Process Design Basis and Narrative
Port of Corpus Christi Industrial Seawater Desalination
Harbor Island

Introduction

The Port of Corpus Christi Authority (PCCA) is developing a project to provide a sustainable supply of potable water for the Corpus Christi area that is not dependent upon rainwater. The proposed system will provide up to 50 million gallons per day (MGD) of permeate through the process of desalination. The purpose of this project is to develop a basis of design in sufficient detail to complete the Texas Commission on Environmental Quality (TCEQ) Industrial Wastewater (TPDES) Permit Application. The proposed facility will have discharges of the following effluents:

- Reject from the membrane desalination process, which is high in Total Dissolved Solids (TDS); and
- Supernatant and filtrate from sediment and sludge dewatering.

The proposed facility will be located on Harbor Island. The plant intake will consist of seawater pumped from one of the adjacent channels. Pre-treatment will include removing sediment in the form of total suspended solids (TSS). The plant will use several clarification and filtration pretreatment processes for this purpose. The final treatment step will be membrane desalination using Reverse Osmosis. The low TDS permeate will then be treated to reduce corrosiveness, chlorinated, and distributed for potable water use. The suspended solids will be concentrated into a dried sludge for offsite disposal. The dewatering filtrate, thickener supernatant and the membrane reject are the subject of the Industrial Wastewater Permit Application.

Project Objective

The overall Project Objective is to develop a sustainable supply of potable water for the Corpus Christi area that is not dependent upon rainwater. This Process Design Basis and Narrative provides information in support of the TPDES Industrial Wastewater Permit application.

Proposed Pre-Treatment and Treatment Unit Processes

The following unit processes will be utilized in the desalination facility:

- Intake screens to remove large particulate from seawater
- Intake clarification with chemical coagulation to remove algae and suspended solids
- Strainers to remove fine debris
- Ultrafiltration to remove fine TSS
- Reverse Osmosis to remove TDS
- Calcite filters to add alkalinity to the permeate to reduce its corrosiveness
- Chlorination
- Distribution pumping

- Energy recovery
- Discharge of the membrane brine or reject under a TPDES permit
- Thickening of the clarifier underflow
- Consolidation of the ultrafiltration membrane backwash solids with thickened clarifier underflow
- Dewatering of consolidated sludge streams
- Discharge of the thickener supernatant and dewatering filtrate under a TPDES permit

Process Narrative

Seawater will be drawn into the plant from a channel adjacent to Harbor Island through coarse screens that will keep large material from entering the pre-treatment processes. The screen will reject captured solids as industrial solid waste into a dumpster. Sodium Hypochlorite (NaOCl) will be added as required to clear marine growth from the screens. The water will enter a rapid mixing unit where one or more treatment chemicals are added. It will then enter the Clarifier Center well, where flocculent is added. It will then flow into the main clarifier tank, where suspended solids will settle. The settled solids will be removed periodically as underflow to the Sludge Thickener. The clarifier effluent will flow to the Settled Water Clearwell, where NaOCl may also be added for oxidation of manganese and for partial disinfection.

From the Settled Water Clearwell, flow will pass into the strainer where solids and debris will be removed as necessary to protect the Ultrafiltration (UF) membranes. The Strainers will be backwashed to the Sludge Thickener. NaOCl may also be added to the strainers, as required. Particles exceeding a diameter greater than 0.001 µm will then be removed by passing the water under high pressure through the UF membranes. This process is semi-continuous, with some UF units in forward flow and others in Backwash or Cleaning mode. Backwash flows will be sent to the UF Reject Tank and then stored for processing in the Sludge Thickener. UF Permeate will be sent to a Clearwell where NaOCl will be added, if required.

From the Clearwell, water will be pumped through Cartridge Filters, the last unit to protect the Desalination reverse osmosis (RO) skids. The RO units will then remove particles larger than 0.1 nm. Pumps taking suction from the Clearwell will apply high pressure to force the seawater through the RO membranes, leaving the TDS behind. The process will be semi-continuous, with some RO units in forward flow and others in Reject or Cleaning mode. RO Permeate will be passed through a calcite filter to add alkalinity and reduce the corrosivity of the product water. The water will then be chlorinated and placed into one of two Permeate Storage Tanks for distribution as potable water. The RO reject will be discharged to a Brine Tank, and then pumped to Outfall 001.

