# TECHNICAL MEMORANDUM

## City of Corpus Christi Desalination Study

## Concentrate Modeling at Inner Harbor Channel

### TPDES Permit No.: WQ0005289000

| | |
|---|---|
| **PREPARED BY** | Ernest To, Ph.D., PE |
| **DATE** | July 16th, 2021. |
| **VERSION** | 1.5 |
| **PROJECT NO.** | 0312-055-02<br>City of Corpus Christi Seawater Desalination |
| **FILE DIRECTORY** | C:\Users\eto\Desktop\CC_Desal\20210504_IH_Memo\!SENT_for_review\20210716_Sent_to_City\InnerHarbor_TM_20210716_1552.docx |

PLUMMER

Texas Registered Engineering Firm F-13

# Table of Contents

# List of Figures



# List of Tables

**LIST OF ABBREVIATONS**

| | |
|---|---|
| ADCP | Acoustic Doppler Current Profiler |
| EPA | United States Environmental Protection Agency |
| HHMZ | Human Health Mixing Zone |
| MGD | Million Gallons per Day |
| MZ | Mixing Zone |
| ppt | Parts per Thousand |
| RO | Reverse Osmosis |
| SOP | TCEQ CORMIX Standard Operating Procedures |
| SWQM | Surface Water Quality Monitoring |
| TCEQ | Texas Commission on Environmental Quality |
| TPDES | Texas Pollutant Discharge Elimination System |
| ZID | Zone of Initial Dilution |

# 1 EXECUTIVE SUMMARY

As part of the Freese and Nichols, Inc. Project Team (Project Team), Plummer conducted a concentrate modeling study at the Inner Harbor site to support the Texas Pollutant Discharge Elimination System (TPDES) industrial wastewater discharge permit application for the potential desalination outfall location and diffuser configurations in the Inner Harbor channel. The CORMIX model software was utilized to evaluate the effluent percentages of the brine concentrate at the edges of the regulatory mixing zones: zone of initial dilution (ZID), aquatic life mixing zone (MZ), and human health mixing zone (HHMZ).

The model scenarios simulated 20 MGD and 30 MGD desalination plant production capacities operating at the minimum and maximum RO recovery rates of 40% and 50%, as well as a range of ambient and discharge densities required by the Texas Commission on Environmental Quality (TCEQ) CORMIX Standard Operating Procedures ("SOP"). The CORMIX modeling also incorporated the background flow measured by an Acoustic Doppler Current Profiler (ADCP) monitoring data deployed at a nearby dock.

The proposed diffuser design is a multiport diffuser consisting of a 50-foot-long diffuser pipe with four risers – each containing two 8-inch diameter ports. The diffuser would be placed at a depth of approximately 32 feet on private property near the south side of the navigation channel. The diffuser pipe would be aligned parallel to the channel while the diffuser ports would be directed towards the center of the channel. The diffuser ports would also be angled 60 degrees above the horizon. Since the diffuser is a multiport diffuser, rectangular mixing zones for the ZID and MZ were defined following SOP requirements. This resulted in the following rectangular dimensions:

- ZID: 100 ft x 78 ft centered around the diffuser pipe with the short side parallel to the pipe and long side perpendicular to the pipe;
- MZ: 400 ft x 314 ft centered around the diffuser pipe with the short side parallel to the pipe and long side perpendicular to the pipe; and,
- HHMZ: 800 ft x 628 ft centered around the diffuser pipe with the short side parallel to the pipe and long side perpendicular to the pipe.

The CORMIX model results were evaluated based on the following criteria:

1. Meeting critical dilutions at the edges of the ZID and MZ that are protective of aquatic life;
2. Achieving the CORMIX flow class of MNU8; and,
3. Meeting effluent velocity limits at the edges of the ZID and MZ that are protective of aquatic life.

Effluent percentages predicted by CORMIX at the edge of the ZID and the MZ mixing zones were compared with the critical dilutions proposed in the Corpus Christi Seawater Desalination Receiving Water Salinity Critical Dilutions White Paper ("White Paper") (FNI, 2020). The White Paper states the critical dilutions (expressed as percentage effluent) that are protective of aquatic life as follows:

- For the reverse osmosis (RO) recovery rate of 40%, the critical dilution for the ZID is 56% and the critical dilution for the MZ is 18%. These critical dilutions would produce salinities of 42 and 35 ppt respectively under average ambient salinity conditions.
- For the RO recovery rate of 50%, the critical dilution for the ZID is 38% and the critical dilution for the MZ is 13%. These critical dilutions would produce salinities of 42 and 35 ppt respectively under average ambient salinity conditions.

The flow class assigned by CORMIX was evaluated to ensure that the diffuser produces a properly dispersed plume. The CORMIX flow class of MNU8 represents a flow regime where "the discharge strength (measured by its momentum flux) is very high in relation to the layer depth and in relation to the stabilizing effect of the discharge buoyancy (measured by its buoyancy flux)". In other words, the predicted effluent has sufficient kinetic energy (characterized by port velocity) to engage and mix with the water column. In contrast, when the effluent has insufficient port velocity, it would flow to the bottom with little interaction with the ambient water. Therefore, the assignment of the flow class MNU8 is desired to ensure proper diffusion of the effluent plume.

To address concerns on aquatic life due to jet velocities in the vicinity of the discharge, effluent velocities at the edge of the ZID and the MZ were evaluated. Jet velocities less than 2 fps at the edge of the ZID and 0.5 fps at the edge of the MZ are considered safe. Effluent velocities along the plume centerline were calculated to ensure that the velocity limits were met.

Table 1 below provides the CORMIX results for the recommended diffuser design when the desalination plant is operating at RO 40% recovery rate for the production capacities of 20 MGD and 30 MGD. Results for each standard density scenario required are not shown separately because the predicted effluent percentages, velocities, and flow classes from CORMIX were identical. Table 1 shows that the recommended diffuser design meets all the criteria mentioned above for effluent percentage, CORMIX flow class and effluent velocity.

**Table 1. Summary of CORMIX results for RO 40% recovery rate.**

| | | | ZID Results | | | MZ results | | | CORMIX Flow Classification | |
|---|---|---|---|---|---|---|---|---|---|---|
| Production Capacity (MGD) | RO Recovery Rate | Effluent Discharge (MGD) | Effluent Percentage (%) | Effluent Velocity (fps) | Evaluation | Effluent Percentage (%) | Effluent Velocity (fps) | Evaluation | Flow Class | Evaluation |
| 20 | 40% | 34.3 | 10.3 | 0.3 | Meets critical dilution (<=56%) and velocity limit (<= 2 fps) for ZID. | 8.5 | 0.2 | Meets critical dilution (<=18%) and velocity limit (0.5 fps) for MZ. | MNU8 | Meets desired flow class (MNU8). |
| 30 | 40% | 51.5 | 12.3 | 0.4 | Meets critical dilution (<=56%) and velocity limit (<= 2 fps) for ZID. | 12.3 | 0.3 | Meets critical dilution (<=18%) and velocity limit (0.5 fps) for MZ. | MNU8 | Meets desired flow class (MNU8). |

Table 2 below provides the CORMIX results for the recommended diffuser design when the desalination plant is operating at RO 50% recovery rate for the production capacities of 20 MGD and 30 MGD. Results for each standard density scenario required are not shown separately because the predicted effluent percentages, velocities, and flow classes from CORMIX were identical. Table 2 shows that the recommended diffuser design meets all the criteria mentioned above for effluent percentage, CORMIX flow class and effluent velocity.

**Table 2. Summary of CORMIX results for RO 50% recovery rate.**

| | | | ZID Results | | | MZ results | | | CORMIX Flow Classification | |
|---|---|---|---|---|---|---|---|---|---|---|
| Production Capacity (MGD) | RO Recovery Rate | Effluent Discharge (MGD) | Effluent Percentage (%) | Effluent Velocity (fps) | Evaluation | Effluent Percentage (%) | Effluent Velocity (fps) | Evaluation | Flow Class | Evaluation |
| 20 | 50% | 23.4 | 10.4 | 0.2 | Meets critical dilution (<=38%) and velocity limit (<= 2 fps) for ZID. | 7.4 | 0.1 | Meets critical dilution (<=13%) and velocity limit (0.5 fps) for MZ. | MNU8 | Meets desired flow class (MNU8) |
| 30 | 50% | 35.2 | 10.3 | 0.3 | Meets critical dilution (<=38%) and velocity limit (<= 2 fps) for ZID. | 8.7 | 0.2 | Meets critical dilution (<=13%) and velocity limit (0.5 fps) for MZ. | MNU8 | Meets desired flow class (MNU8) |

Finally, it is noted that another discharger (Permit #WQ0000457000) is located within 400 ft from the proposed diffuser location. However, it is anticipated that the proposed desalination discharge would have limited interaction with the other discharge. This is because effluent from the other discharger is positively buoyant under all SOP density scenarios. The depth of the other diffuser is 8.2 ft (JMA, 2016) and is significantly shallower than the depth of the proposed diffuser. On the other hand, effluent from the proposed desalination plant would be negatively buoyant under all SOP density scenarios. The proposed depth of the diffuser is 32 ft.

Given the significant difference in buoyancy and discharge depth between the two effluents, it is highly unlikely that their respective plume trajectories would intermix. As such, adjustment of their respective regulatory mixing zones to avoid plume interaction would not be necessary.

For permitting purposes, since 40% and 50% recovery rates can result in different discharge rates even when the production rate is the same, it is recommended that the permits limits for average daily discharge volume be based on a 40% recovery rate (maximum anticipated discharge for each permit phase). The maximum daily discharge would be a factor of 1.20 times the average daily discharge volume.

# 2 INTRODUCTION

As part of the modeling study in support of preparation of the TPDES industrial wastewater discharge permit application, Plummer has performed site-specific concentrate modeling for the Inner Harbor site using the CORMIX modeling software (Jirka, G. H., et. al, 1996) and the ADCP measured flow data. The goal of this study is to recommend a diffuser design and outfall location and to evaluate its performance based primarily on the effluent percentages of the desalination concentrate at the edges of the regulatory mixing zones to compare against the critical dilution defined in the Corpus Christi Seawater Desalination Receiving Water Salinity Critical Dilutions White Paper ("White Paper") (FNI, 2020). The White Paper critical dilutions are listed as follows:

- For reverse osmosis (RO) recovery rate of 40%, critical dilutions (as percentage effluent) of 56% at the ZID and 18% at the MZ; and,
- For the RO Recovery Rate of 50%, critical dilutions of 38% at the ZID and 13% at the MZ.

The desalination plant is expected to undergo two permit phases: an initial phase of 20 MGD plant production capacity followed by a final phase of 30 MGD production capacity. The plant is expected to operate at recovery rates ranging from 40% to 50%. CORMIX modeling was used to evaluate these ranges of operation and identify a feasible outfall location and diffuser design option that would satisfy the critical dilutions. In addition, the flow class assigned by CORMIX was evaluated to ensure that the proposed discharge would have the mixing characteristics of a properly diffused plume. Finally, CORMIX was used to evaluate effluent velocities to address concerns on aquatic life protection due to jet velocities.

## 3 DESCRIPTION OF OUTFALL LOCATION

### 3.1 DIFFUSER PLACEMENT

As per the permit application, the diffuser would be placed within the latitude/longitude window ("outfall window") defined by the coordinates of 27.814°N, 97.4195°W for the southwest corner and the coordinates of 27.8145°N, 97.418°W at the northeast corner (Figure 1). The outfall window is near the Flint Hills dock and off the south bank of the Inner Harbor channel. The recommended diffuser design is a multiport diffuser consisting of a 50-foot-long diffuser pipe. The diffuser would be placed at a depth of approximately 32 feet on the south side of the navigation channel. The diffuser pipe would be aligned parallel to the channel while the diffuser ports would be directed towards the center of the channel.

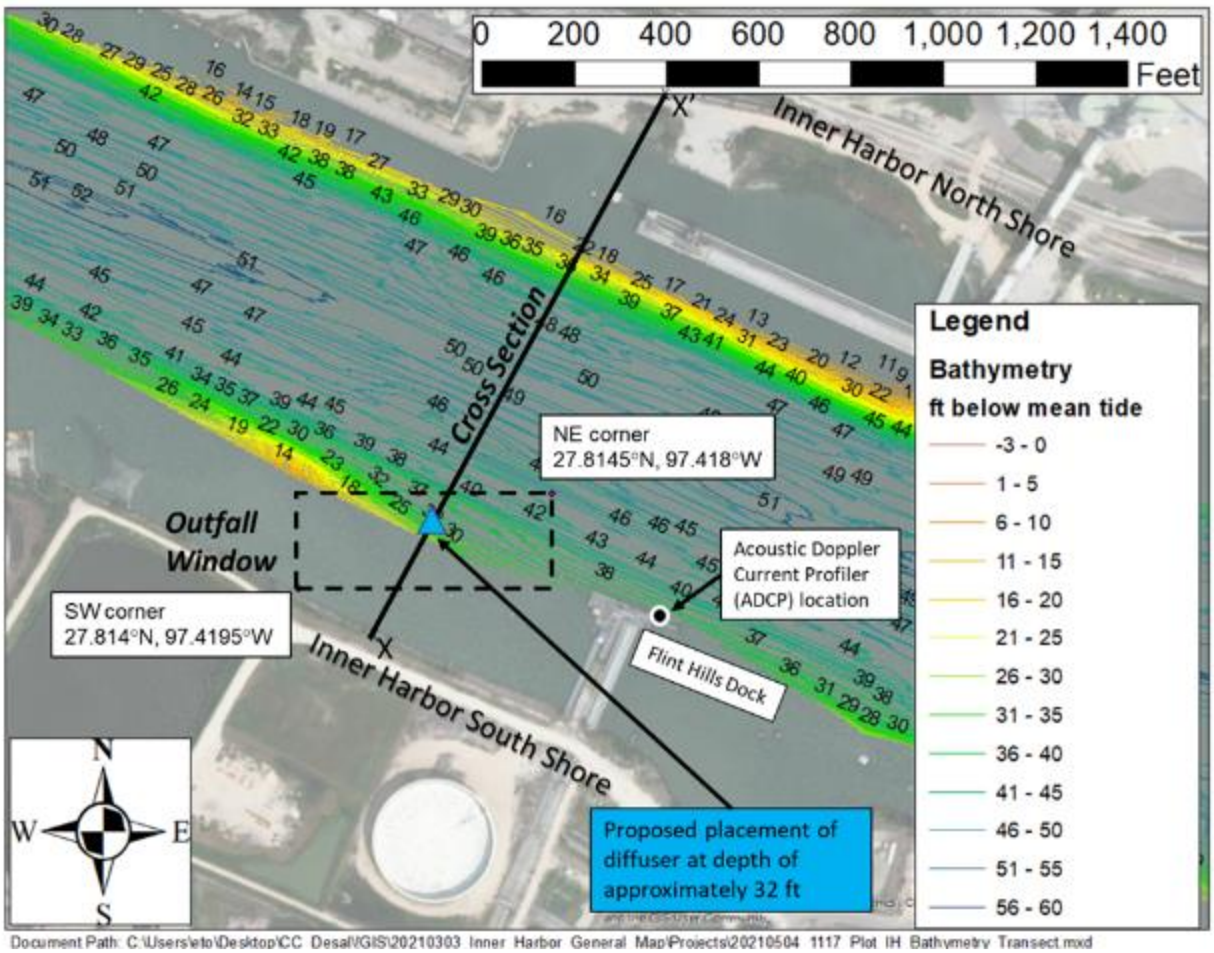



**Figure 1. Map of the Inner Harbor outfall location.**

Based on the bathymetry data collected in the Inner Harbor (see contour lines in Figure 1), a cross-sectional profile is plotted for the proposed outfall location (see Figure 2). The cross-sectional profile (see line X-X') runs from Inner Harbor south shore (located at x = 0 ft in Figure 2) to the north shore (at x ~1200 ft) and the side view of the profile is provided in Figure 2. To model this profile in CORMIX, the cross section is approximated as a rectangle 726 ft wide x 42 ft deep or (221 m wide x 13 m deep). These dimensions reflect the width and average depth of the portion where the elevation data are available. The proposed diffuser would be located on private property adjacent to the navigational channel about 32 ft below the water surface and 21 ft from the southern edge of the approximated rectangular cross-section.

