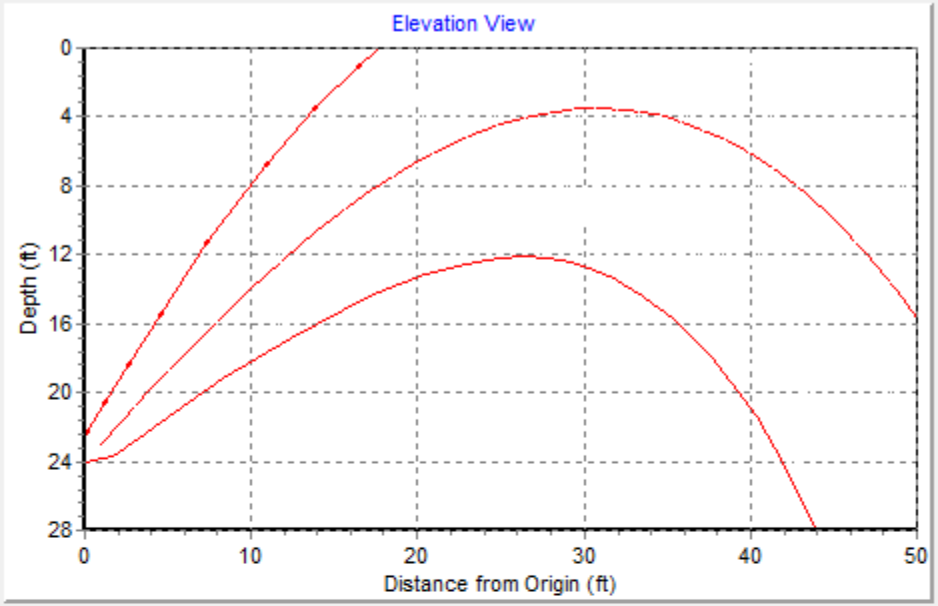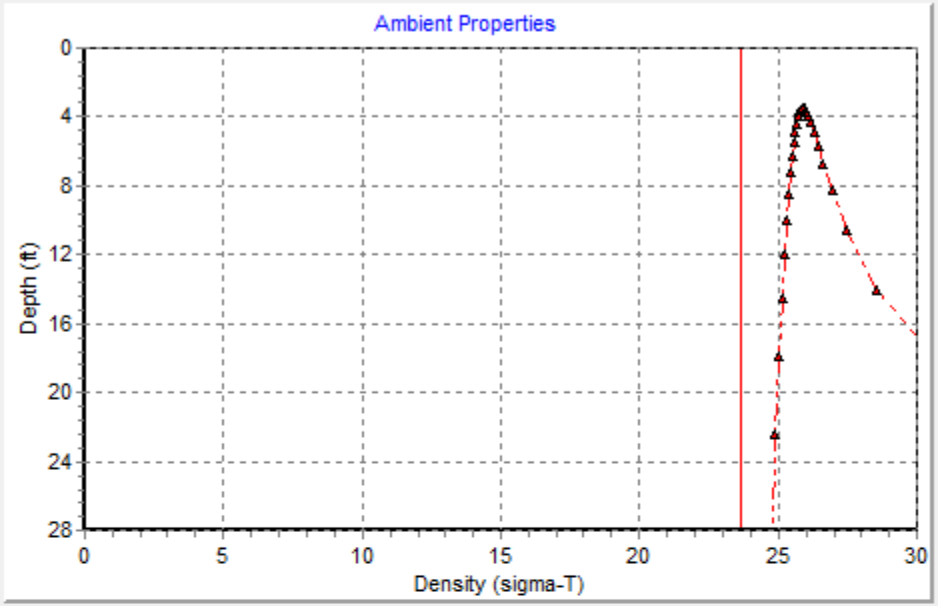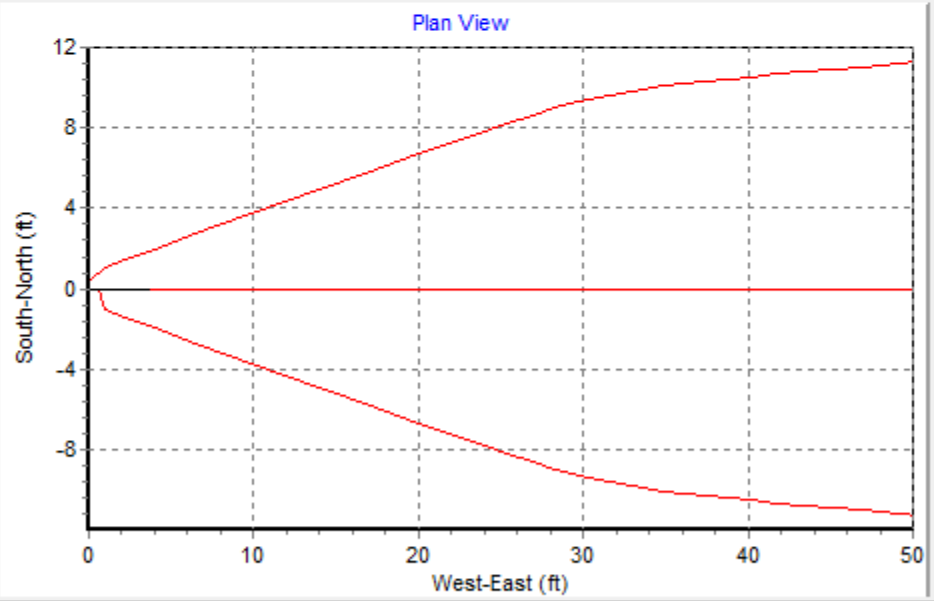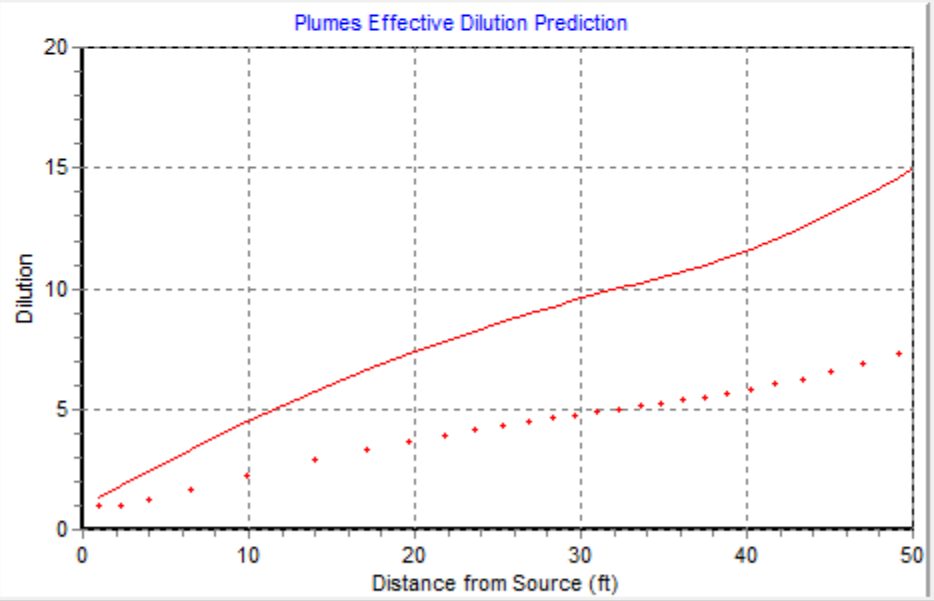
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