Solids and sludge from the Clarifiers, Strainers, and UF Reject will be passed into a Mix Tank where Coagulant may be added, as required, to increase the diameter of the solids and then into a Sludge Thickener. A Flocculent may be added to the center well of the Thickener to enhance solids separation. The Supernatant overflow will pass over the Thickener weirs to the Outfall Storage Tank. Underflow from the thickener will be pumped into a Belt Filter press (BFP) for dewatering. Solids will be taken off site via truck. BFP Filtrate flow will flow to the Outfall Storage Tank where it will combine with the Thickener Supernatant for discharge to Outfall 001.

A Block Flow Diagram of the process is shown in **Figure 1**. The corresponding water balance is shown in **Table 1**. The water balance shows that the intake of the facility will be 150.7MGD to produce 50 MGD of Permeate. The water balance is based on the following design assumptions:

- 5% sludge removal in the clarifier;
- 3% backwash at the strainers;
- 90% permeate recovery in the UF system;
- 55% of RO feed routed through energy recovery;
- 40% permeate recovery in the RO system;
- 50% decant from the thickener; and
- 60% filtrate recovery from the filter press.

Flow Basis and Material Balance

A summary of the projected Wastewater Stream Concentration is show in **Table 2** below. The projected effluent concentrations are based on published sample data for Corpus Christi Bay and the design assumptions identified previously for the water balance. Constituent concentrations for average effluent conditions are derived by assuming 40% recovery of RO permeate, while maximum constituent concentrations are derived by assuming 50% RO permeate recovery. Note that the treatment system is designed to remove suspended solids and associated total organic carbon.

Outfall 001

Diffuser

Outfall 001 will consist of a diffuser oriented parallel to the shoreline, approximately 300 ft away. The design basis assumes a 48-inch buried HDPE discharge pipe will feed the diffuser from the on-shore pump station. The approximate diffuser location is shown in **Figure 2.** While the exact design details of the diffuser have yet to be finalized, a typical diffuser configuration is shown in **Figure 3.** The characteristics of diffuser will be defined during system design to achieve target mixing performances.

Modeling

Diffuser performance was modelled using CORMIX (version 10.0GT). A report describing the modeling program is included as **Appendix A**. Modeling results demonstrate a significant factor in achieving good mixing is locating the diffuser at sufficient water depth. Models were run at water depths of approximately 63 feet.

Significantly better effluent mixing is predicted by the model for 50% RO recovery than for 40% RO recovery for varying diffuser designs. This difference is likely due to the increased density of the effluent at higher recovery rates. Diffuser performance can change significantly across a range of flows for a particular set of design parameters. CORMIX shows that good mixing performance can be achieved when the diffuser effluent is characterized by a certain flow profile, referred to by the CORMIX model as "flow class". As shown in the modeling report, the modeled effluent at the boundaries of the mixing zones for the various diffuser designs achieved percentages below 2.5% at the ZID, 1.5% at the aquatic life mixing zone, and 1.0% at the human health mixing zone. The diffuser will be designed to achieve these target levels of mixing performance as determined through modeling across the range of flow rates.

Natural Salinity Variation

The following discussion about the variability of salinity levels in Corpus Christi Bay is based on the U.S. Environmental Protection Agency document included in **Appendix B.**

Natural salinity levels within the Bay system vary widely and are largely controlled by sources of freshwater inflows entering into the bays and estuaries consisting of rain, groundwater, and the largest contributor, surface water from rivers and streams. The Nueces River is one of the largest contributors of freshwater into the local bays and estuaries.

Natural fluctuations in freshwater inflows into the Bay can have an immense impact on organisms within the Bay system. For example, if a long drought persists and creates a situation of very little freshwater inflow into the Bay, it may cause hypersaline (high salt) conditions that in turn affect bay shrimp catches which need a certain salinity range in order to mature in healthy numbers. On the other extreme, there may be an abundance of freshwater inflow after an extended heavy rain event that causes eutrophication (high nutrient conditions), triggers large algal blooms that deplete oxygen and light within the water column, and negatively affect fish and plants living in the Bay system.

Data obtained from the TCEQ for Buoy 16492 (located in Corpus Christi Bay) demonstrate this natural variation in ambient salinity. This data set, shown in **Figure 4** below, shows a historic salinity variation between 3.06 and 40.9 parts per thousand. Since the proposed effluent modeling demonstrates the system effluent will increase the ambient concentration less than 1% beyond the aquatic life mixing zone, this increase is considered insignificant versus the natural variation and will not lead to the degradation of local water quality.