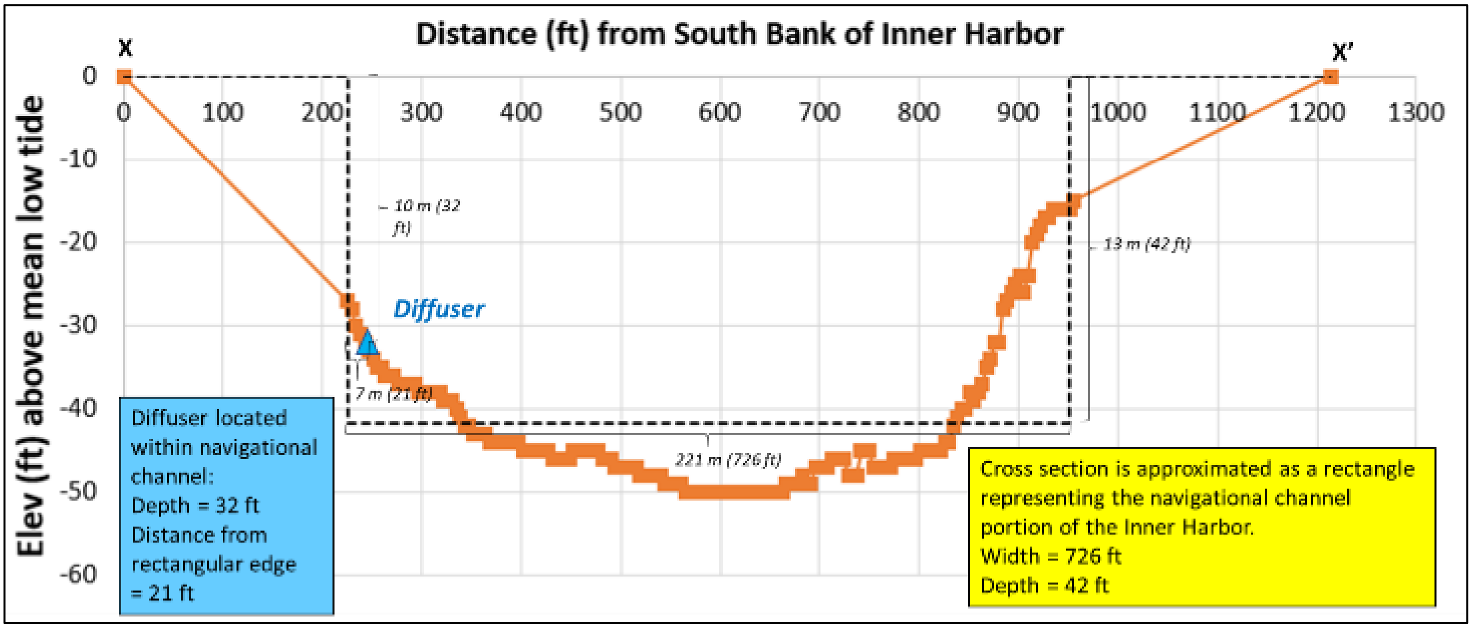



**Figure 2. Cross-sectional profile at proposed diffuser location.**

### 3.2 DIMENSIONS OF MIXING ZONES

Since the proposed diffuser will be a multiport diffuser, rectangular mixing zones for the ZID, MZ and Human Health Mixing Zone (HHMZ) were defined following SOP requirements. SOP require that the area of each rectangular mixing zone be equal or less than the area of the corresponding circular mixing zone for the ZID, MZ and HHMZ. According to the TCEQ Implementation Procedures (TCEQ, 2010) the regulatory mixing distances in wide tidal rivers for the ZID, MZ and HHMZ are 50 ft, 200 ft and 400 ft respectively.

The following rectangular dimensions were defined for the proposed outfall:

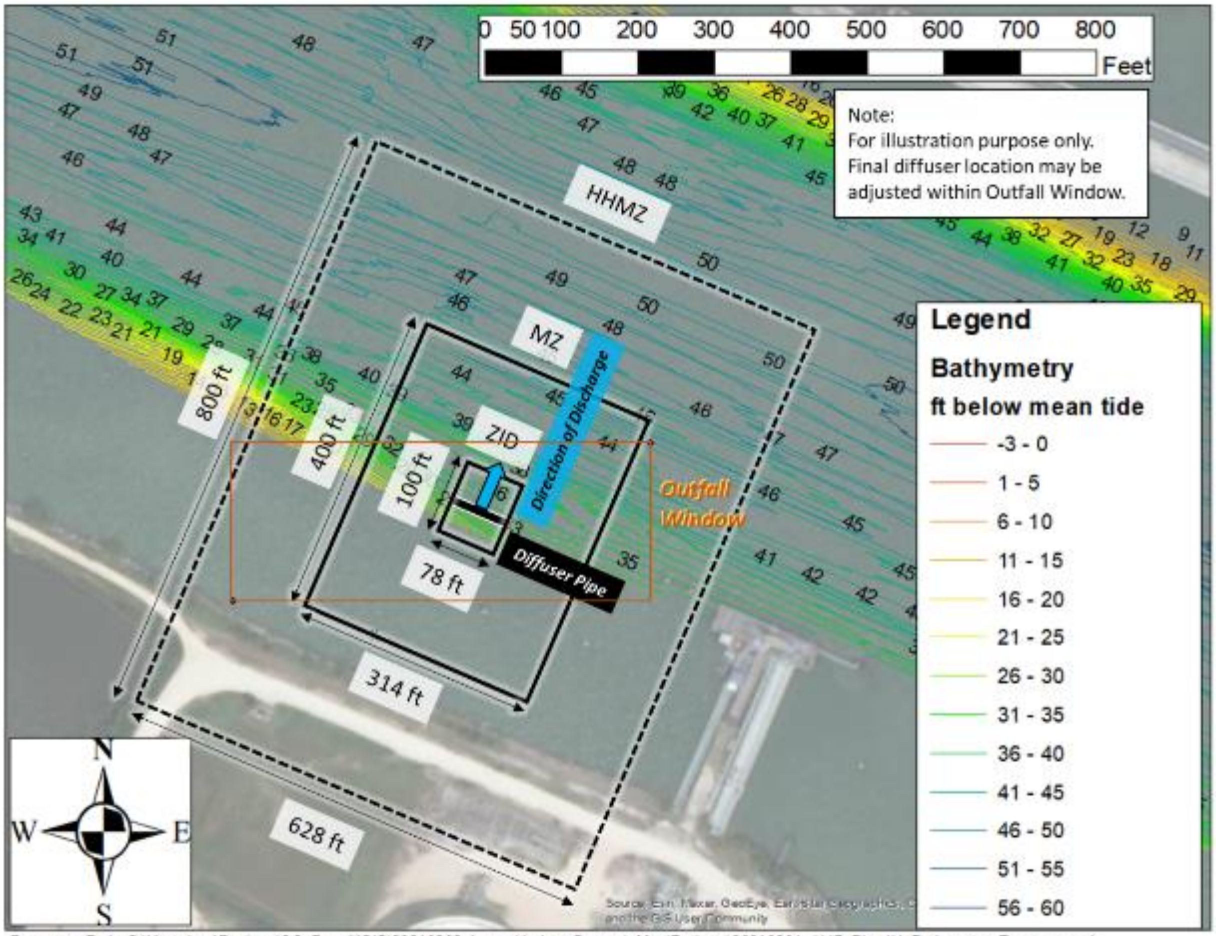
- ZID: 100 ft x 78 ft centered around the diffuser pipe with the short side parallel to the pipe and long side perpendicular to the pipe.
- MZ: 400 ft x 314 ft centered around the diffuser pipe with the short side parallel to the pipe and long side perpendicular to the pipe; and,
- HHMZ: 800 ft x 628 ft centered around the diffuser pipe with the short side parallel to the pipe and long side perpendicular to the pipe.

A comparison between the areas of the rectangular mixing zones and the corresponding circular mixing zones is provided in Table 3.

**Table 3. Comparison of areas of rectangular mixing zones and the corresponding circular mixing zones.**

| Regulatory Mixing Zone | Rectangular Dimensions | Rectangular Area | Corresponding circular mixing zone radius | Circular area |
|---|---|---|---|---|
| ZID | 100 ft x 78 ft | 7,800 sq. ft | 50 ft | 7,850 sq. ft |
| MZ | 400 ft x 314 ft | 125,600 sq. ft | 200 ft | 125,700 sq.ft |
| HHMZ | 800 ft x 628 ft | 502,400 sq. ft | 400 ft | 502,700 sq.ft |

An illustration of the rectangular mixing zones in the vicinity of the outfall is shown in Figure 3. Note that the diffuser location is approximate and may be adjusted within the outfall window based on on-the-ground conditions.




Document Path: C:\Users\eto\Desktop\CC Desal\GIS\20210303 Inner Harbor General Map\Projects\20210504 1117 Plot IH Bathymetry Transect.mxd

**Figure 3. Illustration of rectangular regulatory mixing zones for the proposed diffuser.**

# 4 DESCRIPTION OF PROPOSED DIFFUSER CONFIGURATION

The recommended diffuser design is a multiport diffuser consisting of a 50-foot-long diffuser pipe with four risers – each containing two 8-inch diameter ports (see Figure 4 for plan view of configuration). The diffuser pipe will be aligned parallel to the channel while the risers will be perpendicular to the channel. The two diffuser ports on each riser will be angled at 90 degrees from each other. The diffuser would be placed at a depth of approximately 32 feet on the south side of the navigation channel (see Figure 5 for side view of configuration). The diffuser ports would also be angled 60 degrees upwards above the horizon to enhance mixing with the water column.

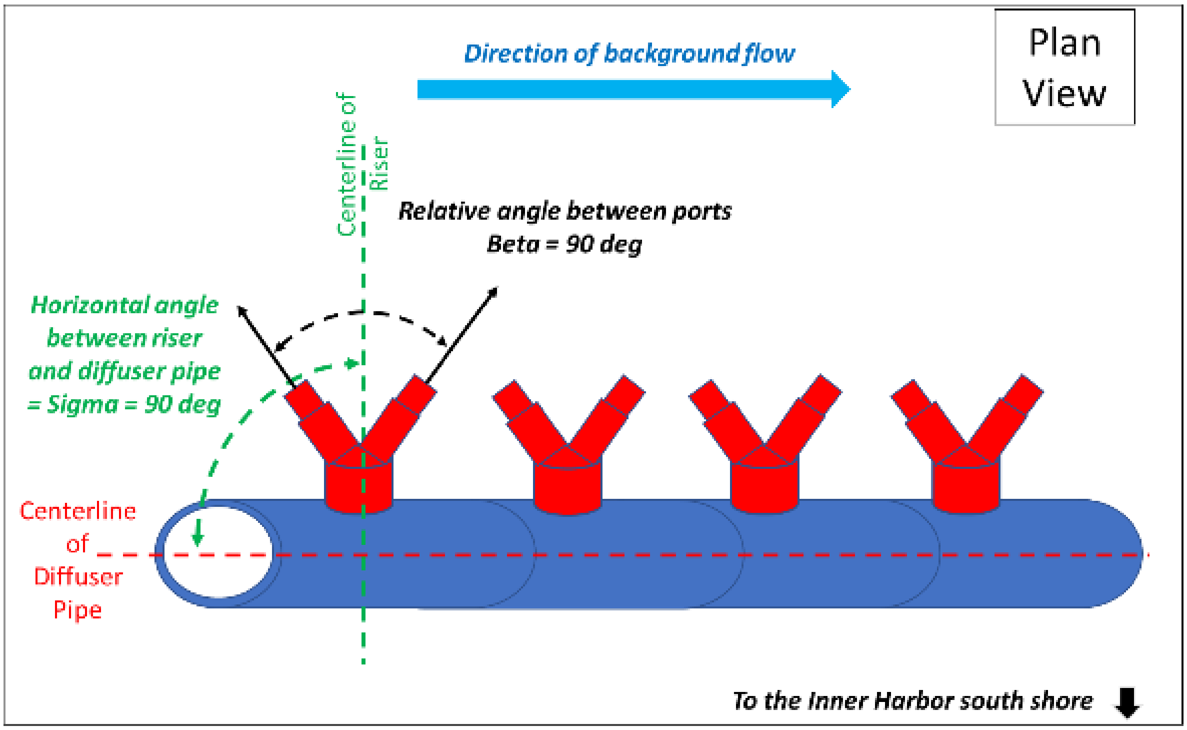



**Figure 4. Diffuser array configuration concept (plan view, not to scale).**

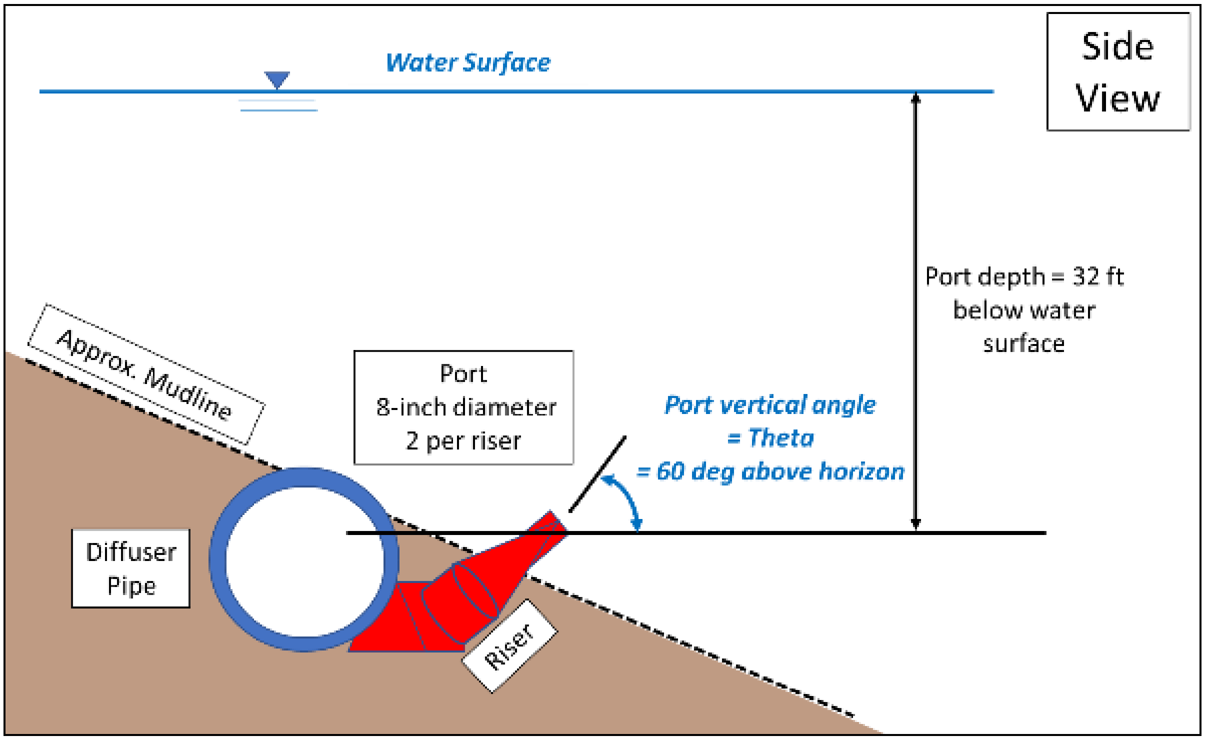



**Figure 5. Diffuser array configuration concept (side view, not to scale).**

Figure 6 provides a screenshot of the CORMIX Discharge which summarizes the dimensions and orientation of the proposed diffused configuration.

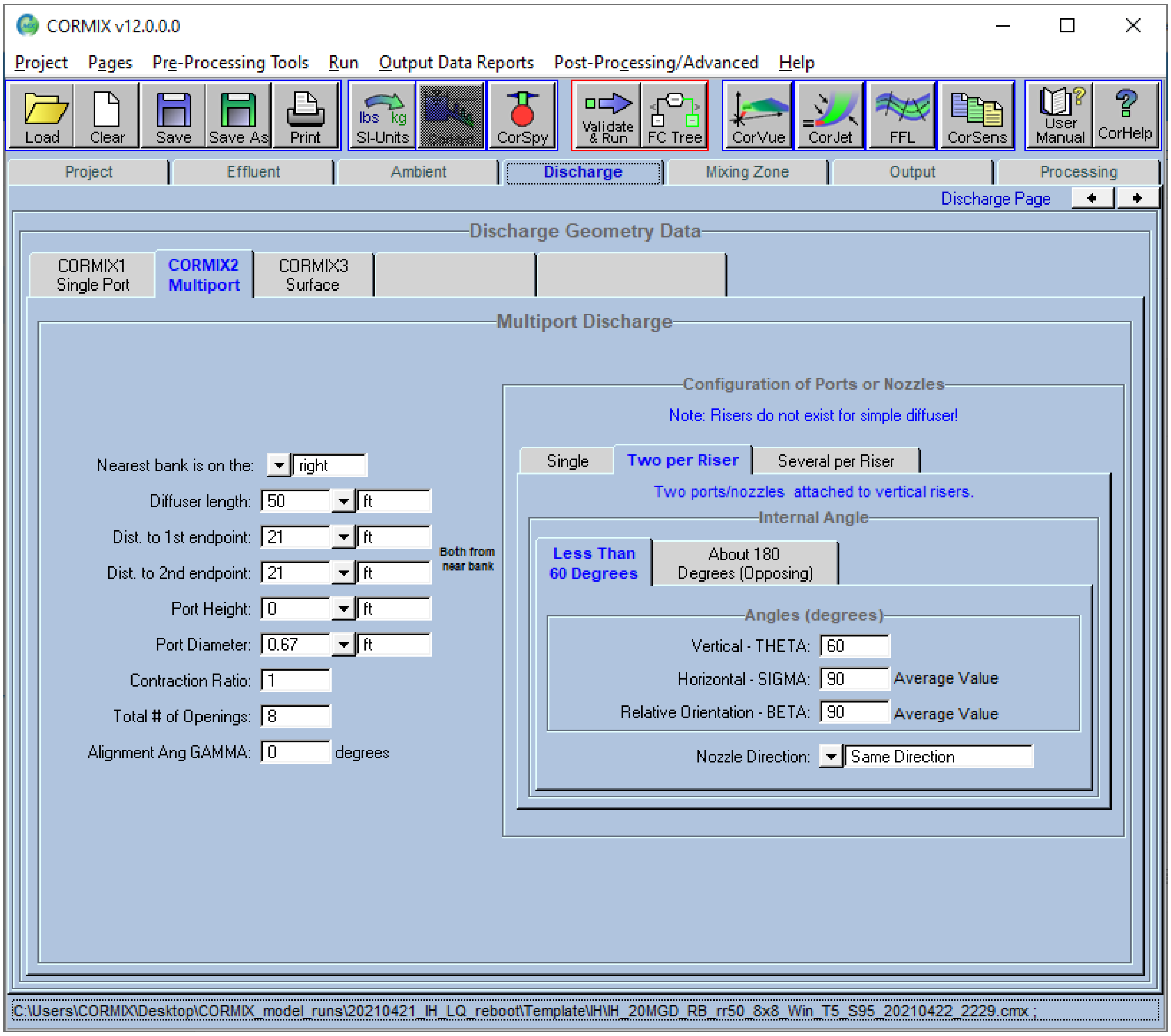



**Figure 6. Screenshot of CORMIX Discharge page showing dimensions and orientation of the proposed diffuser configuration.**

## 5 DESCRIPTION OF AMBIENT CONDITIONS

### 5.1 BACKGROUND FLOW

The background velocity at the Inner Harbor site was derived from the Acoustic Doppler Current Profiler (ADCP) data. The ADCP was deployed at the Flint Hills Dock for a seven-month period from February to September 2020 and collected data at 15-minute intervals. Because CORMIX is a steady-state model, it only accepts one value for background velocity. The background velocity of 0.0057 m/s for the Inner Harbor was calculated from the long-term net average of the ADCP velocities. For details of the calculation methodology please see Appendix A.

### 5.2 BRINE ACCUMULATION

Apart from being used as a CORMIX input, the long-term net average background velocity was also used to evaluate the potential for brine accumulation. Because the outfall is located in a tidal zone, background flows can reverse throughout the course of the day. Incoming tides during one part of the day will move the dispersed effluent into the Inner Harbor and during another part of the day, outgoing tides will move the dispersed effluent out of the Inner Harbor. The background velocity of 0.0057 m/s is the long-term average created by the incoming and outgoing tides.

The long-term net average background velocity averages over transient tidal effects, thereby accounting for the net background flow available to transport the dispersed effluent away from the outfall. A non-zero long-term net average background velocity (0.0057 m/s – in this case) would indicate net transport of the dispersed effluent away from the outfall, thereby preventing long-term brine accumulation.

### 5.3 AMBIENT DENSITY SCENARIOS

According to the SOP, the CORMIX evaluations must be performed on a range of scenarios that capture the ambient densities associated with the 5th and 95th percentile of water salinity and temperature. Per TCEQ staff guidance, eight standard density scenarios were defined as follows:

Summer: $\rho(T_5, S_5),\ \rho(T_5, S_{95}),\ \rho(T_{95}, S_5),\ \rho(T_{95}, S_{95})$

Winter: $\rho(T_5, S_5),\ \rho(T_5, S_{95}),\ \rho(T_{95}, S_5),\ \rho(T_{95}, S_{95})$

where the density ρ (kg/m³) is a function of temperature, T (℃) and salinity, S (ppt) as shown in Equation 1 (TCEQ, 2018):

$$\rho_{s,t,0} = [1 + \left(0.001\left((28.14 - 0.0735T - 0.00469T^2) + (0.802 - 0.002T)(S - 35)\right)\right)] \times 1000.$$

(Equation 1)

The subscripts 5 and 95 for the four standard density cases represent the 5th and 95th percentiles. The salinity and temperature data for the Inner Harbor channel are available at SWQM stations 13430, 13432 and 13439 from 1969 to 2020. Table 4 provides the 5th and 95th percentile temperature and salinity values for the summer months (April through September) and winter months (October through March). These statistics were calculated based on water column averages from the surface to the depth of discharge (32 ft or 10 m). Table 4 also contains the corresponding ambient densities calculated from Equation 1 for the eight standard density scenarios.

**Table 4 Ambient temperature and salinity conditions at Inner Harbor channel**

| Season | Density Scenario | Temperature Statistic | Ambient Temperature (℃) | Salinity Statistic | Ambient Salinity (ppt) | Ambient Density (kg/m³) |
|---|---|---|---|---|---|---|
| Summer | $\rho(T_5, S_5)$, | $T_5$ | 22.0 | $S_5$ | 22.6 | 1014.8 |
| | $\rho(T_{95}, S_5)$, | $T_{95}$ | 30.9 | $S_5$ | 22.6 | 1012.2 |
| | $\rho(T_5, S_{95})$, | $T_5$ | 22.0 | $S_{95}$ | 38.6 | 1026.9 |
| | $\rho(T_{95}, S_{95})$ | $T_{95}$ | 30.9 | $S_{95}$ | 38.6 | 1024.0 |
| Winter | $\rho(T_5, S_5)$, | $T_5$ | 12.2 | $S_5$ | 23.1 | 1017.3 |
| | $\rho(T_{95}, S_5)$, | $T_{95}$ | 26.5 | $S_5$ | 23.1 | 1014.0 |
| | $\rho(T_5, S_{95})$, | $T_5$ | 12.2 | $S_{95}$ | 39.1 | 1029.7 |
| | $\rho(T_{95}, S_{95})$ | $T_{95}$ | 26.5 | $S_{95}$ | 39.1 | 1026.0 |

### 5.4 STRATIFICATION

According to the SOP, if stratification is determined to be a routine characteristic of the receiving waters, another model scenario must be modeled to capture the impacts on mixing. Density stratification is defined when the density difference from surface to bottom is more than 0.1 kilograms per cubic meter (kg/m$^3$). Using temperature, salinity and conductivity depth profiles from SWQM stations within the Inner Harbor (13430, 13432 and 13439), the median density difference is 0.4 kg/m$^3$. Following the SOP, this density difference was used to develop stratification cases for the most critical two cases -Winter $\rho(T_5, S_{95})$ and Summer $\rho(T_5, S_{95})$ as shown in Table 5.

**Table 5 Stratification cases for the Inner Harbor channel**

| Season | Density Scenario | Ambient Density (kg/m3) | Surface Density (kg/m3)<br>*(Ambient density – 0.5*0.4 kg/m$^3$)* | Bottom Density (kg/m3)<br>*(Ambient density + 0.5* 0.4 kg/m$^3$)* |
|---|---|---|---|---|
| Summer | $\rho(T_5, S_{95})$ – stratification | 1026.9 | 1026.7 | 1027.1 |
| Winter | $\rho(T_5, S_{95})$ - stratification | 1029.7 | 1029.5 | 1029.9 |

## 6 DESCRIPTION OF EFFLUENT SCENARIOS

The model scenarios simulated 20 MGD and 30 MGD desalination plant production capacities operating at the minimum and maximum RO recovery rates of 40% and 50%. The effluent discharge associated with each of the four combinations of production capacity and recovery rate ("combination") is provided in Table 6.

**Table 6 Effluent discharges associated with proposed production capacities and recovery rates.**

| Production Capacity | Recovery Rate | Effluent Discharge |
|---|---|---|
| 20 MGD | 40% | 34.3 MGD |
| | 50% | 23.4 MGD |
| 30 MGD | 40% | 51.5 MGD |
| | 50% | 35.2 MGD |

It is expected that the salinity of the effluent discharge would increase with the RO recovery rate and the salinity of the source water. It is also expected that heat from the desalination process would raise the temperature of the effluent discharge slightly higher than the ambient water (by less than 1.5 $^o$F). Since the temperature and salinity of the effluent depend on those of the source water, the effluent density is expected to vary with the ambient density and therefore need to be calculated for each of the ten density scenarios. Table 7 and Table 8 provides the effluent densities for the ten density scenarios (eight unstratified + two stratified) under each of the two RO recovery rates (40% and 50%) and two production capacities. The tables provide densities for in a total of 40 scenarios evaluated for the proposed diffuser configuration.

**Table 7 Effluent Densities for Various Production Capacities and 40% RO Recovery Rate Scenarios.**

| | | | | Scenario | | Ambient | | | Effluent | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Production Capacity | Recovery Rate | Effluent Discharge | Season | Temp stat | Sal stat | T (°C) | S (ppt) | Density (kg/m3) | T (°C) | S (ppt) | Density (kg/m3) |
| 20 MGD/ 30 MGD | 40% | 34.3 MGD/ 51.5 MGD | Summer | T5 | S5 | 22.0 | 22.6 | 1014.8 | 22.8 | 35.6 | 1024.5 |
| | | | | T5 | S95 | 22.0 | 38.6 | 1026.9 | 22.8 | 60.9 | 1043.6 |
| | | | | T95 | S5 | 30.9 | 22.6 | 1012.2 | 31.8 | 35.6 | 1021.5 |
| | | | | T95 | S95 | 30.9 | 38.6 | 1024.0 | 31.8 | 60.9 | 1040.2 |
| | | | Summer Strat-ification | T5 | S95 | 22.0 | 38.6 | Top: 1026.7 Bottom: 1027.1 | 22.8 | 60.9 | 1043.6 |
| | | | Winter | T5 | S5 | 12.2 | 23.1 | 1017.3 | 13.0 | 36.5 | 1027.6 |
| | | | | T5 | S95 | 12.2 | 39.1 | 1029.7 | 13.0 | 61.8 | 1047.2 |
| | | | | T95 | S5 | 26.5 | 23.1 | 1014.0 | 27.4 | 36.5 | 1023.7 |
| | | | | T95 | S95 | 26.5 | 39.1 | 1026.0 | 27.4 | 61.8 | 1042.6 |
| | | | Winter Strat-ification | T5 | S95 | 12.2 | 39.1 | Top: 1029.5 Bottom: 1029.9 | 13.0 | 61.8 | 1047.2 |

**Table 8. Effluent Densities for Various Production Capacities and 50% RO Recovery Rate Scenarios.**

| | | | | Scenario | | Ambient | | | Effluent | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Production Capacity** | **Recovery Rate** | **Effluent Discharge** | **Season** | **Temp stat** | **Sal stat** | **T (°C)** | **S (ppt)** | **Density (kg/m3)** | **T (°C)** | **S (ppt)** | **Density (kg/m3)** |
| 20 MGD/ 30 MGD | 50% | 23.4 MGD/ 35.2 MGD | Summer | T5 | S5 | 22.0 | 22.6 | 1014.8 | 22.8 | 41.7 | 1029.1 |
| | | | | T5 | S95 | 22.0 | 38.6 | 1026.9 | 22.8 | 71.3 | 1051.4 |
| | | | | T95 | S5 | 30.9 | 22.6 | 1012.2 | 31.8 | 41.7 | 1026.0 |
| | | | | T95 | S95 | 30.9 | 38.6 | 1024.0 | 31.8 | 71.3 | 1047.8 |
| | | | Summer Strat-ification | T5 | S95 | 22.0 | 38.6 | Top: 1026.7 Bottom: 1027.1 | 22.8 | 71.3 | 1051.4 |
| | | | Winter | T5 | S5 | 12.2 | 23.1 | 1017.3 | 13.0 | 42.7 | 1032.4 |
| | | | | T5 | S95 | 12.2 | 39.1 | 1029.7 | 13.0 | 72.3 | 1055.3 |
| | | | | T95 | S5 | 26.5 | 23.1 | 1014.0 | 27.4 | 42.7 | 1028.4 |
| | | | | T95 | S95 | 26.5 | 39.1 | 1026.0 | 27.4 | 72.3 | 1050.5 |
| | | | Winter Strat-ification | T5 | S95 | 12.2 | 39.1 | Top: 1029.5 Bottom: 1029.9 | 13.0 | 72.3 | 1055.3 |

## 7 EVALUATION CRITERIA AND RESULTS

CORMIX was used to simulate the performance of the diffuser configuration by incorporating the information about outfall location, proposed diffuser configuration, background flow, and ambient and effluent density scenarios. CORMIX results from each of the 40 scenarios were evaluated based on three criteria:

1. Effluent percentages at the MZ and ZID;
2. CORMIX-assigned flow class; and,
3. Effluent velocities at the MZ and ZID.

Detailed descriptions of each criteria are provided in the following subsections.