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Table 1: 50 MGD Desalination Facility Water Balance

Stream #	Stream Description	Design Flow (MGD)
01	Seawater Intake	150.7
02	Screened Seawater	150.7
03	Clarifier Feed	150.7
04	Settled Seawater from Clarifier	143.2
05	Clarifier Sludge to Thickener	7.5
06	Settled Seawater to Strainers	143.2
07	UF Feed from Strainers	138.9
08	Strainer Backwash to Thickener	4.3
09	UF Permeate	125
10	UF Reject	13.9
11	UF Permeate Feed to RO	125
12	RO Feed HP Pump Flow	56.3
13	RO Permeate	50
14	RO Permeate from Calcite Filters	50
15	Water to Distribution Pumps	50
16	RO Reject Thru ERU	75
17	RO Feed Thru ERU	68.8
18	RO Reject to Disposal	75
19	Waste from UF Reject Tank	13.9
20	Combined Wastes to Rapid Mixer	25.7
21	Combined Wastes to Thickener	25.7
22	Thickener Decant to Outfall Tank	12.9
23	Thickener Slurry to Filter Presses	12.9
24	Filter Press Filtrate to Outfall Tank	7.7
25	Filter Cake Solids to Landfill	5.1
26	Outfall to Disposal	20.6

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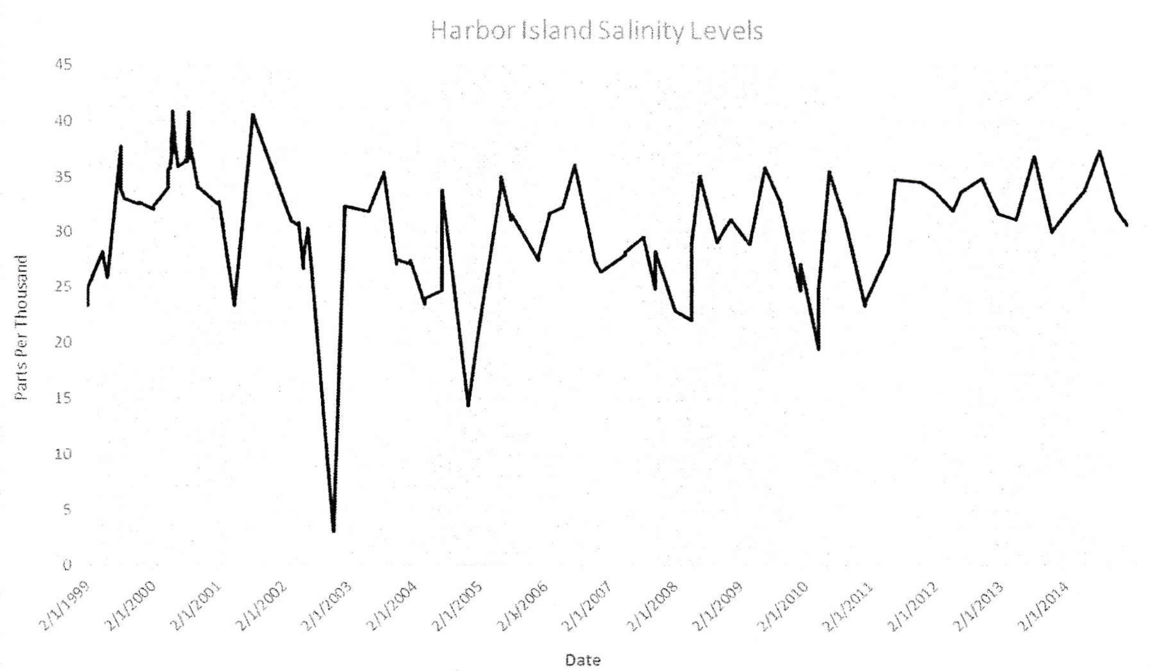
Table 2: 50 MGD Desalination Facility Design Basis Source Water and Effluent Constituent Concentrations