### 7.1 EFFLUENT PERCENTAGES AT THE ZONE OF INITIAL DILUTION AND MIXING ZONE

Effluent percentages predicted by CORMIX at the edge of the ZID and the MZ mixing zones were compared with the critical dilutions proposed in the Corpus Christi Seawater Desalination Receiving Water Salinity Critical Dilutions White Paper (“White Paper”) (FNI, 2020). The White Paper states the critical dilutions (expressed as percentage effluent) that are protective of aquatic life as follows:

- For the reverse osmosis (RO) recovery rate of 40%, the critical dilution for the ZID is 56% and the critical dilution for the MZ is 18%.
- For the RO recovery rate of 50%, the critical dilution for the ZID is 38% and the critical dilution for the MZ is 13%.

### 7.1.1 Considering the Limiting Effluent Percentage

It is necessary to consider the Limiting Effluent Percentage (LE) when interpreting the numerical predictions of effluent percentages from CORMIX. The LE represents the lowest physically achievable effluent percentage after mixing within a system. Because the effluent is discharged into a channel, the ability to dilute with ambient water is constrained by background flow passing through the channel. LE is inversely related to the Limiting Dilution, which is a limit established by CORMIX. The limiting dilution is based on mass balance of the concentrate discharge flow and the background flow as shown in Equation 2:

$$Limiting\ Dilution = QA/Q0 + 1.0, \qquad \text{(Equation 2)}$$

where $QA$ is the background flow rate and $Q0$ is the effluent discharge flow rate.

If the predictions of effluent dilution (i.e., the inverse of the effluent percentage) exceed the limiting dilution, the CORMIX software would provide a note stating that those predictions that exceed would be unreliable. (see screenshot in Figure 7).

```
The LIMITING DILUTION (given by ambient flow/discharge ratio) is:    11.7
  This value is LESS than the predicted dilution of    20.1 at the end
  of the NFR.
  Mixing for this discharge configuration is constrained by the ambient flow.

The previous module predictions MAYBE UNRELIABLE since the limiting dilution
  cannot be exceeded for this unstable shallow discharge configuration.
CAREFULLY evalute the degree of near-field lateral boundary interaction.
```

**Figure 7. Screenshot of CORMIX warning about exceeding the Limiting Dilution (from simulation of 20 MGD x 40% RO Recovery Rate, summer (T5, S95) scenario).**

Since evaluations are based on effluent percentage, instead of dilutions, Effluent Percentage (LE) is therefore calculated from the limiting dilution by taking the inverse of Equation 2:

$$LE = Limiting\ Effluent\ Percentage$$

$$= \frac{1}{Limiting\ Dilution} x\ 100\%$$

$$= \frac{1}{\frac{QA}{Q0} + 1} x\ 100\%$$

$$= \frac{Q0}{QA + Q0} x\ 100\%$$

(Equation 3)

Because the LE constrains the effluent percentage value, consequently, in the interpretation of the CORMIX model results, any predicted effluent percentage value less than the LE was set to the value of the LE.

The LE is different for each combination because the effluent discharge, $Q0$, depends on production capacity and RO recovery rate. Table 9 summarizes the LE calculated for each combination.

The background flow, $QA$, is calculated based on the net average background velocity of 0.0057 m/s (see Appendix A) and the rectangular channel dimensions of 221 m wide x 13 m deep (see Section 3). Therefore QA = 0.0057 x 221 x 13 = 16.2 $m^3$/s (or 369 MGD).

**Table 9. Summary of limiting effluent percentages (LE) for proposed production rate/RO recovery rate combinations.**

| Production Rate | RO Recovery Rate | Effluent Discharge | Background Flow | Limiting Effluent Percentage |
|---|---|---|---|---|
| 20 MGD production | 40% | 34.3 MGD | 369 MGD | 8.5% |
| 30 MGD production | | 51.5 MGD | | 12.2% |
| 20 MGD production | 50% | 23.4 MGD | | 6.0% |
| 30 MGD production | | 35.2 MGD | | 8.7% |

### 7.1.2 Evaluation of Effluent Percentage Results

Graphs of the effluent percentages along the direction of discharge (i.e., the long side of the rectangular mixing zones – recall Figure 3) are provided in Figure 8 to Figure 11 for the four production rate/RO recovery rate combinations. Tables comparing the effluent percentages with the critical dilution at the ZID and the MZ are provided in

Table 10 to Table 13. It can be observed that within each combination, the effluent percentages predicted for the eight standard density scenarios were identical. The proposed diffuser configuration met the critical dilutions under all four combinations of production rate/RO recovery rate.

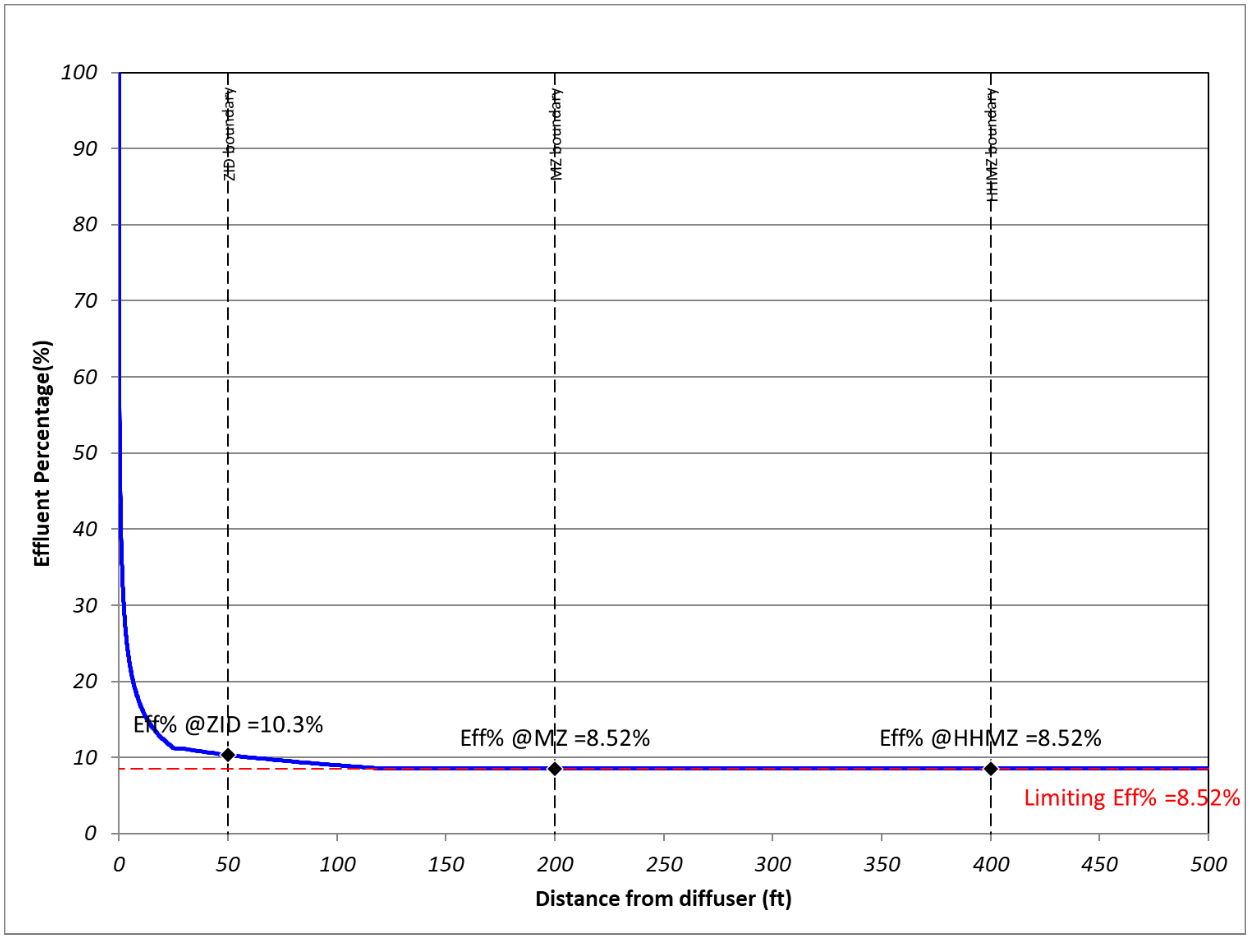



**Figure 8. Graph of effluent percentages predicted for 20 MGD x 40% RO Recovery Rate along direction of effluent discharge.**

**Table 10. Comparison of effluent percentages for 20 MGD x 40% RO Recovery Rate with critical dilutions.**

| | | | | ZID Results | | MZ Results | | HHMZ Results |
|---|---|---|---|---|---|---|---|---|
| Production Rate (MGD) | Recovery Rate | Effluent Discharge (MGD) | Density Scenario | Effluent Percentage (%) | Evaluation (<=56%?) | Effluent Percentage (%) | Evaluation (<=18%?) | Effluent Percentage (%) |
| 20 | 40% | 34.3 | Summer (T5, S5) | 10.3 | Yes | 8.5 | Yes | 8.5 |
| | | | Summer (T5, S95) | 10.3 | Yes | 8.5 | Yes | 8.5 |
| | | | Summer (T95, S5) | 10.3 | Yes | 8.5 | Yes | 8.5 |
| | | | Summer (T95, S95) | 10.3 | Yes | 8.5 | Yes | 8.5 |
| | | | Winter (T5, S5) | 10.3 | Yes | 8.5 | Yes | 8.5 |
| | | | Winter (T5, S95) | 10.3 | Yes | 8.5 | Yes | 8.5 |
| | | | Winter (T95, S5) | 10.3 | Yes | 8.5 | Yes | 8.5 |
| | | | Winter (T95, S95) | 10.3 | Yes | 8.5 | Yes | 8.5 |
| | | | Summer stratified (T5, S95) | 10.3 | Yes | 8.5 | Yes | 8.5 |
| | | | Winter stratified (T5, S95) | 10.3 | Yes | 8.5 | Yes | 8.5 |

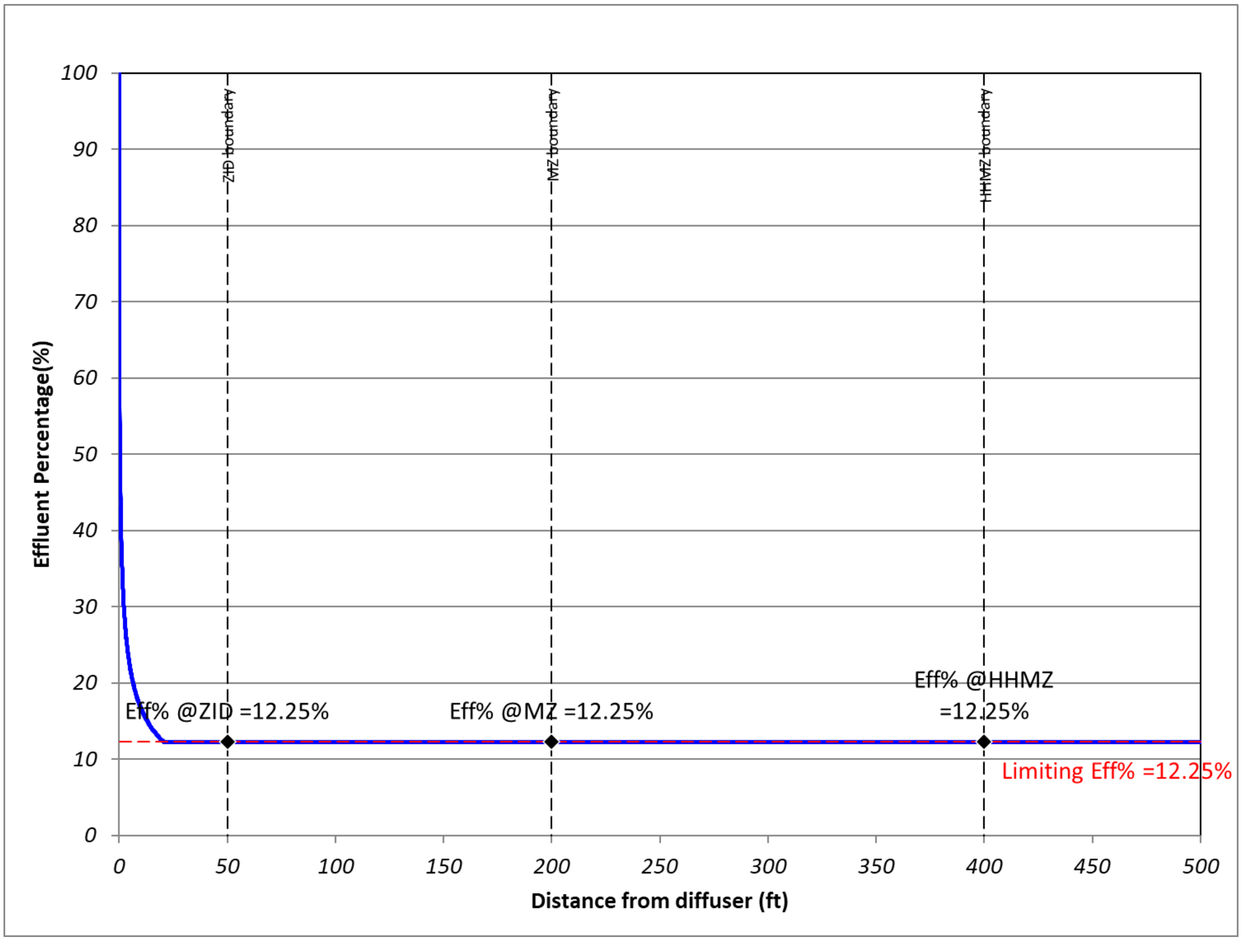



**Figure 9. Graph of effluent percentages predicted for 30 MGD x 40% RO Recovery Rate along direction of discharge.**

**Table 11. Comparison of effluent percentages for 20 MGD x 40% RO Recovery Rate with critical dilutions.**

| | | | | ZID Results | | MZ Results | | HHMZ Results |
|---|---|---|---|---|---|---|---|---|
| Production Rate (MGD) | Recovery Rate | Effluent Discharge (MGD) | Density Scenario | Effluent Percentage (%) | Evaluation (<=56%?) | Effluent Percentage (%) | Evaluation (<=18%?) | Effluent Percentage (%) |
| 30 | 40% | 51.5 | Summer (T5, S5) | 12.3 | Yes | 12.3 | Yes | 12.3 |
| | | | Summer (T5, S95) | 12.3 | Yes | 12.3 | Yes | 12.3 |
| | | | Summer (T95, S5) | 12.3 | Yes | 12.3 | Yes | 12.3 |
| | | | Summer (T95, S95) | 12.3 | Yes | 12.3 | Yes | 12.3 |
| | | | Winter (T5, S5) | 12.3 | Yes | 12.3 | Yes | 12.3 |
| | | | Winter (T5, S95) | 12.3 | Yes | 12.3 | Yes | 12.3 |
| | | | Winter (T95, S5) | 12.3 | Yes | 12.3 | Yes | 12.3 |
| | | | Winter (T95, S95) | 12.3 | Yes | 12.3 | Yes | 12.3 |
| | | | Summer stratified (T5, S95) | 12.3 | Yes | 12.3 | Yes | 12.3 |
| | | | Winter stratified (T5, S95) | 12.3 | Yes | 12.3 | Yes | 12.3 |

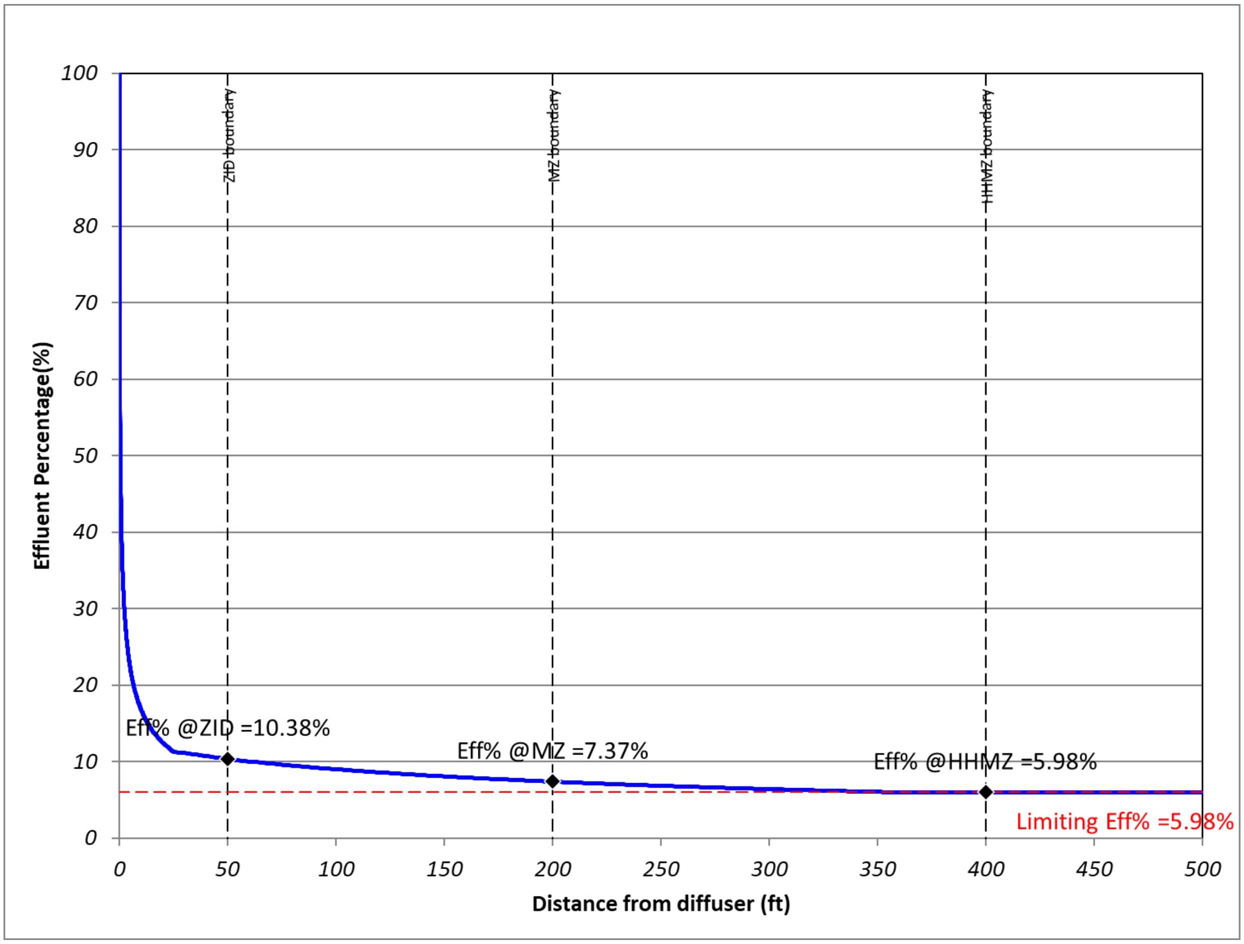



**Figure 10. Graph of effluent percentages predicted for 20 MGD x 50% RO Recovery Rate along direction of discharge.**

**Table 12. Comparison of effluent percentages for 20 MGD x 50% RO Recovery Rate with critical dilutions.**

| | | | | ZID Results | | MZ Results | | HHMZ Results |
|---|---|---|---|---|---|---|---|---|
| Production Rate (MGD) | Recovery Rate | Effluent Discharge (MGD) | Density Scenario | Effluent Percentage (%) | Evaluation (<=38%?) | Effluent Percentage (%) | Evaluation (<=13%?) | Effluent Percentage (%) |
| 20 | 50% | 23.4 | Summer (T5, S5) | 10.4 | Yes | 7.4 | Yes | 6.0 |
| | | | Summer (T5, S95) | 10.4 | Yes | 7.4 | Yes | 6.0 |
| | | | Summer (T95, S5) | 10.4 | Yes | 7.4 | Yes | 6.0 |
| | | | Summer (T95, S95) | 10.4 | Yes | 7.4 | Yes | 6.0 |
| | | | Winter (T5, S5) | 10.4 | Yes | 7.4 | Yes | 6.0 |
| | | | Winter (T5, S95) | 10.4 | Yes | 7.4 | Yes | 6.0 |
| | | | Winter (T95, S5) | 10.4 | Yes | 7.4 | Yes | 6.0 |
| | | | Winter (T95, S95) | 10.4 | Yes | 7.4 | Yes | 6.0 |
| | | | Summer stratified (T5, S95) | 10.4 | Yes | 7.4 | Yes | 6.0 |
| | | | Winter stratified (T5, S95) | 10.4 | Yes | 7.4 | Yes | 6.0 |

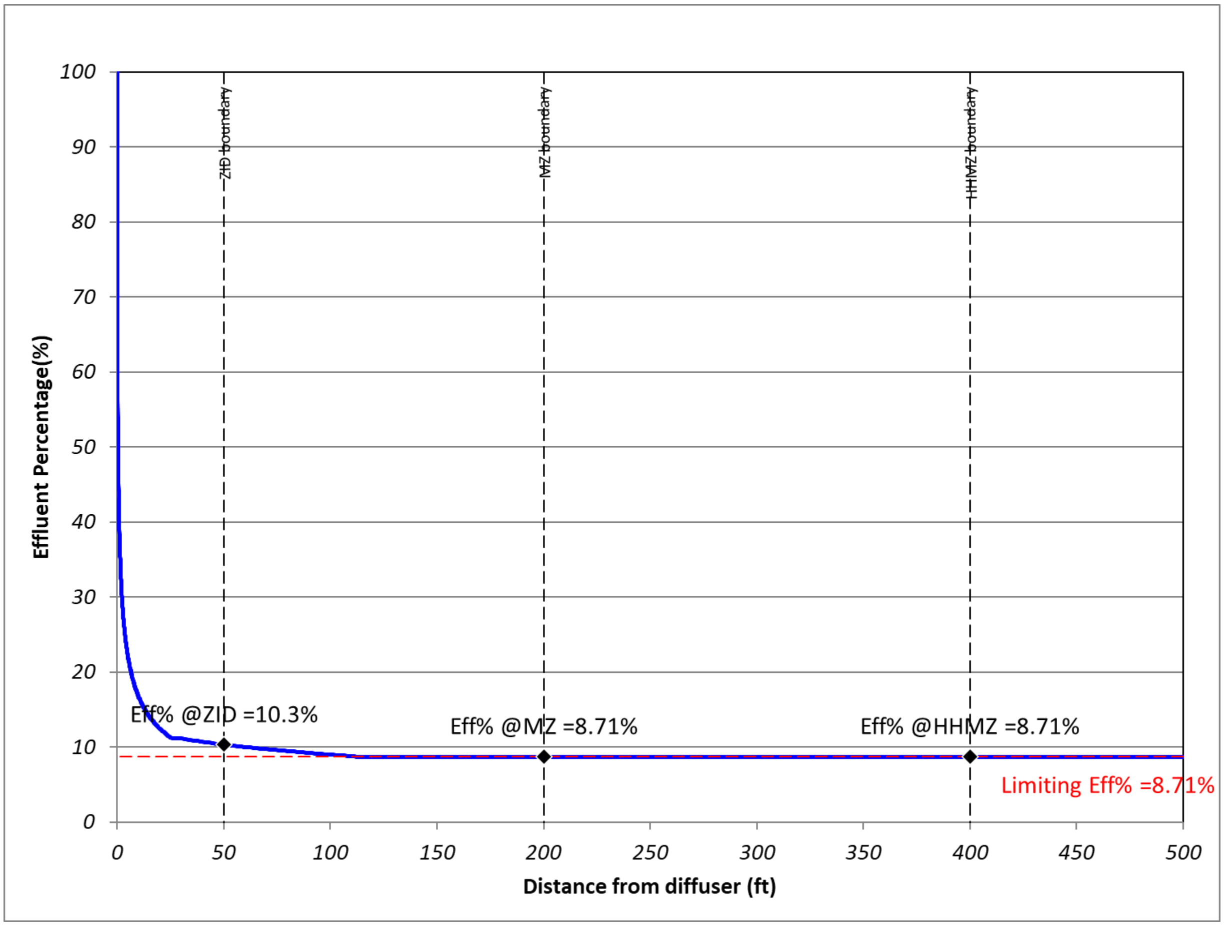



**Figure 11. Graph of effluent percentages predicted for 30 MGD x 50% RO Recovery Rate along direction of discharge.**

**Table 13. Comparison of effluent percentages for 30 MGD x 50% RO Recovery Rate with critical dilutions.**

| | | | | ZID Results | | MZ Results | | HHMZ Results |
|---|---|---|---|---|---|---|---|---|
| Production Rate (MGD) | Recovery Rate | Effluent Discharge (MGD) | Density Scenario | Effluent Percentage (%) | Evaluation (<=38%?) | Effluent Percentage (%) | Evaluation (<=13%?) | Effluent Percentage (%) |
| 30 | 50% | 35.2 | Summer (T5, S5) | 10.3 | Yes | 8.7 | Yes | 8.7 |
| | | | Summer (T5, S95) | 10.3 | Yes | 8.7 | Yes | 8.7 |
| | | | Summer (T95, S5) | 10.3 | Yes | 8.7 | Yes | 8.7 |
| | | | Summer (T95, S95) | 10.3 | Yes | 8.7 | Yes | 8.7 |
| | | | Winter (T5, S5) | 10.3 | Yes | 8.7 | Yes | 8.7 |
| | | | Winter (T5, S95) | 10.3 | Yes | 8.7 | Yes | 8.7 |
| | | | Winter (T95, S5) | 10.3 | Yes | 8.7 | Yes | 8.7 |
| | | | Winter (T95, S95) | 10.3 | Yes | 8.7 | Yes | 8.7 |
| | | | Summer stratified (T5, S95) | 10.3 | Yes | 8.7 | Yes | 8.7 |
| | | | Winter stratified (T5, S95) | 10.3 | Yes | 8.7 | Yes | 8.7 |

### 7.2 CORMIX-ASSIGNED FLOW CLASS

In addition to the effluent percentage, the performance of the diffuser in CORMIX was evaluated in terms of flow class. The CORMIX flow classification scheme categorizes the discharge/environment interaction into one of many flow classes with distinct hydrodynamic features and accounts for factors such as ambient conditions, effluent conditions and the diffuser design (Jirka, et.al., 1996). Once a flow class has been assigned, a specific modeling procedure unique to the flow class is utilized by CORMIX to simulate the interaction of the discharge with the receiving water.

In the process of identifying the proposed diffuser configuration, different port sizes, port numbers and other diffuser parameters were tested using CORMIX. It was observed that CORMIX assigned either one of two flow classes MNU8 or MNU3 to the resulting flow regime. These two classifications are explained in further detail below.

According to the CORMIX prediction file, MNU is a family of flow classes for “deeply submerged negatively buoyant multiport diffuser discharge” and MNU8 represents a situation where “the discharge strength (measured by its momentum flux) is very high in relation to the layer depth and in relation to the stabilizing effect of the discharge buoyancy (measured by its buoyancy flux)”. For the flow class of MNU8, the predicted effluent discharges upwards and engages the water column before falling to the bottom (Figure 12). This flow class represents a behavior desirable for a diffuser and is preferred for the purpose of diffuser design. MNU8 is usually assigned by CORMIX to diffuser configurations with smaller port diameters or smaller number of ports because they result in higher port velocities that provide more kinetic energy for mixing. MNU8 is also more common for density scenarios where ambient and effluent densities are more similar and it takes less energy to mix the two fluids.

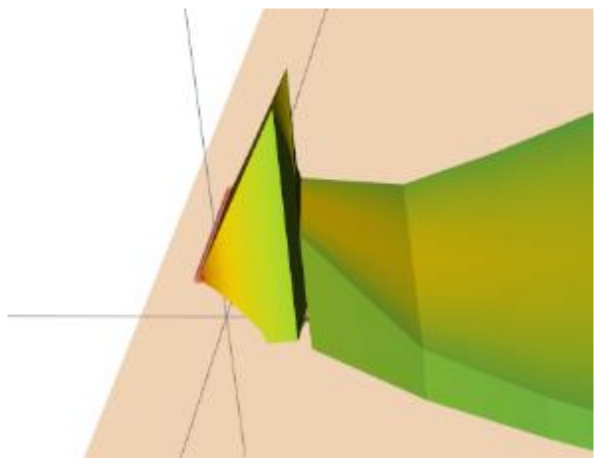


**Figure 12 CORMIX prediction in flow class MNU8.**

On the other hand, MNU3 represents a situation where “the discharge strength (measured by its momentum flux) is weak in relation to the layer depth and in relation to the stabilizing effect of the negative discharge buoyancy (measured by its buoyancy flux)”. The predicted effluent flows out onto the bottom with limited engagement with the water column (Figure 13). This flow class represents a less desirable behavior for a diffuser. MNU3 is usually assigned by CORMIX to diffuser configurations with larger port diameters or larger number of ports since they result in lower port velocities that provide less kinetic energy for mixing. MNU3 is also more common for density scenarios where the difference between ambient and effluent densities are larger and it takes more energy to mix the two.

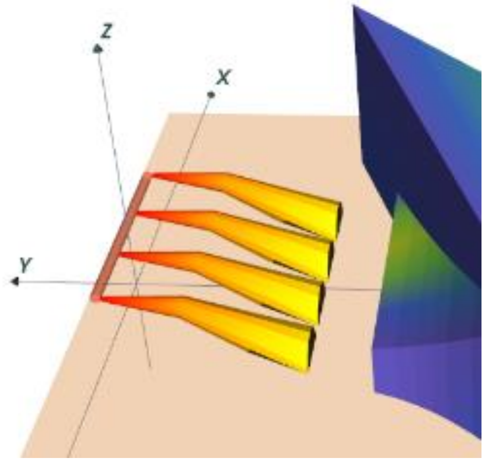



**Figure 13 CORMIX prediction in flow class MNU3.**

In this modeling study, the diffuser port has been tested with various sizes. The port diameter of 8 inches is deemed optimal that allows the diffuser to maintain high discharge velocities and sufficient dilution. The resulting flow class is MNU8 for all test scenarios. In contrast, increasing the port diameter to 10 inch reduces the discharge velocities and will result in a change in flow classification from MNU8 to MNU3 for most density scenarios at 20 MGD production and 50% recovery rate when the effluent discharge rate is the lowest. Table 14 and Table 15 provides comparison in CORMIX assigned flow class between the 8 x 8-inch port diameter (proposed configuration) and 8 x 10-inch diameter configurations.