Parameter		Source Water Quality Design Basis[1]	Average Outfall 001 Effluent[2]	Max Outfall 001 Effluent[3]
Flow, mgd		150.7	96	125
Sodium (Na)	mg/L	11,600	18,500	21,800
Calcium (Ca)	mg/L	1,700	2,720	3,200
Magnesium (Mg)	mg/L	1,400	2,240	2,640
Potassium (K)	mg/L	368	590	690
Barium (Ba)	mg/L	0.04	0.06	0.1
Strontium (Sr)	mg/L	6.8	11.0	12.7
Iron (Fe)	mg/L	1.5	2.4	2.8
Bicarbonate (HCO3)	mg/L	145	230	270
Chloride (Cl)	mg/L	23,000	36,700	43,200
Sulfate (SO4)	mg/L	3,000	4,800	5,660
Nitrate (NO3)	mg/L	2.0	3.1	3.6
Fluoride (F)	mg/L	2.0	3.2	3.7
Silicon Dioxide (SiO2)	mg/L	5.0	8.0	9.4
Boron	mg/L	6.0	8.0	8.9
Total Dissolved Solids (TDS)	mg/L	41,252	66,000	77,460
pH	S.U.	7.5	7.5	7.5
Temperature	°C	14-32	14-32	14-32
Total Organic Carbon (TOC)	mg/L	4	1	2
Total Suspended Solids (TSS)	mg/L	30	15.0	30.0

Note:

1. The source water quality design basis data are based on sample data for Corpus Christi Bay listed in the Freese and Nichols report, "Variable Salinity Desalination Demonstration Project: Technical Memorandum No. 2, VSD Plant Siting Analysis", April 26, 2016.
2. Average constituent values based on 40% RO permeate recovery.
3. Maximum constituent values based on 50% RO permeate recovery.

Figure 4 – Variability of Salinity Levels Over Time



Note: Data from Buoy 16492

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Appendix A

Brine Discharge Mixing Analysis

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Brine Discharge Mixing Analysis
Proposed Harbor Island Desalination Facility
December 2017

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Attachment A: Mixing Analysis using CORMIX

Attachment B: Reported Corpus Christi Bay Ambient Properties

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1. Introduction

The Port of Corpus Christi Authority (PCCA) proposes to construct a desalination plant at the Harbor Island site (Figure 1) near Corpus Christi, Texas. This facility is expected to produce up to 50 MGD of product water with an anticipated discharge flow of 96 MGD based on 40% recovery of permeate water during reverse osmosis (RO) processing. The desalination facility will utilize reverse osmosis (RO) to produce water. The proposed diffuser from this facility will discharge into the Corpus Christi Channel.