**Table 14. Comparison of CORMIX flow classes between 8x8" and 8x10" diffuser configurations for 20 MGD production.**

| Production Rate (MGD) | Recovery Rate | Effluent Discharge (MGD) | Density Scenario | CORMIX Flow Class: 8x8" (proposed configuration) | CORMIX Flow Class: 8x10" (for comparison) |
|---|---|---|---|---|---|
| 20 | 40% | 34.3 | Summer (T5, S5) | MNU8 | MNU8 |
| | | | Summer (T5, S95) | MNU8 | MNU8 |
| | | | Summer (T95, S5) | MNU8 | MNU8 |
| | | | Summer (T95, S95) | MNU8 | MNU8 |
| | | | Winter (T5, S5) | MNU8 | MNU8 |
| | | | Winter (T5, S95) | MNU8 | MNU8 |
| | | | Winter (T95, S5) | MNU8 | MNU8 |
| | | | Winter (T95, S95) | MNU8 | MNU8 |
| 20 | 50% | 23.4 | Summer (T5, S5) | MNU8 | MNU8 |
| | | | Summer (T5, S95) | MNU8 | MNU3 |
| | | | Summer (T95, S5) | MNU8 | MNU8 |
| | | | Summer (T95, S95) | MNU8 | MNU3 |
| | | | Winter (T5, S5) | MNU8 | MNU8 |
| | | | Winter (T5, S95) | MNU8 | MNU3 |
| | | | Winter (T95, S5) | MNU8 | MNU8 |
| | | | Winter (T95, S95) | MNU8 | MNU3 |

**Table 15. Comparison of CORMIX flow classes between 8x8" and 8x10" diffuser configurations for 30 MGD production.**

| Production Rate (MGD) | Recovery Rate | Effluent Discharge (MGD) | Density Scenario | CORMIX Flow Class 8x8" (proposed configuration) | CORMIX Flow Class 8x10" (for comparison) |
|---|---|---|---|---|---|
| 30 | 40% | 51.5 | Summer (T5, S5) | MNU8 | MNU8 |
| | | | Summer (T5, S95) | MNU8 | MNU8 |
| | | | Summer (T95, S5) | MNU8 | MNU8 |
| | | | Summer (T95, S95) | MNU8 | MNU8 |
| | | | Winter (T5, S5) | MNU8 | MNU8 |
| | | | Winter (T5, S95) | MNU8 | MNU8 |
| | | | Winter (T95, S5) | MNU8 | MNU8 |
| | | | Winter (T95, S95) | MNU8 | MNU8 |
| 30 | 50% | 35.2 | Summer (T5, S5) | MNU8 | MNU8 |
| | | | Summer (T5, S95) | MNU8 | MNU8 |
| | | | Summer (T95, S5) | MNU8 | MNU8 |
| | | | Summer (T95, S95) | MNU8 | MNU8 |
| | | | Winter (T5, S5) | MNU8 | MNU8 |
| | | | Winter (T5, S95) | MNU8 | MNU8 |
| | | | Winter (T95, S5) | MNU8 | MNU8 |
| | | | Winter (T95, S95) | MNU8 | MNU8 |

### 7.3 EFFLUENT VELOCITIES AT THE MZ AND ZID

The jet velocities of the diffuser have also been evaluated at the edges of ZID and MZ, as high velocities can cause concerns regarding the aquatic life protection in the mixing zones.

The jet velocities were calculated using the CORMIX-predicted travel times and distances along the plume centerline. The centerline velocities ($v_{centerline}$) can be estimated by dividing the incremental increase in cumulative travel distance ($\Delta Distance$) by the incremental increase in cumulative travel time ($\Delta Travel\ Time$). The $Distance$ value is calculated using the Pythagoras equation on the X, Y, Z distances between the plume centerline and the diffuser location along the axes (see Figure 8) (Equation 5).

$$v_{centerline} = \Delta Distance/\Delta Travel\ Time, \qquad \text{(Equation 4)}$$

$$Distance = \left(\sqrt{X^2 + Y^2 + Z^2}\right) \quad . \qquad \text{(Equation 5)}$$

Graphs of the effluent velocities along the direction of discharge (i.e., the long side of the rectangular mixing zones – recall Figure 3) are provided in Figure 14 to Figure 17 for the four production rate/RO recovery rate combinations. Tables comparing the effluent velocities with the critical dilution at the ZID and the MZ are provided in Table 16 to Table 19. It was noted that, within each combination, the effluent velocities predicted for the eight standard density scenarios are essentially identical. The proposed diffuser configuration met the velocity limits under all four production rate/RO recovery rate combinations.

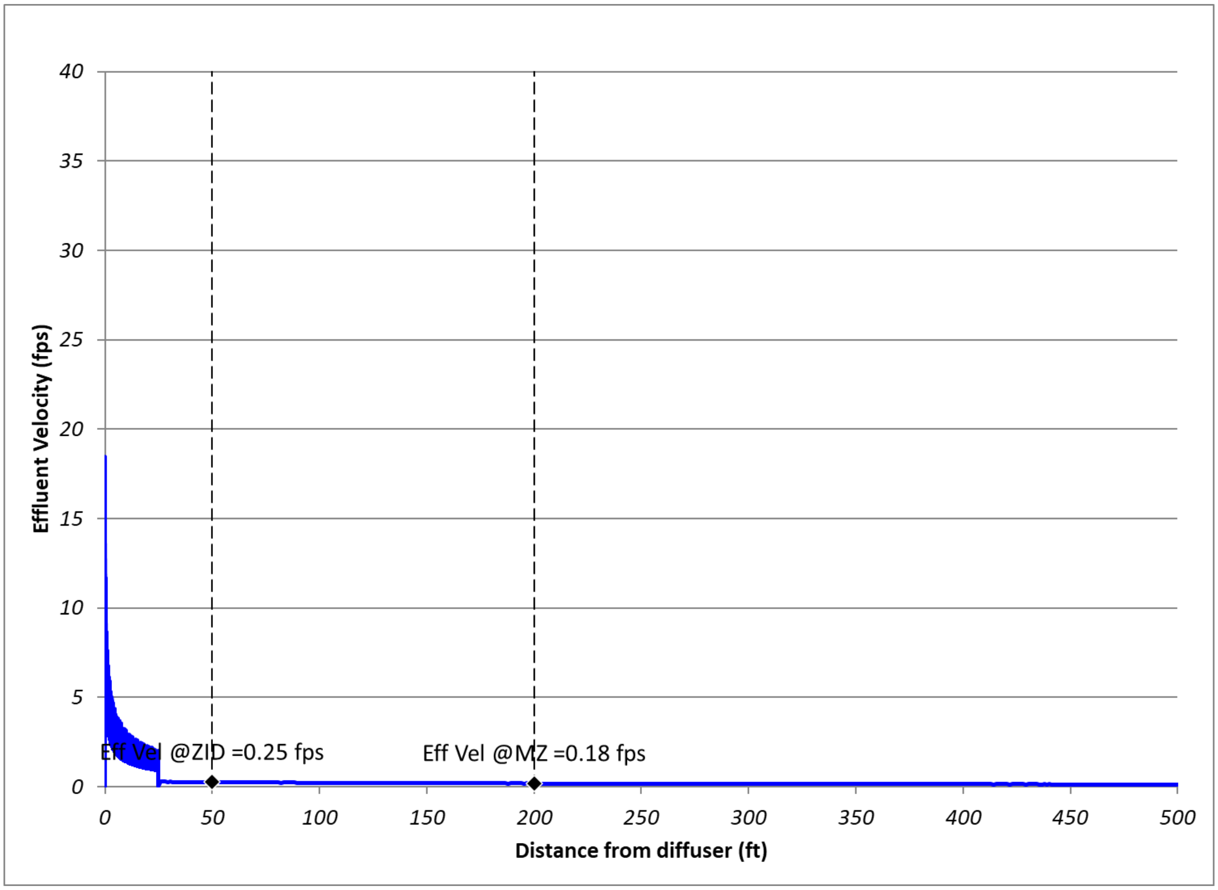



**Figure 14. Graph of effluent velocities predicted for 20 MGD x 40% RO Recovery Rate along direction of effluent discharge.**

**Table 16. Comparison of effluent velocities for 20 MGD x 40% RO Recovery Rate with velocity limits.**

| | | | | ZID Results | | MZ results | |
|---|---|---|---|---|---|---|---|
| **Production Rate (MGD)** | **Recovery Rate** | **Effluent Discharge (MGD)** | **Density Scenario** | **Effluent Velocity (fps)** | **Evaluation (<=2 fps?)** | **Effluent Velocity (fps)** | **Evaluation (<=0.5 fps?)** |
| 20 | 40% | 34.3 | Summer (T5, S5) | 0.3 | Yes | 0.2 | Yes |
| | | | Summer (T5, S95) | 0.3 | Yes | 0.2 | Yes |
| | | | Summer (T95, S5) | 0.3 | Yes | 0.2 | Yes |
| | | | Summer (T95, S95) | 0.3 | Yes | 0.2 | Yes |
| | | | Winter (T5, S5) | 0.3 | Yes | 0.2 | Yes |
| | | | Winter (T5, S95) | 0.3 | Yes | 0.2 | Yes |
| | | | Winter (T95, S5) | 0.3 | Yes | 0.2 | Yes |
| | | | Winter (T95, S95) | 0.3 | Yes | 0.2 | Yes |
| | | | Summer Stratified (T5, S95) | 0.3 | Yes | 0.2 | Yes |
| | | | Winter Stratified (T5, S95) | 0.3 | Yes | 0.2 | Yes |

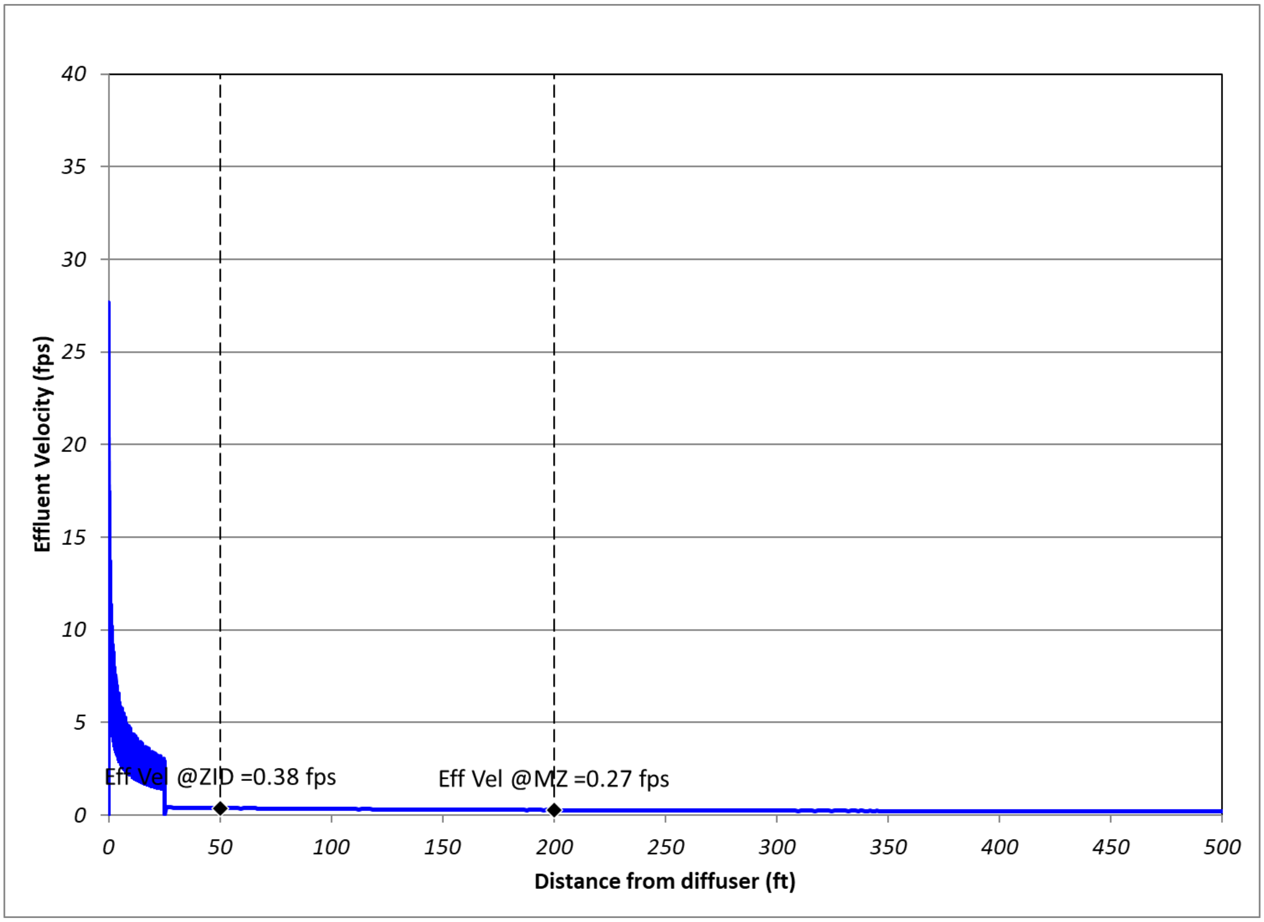



**Figure 15. Graph of effluent velocities predicted for 30 MGD x 40% RO Recovery Rate (all density scenarios).**

**Table 17. Comparison of effluent velocities for 30 MGD x 40% RO Recovery Rate with velocity limits.**

| | | | | ZID Results | | MZ results | |
|---|---|---|---|---|---|---|---|
| **Production Rate (MGD)** | **Recovery Rate** | **Effluent Discharge (MGD)** | **Density Scenario** | **Effluent Velocity (fps)** | **Evaluation (<=2 fps?)** | **Effluent Velocity (fps)** | **Evaluation (<=0.5 fps?)** |
| 30 | 40% | 51.5 | Summer (T5, S5) | 0.4 | Yes | 0.3 | Yes |
| | | | Summer (T5, S95) | 0.4 | Yes | 0.3 | Yes |
| | | | Summer (T95, S5) | 0.4 | Yes | 0.3 | Yes |
| | | | Summer (T95, S95) | 0.4 | Yes | 0.3 | Yes |
| | | | Winter (T5, S5) | 0.4 | Yes | 0.3 | Yes |
| | | | Winter (T5, S95) | 0.4 | Yes | 0.3 | Yes |
| | | | Winter (T95, S5) | 0.4 | Yes | 0.3 | Yes |
| | | | Winter (T95, S95) | 0.4 | Yes | 0.3 | Yes |
| | | | Summer Stratified (T5, S95) | 0.4 | Yes | 0.3 | Yes |
| | | | Winter Stratified (T5, S95) | 0.4 | Yes | 0.3 | Yes |

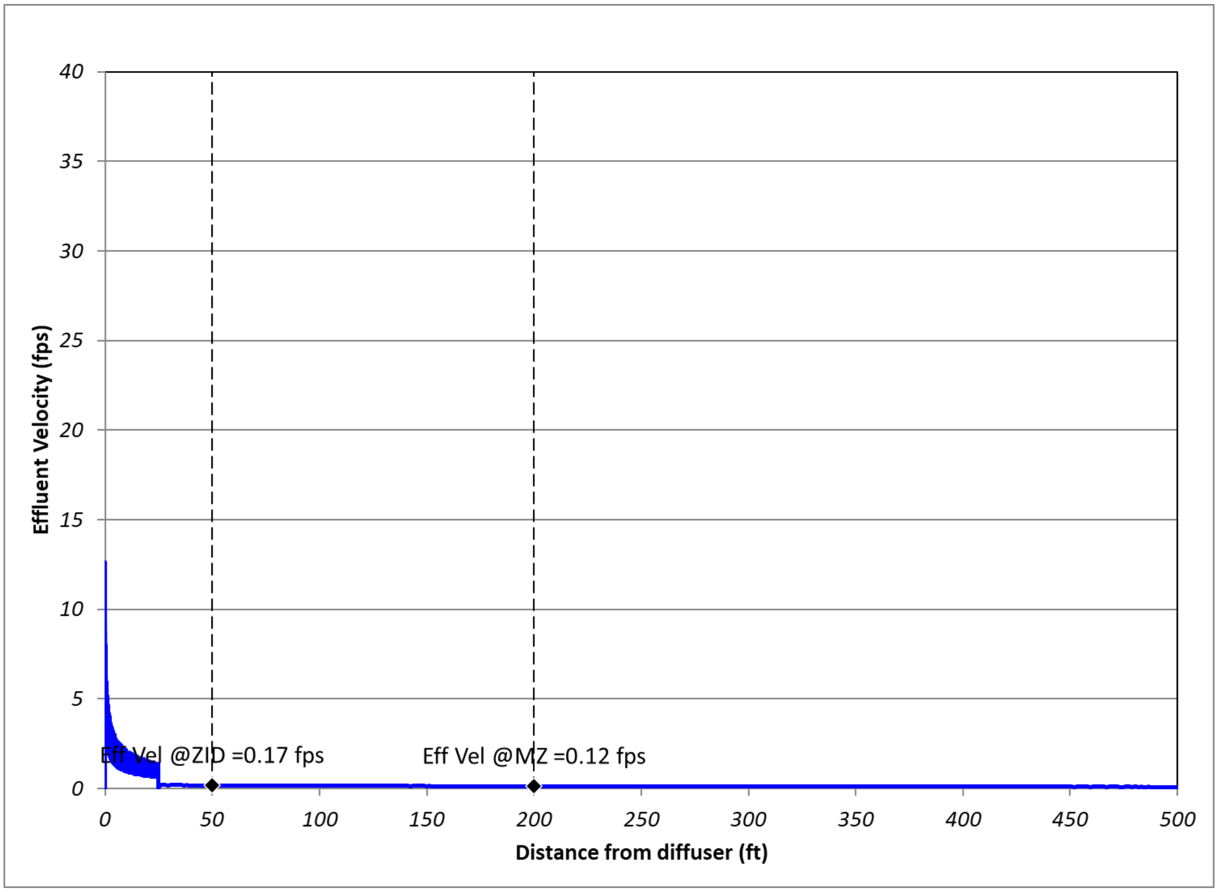



**Figure 16. Graph of effluent velocities predicted for 20 MGD x 50% RO Recovery Rate (all density scenarios).**

**Table 18. Comparison of effluent velocities for 20 MGD x 50% RO Recovery Rate with velocity limits.**

| Production Rate (MGD) | Recovery Rate | Effluent Discharge (MGD) | Density Scenario | ZID Results | | MZ results | |
|---|---|---|---|---|---|---|---|
| | | | | Effluent Velocity (fps) | Evaluation (<=2 fps?) | Effluent Velocity (fps) | Evaluation (<=0.5 fps?) |
| 20 | 50% | 23.4 | Summer (T5, S5) | 0.2 | Yes | 0.1 | Yes |
| | | | Summer (T5, S95) | 0.2 | Yes | 0.1 | Yes |
| | | | Summer (T95, S5) | 0.2 | Yes | 0.1 | Yes |
| | | | Summer (T95, S95) | 0.2 | Yes | 0.1 | Yes |
| | | | Winter (T5, S5) | 0.2 | Yes | 0.1 | Yes |
| | | | Winter (T5, S95) | 0.2 | Yes | 0.1 | Yes |
| | | | Winter (T95, S5) | 0.2 | Yes | 0.1 | Yes |
| | | | Winter (T95, S95) | 0.2 | Yes | 0.1 | Yes |
| | | | Summer Stratified (T5, S95) | 0.2 | Yes | 0.1 | Yes |
| | | | Winter Stratified (T5, S95) | 0.2 | Yes | 0.1 | Yes |

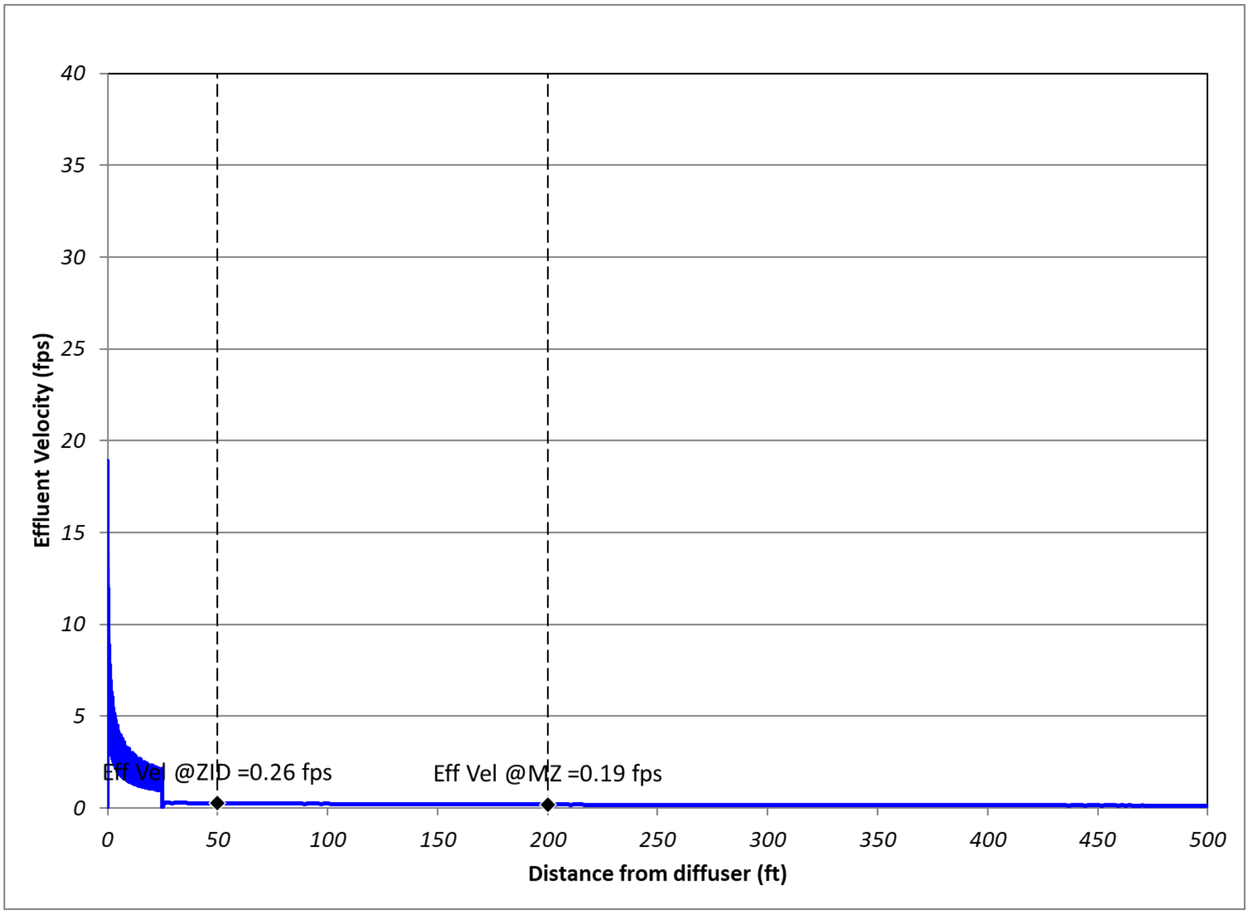



**Figure 17. Graph of effluent velocities predicted for 30 MGD x 50% RO Recovery Rate (all density scenarios).**

**Table 19. Comparison of effluent velocities for 30 MGD x 50% RO Recovery Rate with velocity limits.**

| | | | | ZID Results | | MZ results | |
|---|---|---|---|---|---|---|---|
| **Production Rate (MGD)** | **Recovery Rate** | **Effluent Discharge (MGD)** | **Density Scenario** | **Effluent Velocity (fps)** | **Evaluation (<=2 fps?)** | **Effluent Velocity (fps)** | **Evaluation (<=0.5 fps?)** |
| 30 | 50% | 35.2 | Summer (T5, S5) | 0.3 | Yes | 0.2 | Yes |
| | | | Summer (T5, S95) | 0.3 | Yes | 0.2 | Yes |
| | | | Summer (T95, S5) | 0.3 | Yes | 0.2 | Yes |
| | | | Summer (T95, S95) | 0.3 | Yes | 0.2 | Yes |
| | | | Winter (T5, S5) | 0.3 | Yes | 0.2 | Yes |
| | | | Winter (T5, S95) | 0.3 | Yes | 0.2 | Yes |
| | | | Winter (T95, S5) | 0.3 | Yes | 0.2 | Yes |
| | | | Winter (T95, S95) | 0.3 | Yes | 0.2 | Yes |
| | | | Summer Stratified (T5, S95) | 0.3 | Yes | 0.2 | Yes |
| | | | Winter Stratified (T5, S95) | 0.3 | Yes | 0.2 | Yes |

## 7.4 CONCLUSIONS ON CORMIX RESULTS

CORMIX was used to evaluate the proposed diffuser configuration for 40 scenarios – which encompass 2 proposed production capacities x 2 recovery rates x 10 density scenarios (8 uniform + 2 stratified). Results from each of the 40 scenarios were evaluated based on three criteria:

1. Effluent percentages at the MZ and ZID;
2. CORMIX-assigned flow class; and,
3. Effluent velocities at the MZ and ZID.

Results showed the proposed diffuser configuration met all three criteria and is a feasible design for the Inner Harbor desalination plant outfall.

## 8 INTERACTION WITH NEIGHBORING DISCHARGER

It is noted that another discharger (Permit #WQ0000457000) is located within 400 ft of the proposed diffuser location (see Figure 18). Typically, in such a situation, the areas of the regulatory mixing zones would need to be truncated to avoid interaction between the two plumes. However, in a conversation with TCEQ staff on March, 2021, TCEQ noted that it is common practice for the TCEQ to consider buoyancy of the two effluents and evaluate whether there would be vertical overlap between the two plumes. If it can be demonstrated that there would be no meaningful overlap between the plumes from the two outfalls then the mixing zones would not need to be adjusted. This section provides this evaluation between the proposed discharge and the neighboring discharging.

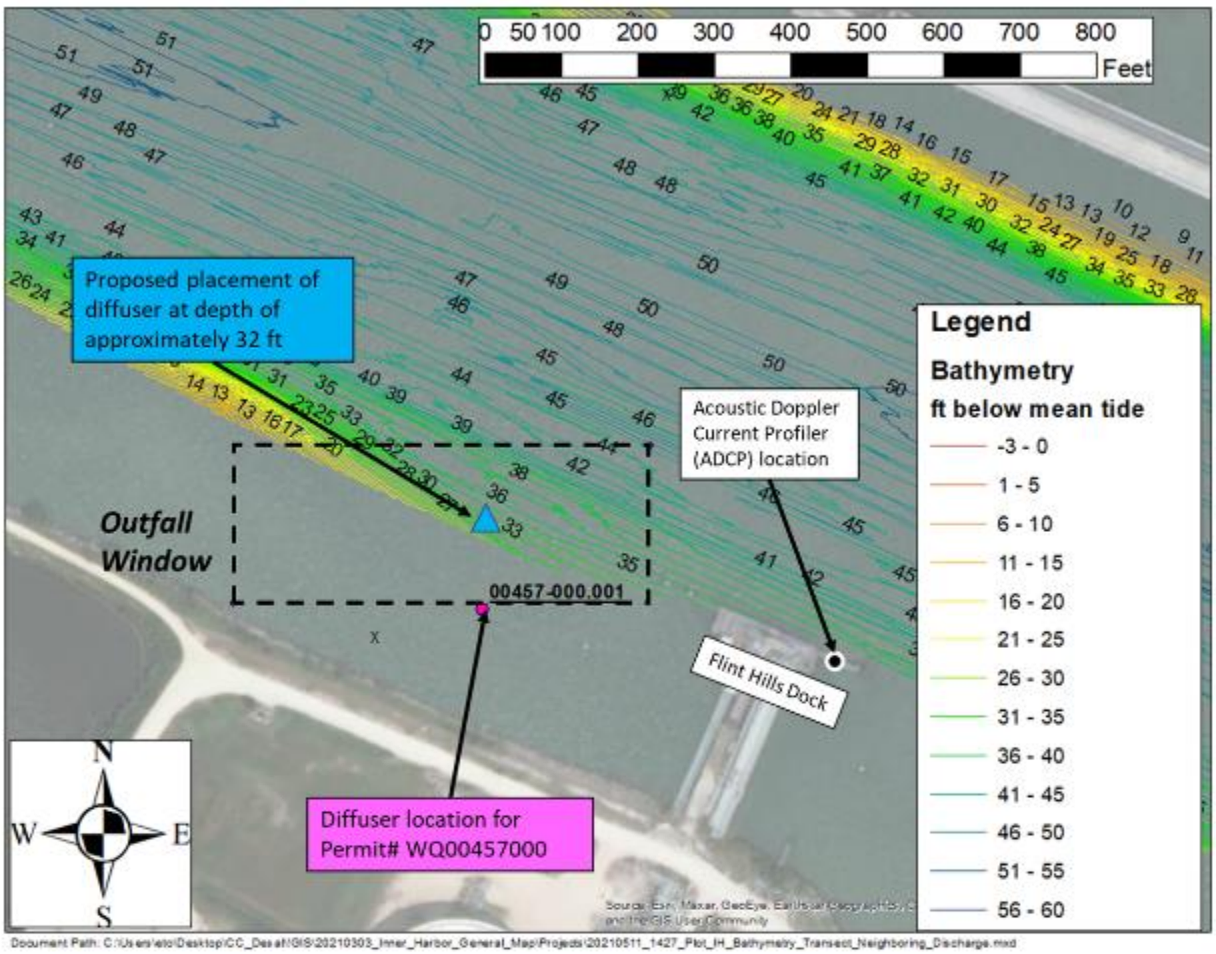



Figure 18. Location of neighboring diffuser in vicinity of proposed outfall.

Based on the CORMIX modeling report for the neighboring discharge (JMA, 2016), a diffuser is used and was modeled in accordance with the SOP. The neighboring diffuser is discharging at a relatively shallow depth (2.5 m – see Figure 19) compared to the proposed diffuser (10 m or 32 ft) (recall Section 3). The standard density scenarios for the neighboring diffuser show that the neighboring effluent density is always less than the ambient density, which results in a positively buoyant plume. On the other hand, the standard density scenarios for the proposed diffuser (recall Table 7 and Table 8) show that the effluent density is always higher than the ambient density, which results in a negatively buoyant plume.