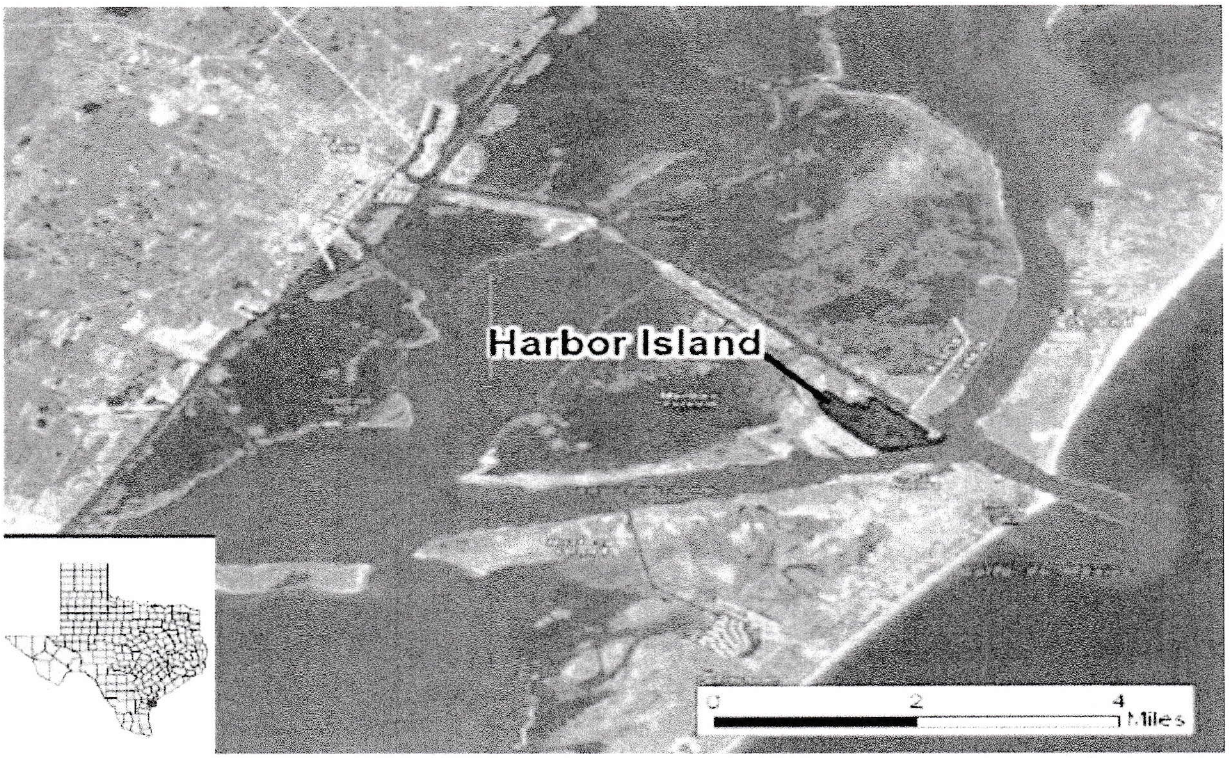

Figure 1: Harbor Island

Because the impact of the discharge on salinity levels in Corpus Christi Bay was unknown, the Texas Commission on Environmental Quality (TCEQ) requested that the PCCA conduct an assessment of the discharge using CORMIX and present the findings in a report submitted with the TPDES permit application. CORMIX is a proprietary program widely used for mixing zone analysis. CORMIX provides estimates of the effluent concentration percentages at varying distances from a point discharge source from which any associated downstream concentration can be estimated. The comparison between various CORMIX analyses were conducted based on the effluent concentrations at the edge of the zone of initial dilution (ZID), aquatic life mixing zone (MZ), and human health mixing zone (HH MZ).

This report describes the modeling that was conducted using CORMIX, including the model inputs that were used. Results of the model runs are provided, and achievable mixing zone targets are proposed based on the CORMIX modeling output. If approved by the TCEQ, the PCCA proposes to design a diffuser for the effluent discharge that would meet the target effluent concentrations as determined through CORMIX modeling.

2. CORMIX Analysis and Required Inputs

CORMIX (version 10.0GT) software and current modeling guidelines provided by the TCEQ were used to analyze the mixing of the Harbor Island desalination plant discharge. The TCEQ modeling guidelines are included as **Attachment A**. The required and selected modeling input including the receiving water properties, effluent properties, and diffuser properties are described in this section.

2.1 Ambient Conditions

In this section, the basis and estimates for the ambient parameters are presented. The main CORMIX parameters for ambient condition include: ambient density, water velocity, bed slopes, and wind velocity. The ambient data were obtained from different sources as explained in the following sections. Although not used in the modeling study, additional ambient properties associated with Corpus Christi Bay are included in **Attachment B**.

2.1.1 Density

The TCEQ modeling guidelines require modeling to be performed at varying water densities during the summer and winter months. The water density is a function of both salinity and temperature. Specifically, the guidelines require modeling with the densities associated with the 5th and 95th percentiles of both temperature and salinity during the summer and winter months. The various densities associated with these temperature and salinity combinations can be expressed as:

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

The equation used to calculate ambient density as a function of temperature and salinity can be found in the modeling guidelines in **Attachment A**.

Salinity and temperature data from 1999 to 2015 were obtained from Surface Water Quality Monitoring (SWQM) station 16492. The station location is shown in **Figure 2**.