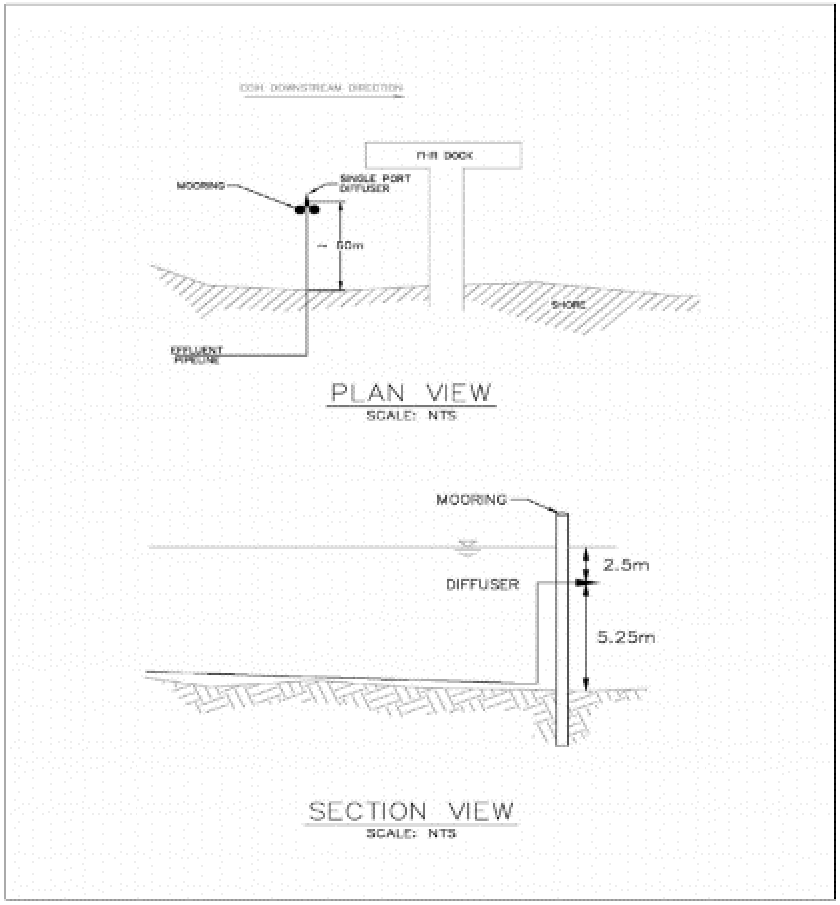



**Figure 19. Diffuser layout (Conceptual) for Permit #WQ0000457000) (JMA, 2016)**

**Table 20. CORMIX standard density scenarios for neighboring diffuser (JMA, 2016)**

| SEASON | CASE | AMBIENT TEMPERATURE PERCENTILE | AMBIENT SALINITY PERCENTILE | AMBIENT TEMPERATURE (C) | AMBIENT SALINITY (ppt) | AMBIENT DENSITY (kg/m3) | AMBIENT VELOCITY (m/s) | EFFLUENT FLOW (MGD) | EFFLUENT TEMPERATURE (C) | EFFLUENT SALINITY (ppt) | EFFLUENT DENSITY (kg/m3) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Winter | Avg Vel, High Density | 5 | 95 | 11.6 | 35.3 | 1026.89 | 0.1 | 2.16 | 24.1 | 5.5 | 1001.41 |
| | Avg Vel, Low Density | 95 | 5 | 19.6 | 23.4 | 1016.05 | 0.1 | 2.16 | 24.1 | 5.5 | 1001.41 |
| Summer | Avg Vel, High Density | 5 | 95 | 27.8 | 40.1 | 1026.28 | 0.1 | 2.16 | 32.9 | 5.5 | 998.93 |
| | Avg Vel, Low Density | 95 | 5 | 30.7 | 24.0 | 1013.32 | 0.1 | 2.16 | 32.9 | 5.5 | 998.93 |
| Winter | Avg Vel, Low Den, Historic Flow | 95 | 5 | 19.6 | 23.4 | 1016.05 | 0.1 | 1.09 | 24.1 | 5.5 | 1001.41 |
| Summer | Avg Vel,Low Den, Historic Flow | 95 | 5 | 30.7 | 24.0 | 1013.32 | 0.1 | 1.09 | 32.9 | 5.5 | 998.93 |
| | | | | | | | | | | | |
| Winter | Low Vel, High Density | 5 | 95 | 11.6 | 35.3 | 1026.89 | 0.03 | 2.16 | 24.1 | 5.5 | 1001.41 |
| | Low Vel, Low Density | 95 | 5 | 19.6 | 23.4 | 1016.05 | 0.03 | 2.16 | 24.1 | 5.5 | 1001.41 |
| Summer | Low Vel, High Density | 5 | 95 | 27.8 | 40.1 | 1026.28 | 0.03 | 2.16 | 32.9 | 5.5 | 998.93 |
| | Low Vel, Low Density | 95 | 5 | 30.7 | 24.0 | 1013.32 | 0.03 | 2.16 | 32.9 | 5.5 | 998.93 |
| Winter | Low Vel, High Den, Historic Flow | 5 | 95 | 11.6 | 35.3 | 1026.89 | 0.03 | 1.09 | 24.1 | 5.5 | 1001.41 |
| Summer | Low Vel, High Den, Historic Flow | 5 | 95 | 27.8 | 40.1 | 1026.28 | 0.03 | 1.09 | 32.9 | 5.5 | 998.93 |

To visualize the maximum height of the desalination discharge plume, CORVIEW was run on the scenario for 30 MGD production rate, 40% recovery rate, and summer T95, S5 ambient density. This scenario contains the lowest effluent density (1026 kg/m$^3$) and the highest port velocity 28.5 fps and is expected to generate the highest plume rise among the various model scenarios. The visualization of the plume shows that the maximum height extent (after considering plume thickness) is about 4.5 m below the surface (see Figure 20). This is deeper than the discharge depth of the neighboring diffuser (2.5 m) and is anticipated to leave about 2 m of spacing between the neighboring (positively-buoyant) plume and the negatively-buoyant desalination discharge plume.

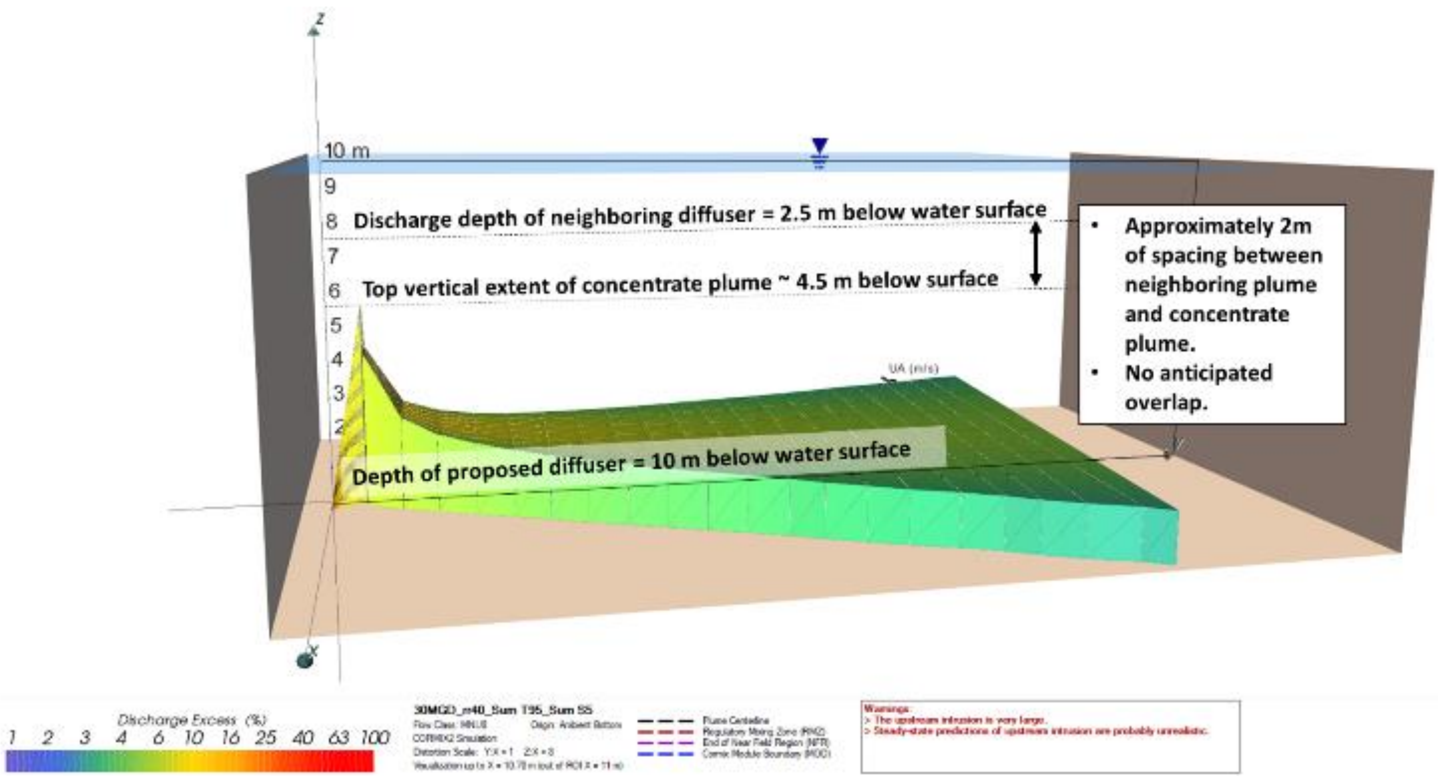



**Figure 20. CORMIX visualization of maximum height extent (after considering plume thickness).**

Therefore, the trajectories of the two plumes are expected to be divergent and it is highly unlikely that there would be meaningful vertical overlap between the two dischargers. As such. adjusting the regulatory mixing zones of the proposed outfall to avoid interaction with the neighboring plume would not be advised.

# 9 CONCLUSIONS

This technical memorandum describes the concentrate modeling study at the Inner Harbor site. The modeling activities have been performed for the desalination plant operating at 20 MGD and 30 MGD productions with the RO recovery rates of 40% and 50% under different ambient density conditions (represented by combinations of salinity and temperature extremes) and stratifications.

The proposed diffuser design is a multiport diffuser consisting of a 50-foot-long diffuser pipe with four risers – each containing two 8-inch diameter ports. The diffuser would be placed at a depth of approximately 32 feet on the south side of the navigation channel. The diffuser pipe would be aligned parallel to the channel while the diffuser ports would be directed towards the center of the channel. The diffuser ports would also be angled 60 degrees above the horizon. Since the diffuser is a multiport diffuser, rectangular mixing zones for the ZID and MZ were defined following SOP requirements. This resulted in the following rectangular dimensions:

- ZID: 100 ft x 78 ft centered around the diffuser pipe with the short side parallel to the pipe and long side perpendicular to the pipe;
- MZ: 400 ft x 314 ft centered around the diffuser pipe with the short side parallel to the pipe and long side perpendicular to the pipe; and,
- HHMZ: 800 ft x 628 ft centered around the diffuser pipe with the short side parallel to the pipe and long side perpendicular to the pipe.

The CORMIX model results were evaluated based on the following criteria:

1. Meeting critical dilutions proposed in the White Paper at the edges of the ZID and MZ that are protective of aquatic life;
2. Achieving the CORMIX flow class of MNU8; and,
3. Meeting effluent velocity limits at the edges of the ZID and MZ that are protective of aquatic life.

Table 21 below provides the CORMIX results for the recommended diffuser design when the desalination plant is operating at RO 40% and 50% recovery rates for the production capacities of 20 MGD and 30 MGD. The recommended diffuser design meets all the criteria mentioned above for effluent percentage, CORMIX flow class and effluent velocity.

**Table 21. Summary of CORMIX results for proposed diffuser configuration.**

| | | | ZID Results | | | MZ Results | | | HHMZ Results | CORMIX Flow Classification | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Production Capacity (MGD) | RO Recovery Rate | Effluent Discharge (MGD) | Effluent Percentage (%) | Effluent Velocity (fps) | Evaluation | Effluent Percentage (%) | Effluent Velocity (fps) | Evaluation | Effluent Percentage (%) | Flow Class | Evaluation |
| 20 | 40% | 34.3 | 10.3 | 0.3 | Meets critical dilution (<=56%) and velocity limit (<= 2 fps) for ZID. | 8.5 | 0.2 | Meets critical dilution (<=18%) and velocity limit (0.5 fps) for MZ. | 8.5 | MNU8 | Meets desired flow class (MNU8). |
| 30 | 40% | 51.5 | 12.3 | 0.4 | Meets critical dilution (<=56%) and velocity limit (<= 2 fps) for ZID. | 12.3 | 0.3 | Meets critical dilution (<=18%) and velocity limit (0.5 fps) for MZ. | 12.3 | MNU8 | Meets desired flow class (MNU8). |
| 20 | 50% | 23.4 | 10.4 | 0.2 | Meets critical dilution (<=38%) and velocity limit (<= 2 fps) for ZID. | 7.4 | 0.1 | Meets critical dilution (<=13%) and velocity limit (0.5 fps) for MZ. | 6.0 | MNU8 | Meets desired flow class (MNU8) |
| 30 | 50% | 35.2 | 10.3 | 0.3 | Meets critical dilution (<=38%) and velocity limit (<= 2 fps) for ZID. | 8.7 | 0.2 | Meets critical dilution (<=13%) and velocity limit (0.5 fps) for MZ. | 8.7 | MNU8 | Meets desired flow class (MNU8) |

Finally, it is noted that another discharger (Permit #WQ0000457000) is located within 400 ft from the proposed diffuser location. However, it is anticipated that the proposed desalination discharge would have limited interaction with the other discharge. This is because of the following:

- Effluent from the proposed desalination plant would be negatively buoyant under all SOP density scenarios. The proposed depth of the diffuser is 32 ft.
- Effluent from the other discharger is positively buoyant under all SOP density scenarios. The depth of the discharge is 8.2 ft (JMA, 2016).

Given the significant difference in buoyancy and discharge depth between the two effluents, it is highly unlikely that their respective plume trajectories would overlap. As such, adjustment of their respective regulatory mixing zones would not be necessary.

For permitting purposes, since 40% and 50% recovery rates can result in different discharge rates even when the production rate is the same, it is recommended that the permits limits for average daily discharge volume be based on a 40% recovery rate (maximum anticipated discharge for each permit phase). The maximum daily discharge would be a factor of 1.20 times the average daily discharge volume.

## 10 REFERENCES


Freese & Nichols, Inc. (FNI), 2020. White Paper: Corpus Christi Seawater Desalination, Receiving Water Salinity Critical Dilutions, City of Corpus Christi, Table ES-1.

Jirka, G. H., et. al, 1996, User's Manual for CORMIX: A Hydrodynamic Mixing Zone Model and Decision Support System for Pollutant Discharges into Surface Waters. https://19january2017snapshot.epa.gov/sites/production/files/2015-10/documents/cormix-users_0.pdf

James Miertschin & Associates, Inc. (JMA), May 2016, Effluent Diffuser Modeling Report, Flint Hills Resources Corpus Christi, LLC – East Refinery

Plummer, 2020. City of Corpus Christi Desalination Study Concentrate Modeling Methodology.

Texas Commission on Environmental Quality, 2010, Procedures to Implement the Texas Surface Water Quality Standards

TCEQ, 2018, Mixing Analyses Using CORMIX, TCEQ, Water Quality Division.