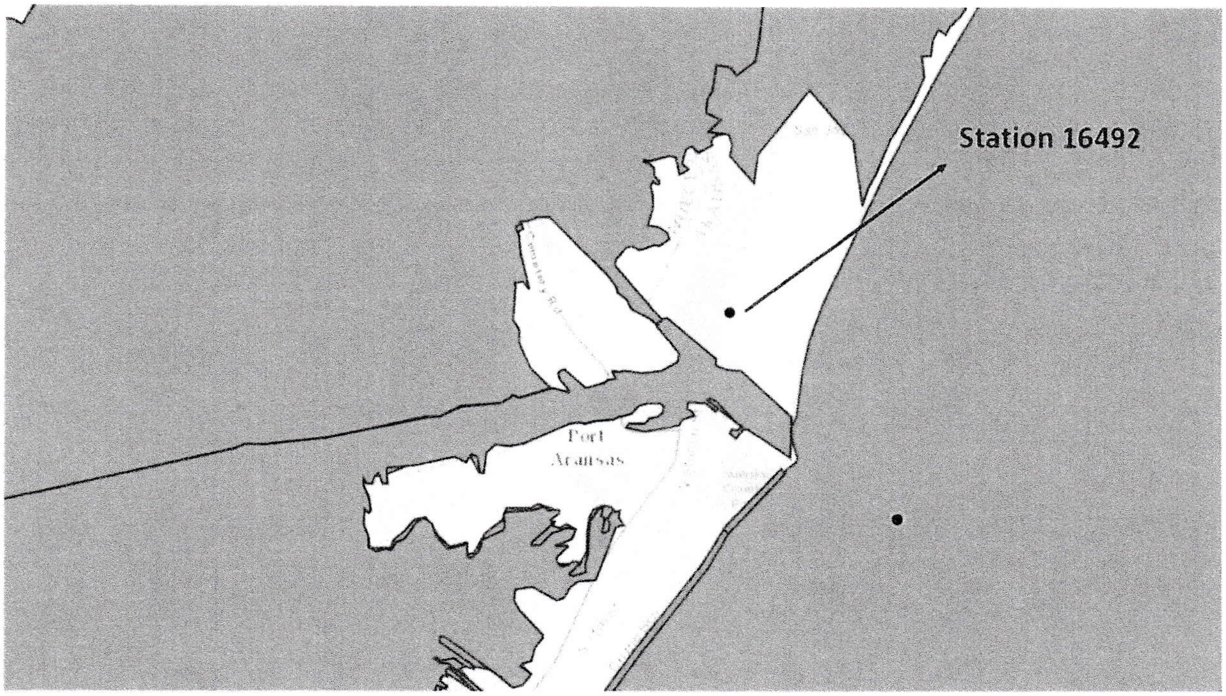

Figure 2: SWQM Station 16492 Location

The calculated ambient density and effluent density for the Harbor Island site (Winter and Summer) for RO recovery rates of 50% and 40% are demonstrated in **Table 1** and **Table 2,** respectively. In **Table 1, t**he effluent density was calculated at twice the ambient salinity based on the design assumption that 50% recovery of permeate will be achieved at the RO unit. In **Table 2, t**he effluent density was calculated at 1.6 times the ambient salinity based on the design assumption that 40% recovery of permeate will be achieved at the RO unit. In both RO rates, the entire salinity would be assumed to be rejected by the RO membranes and would be discharged with the effluent through the diffuser.

Table 1: Ambient Density Values for Each Temperature and Salinity Combination in Summer and Winter at 50% RO Recovery

Condition	Summer			Winter		
	Ambient Density (kg/m³)	Discharge Density (kg/m³)	Δ Density (kg/m³)	Ambient Density (kg/m³)	Discharge Density (k/m³)	Δ Density (kg/m³)
ρ (T5, S5)	1013.65	1030.77	17.12	1020.67	1041.64	20.96
ρ (T_5, S_{95})	1025.51	1054.49	28.98	1027.68	1055.65	27.97
ρ (T_{95}, S_5)	1012.49	1029.45	16.96	1019.00	1039.47	20.47
ρ (T_{95}, S_{95})	1024.24	1052.94	28.70	1025.84	1053.15	27.31

Table 2: Ambient Density Values for Each Temperature and Salinity Combination in Summer and Winter at 40% RO Recovery

Condition	Summer			Winter		
	Ambient Density (kg/m³)	Discharge Density (kg/m³)	Δ Density (kg/m³)	Ambient Density (kg/m³)	Discharge Density (k/m³)	Δ Density (kg/m³)
ρ (T5, S5)	1013.65	1023.92	10.27	1020.67	1033.25	12.58
ρ (T_5, S_{95})	1025.51	1042.89	17.39	1027.68	1044.46	16.78
ρ (T_{95}, S_5)	1012.49	1022.67	10.18	1019.00	1031.28	12.28
ρ (T_{95}, S_{95})	1024.24	1041.46	17.22	1025.84	1042.23	16.38

2.1.2 Water Velocity

The TCEQ modeling guidelines state that a small water velocity should be assumed for modeling discharges into bays. TCEQ personnel suggested a value of 0.05 m/s, which was used in the modeling analyses.

2.1.3 Slope

CORMIX analysis for brine discharge requires determining the near- and far-shore slopes. CORMIX specifies both the near- and far-shore bottom slope to be greater than zero. According to the CORMIX definition, the near-shore slope is steeper than the far-shore one. The point at which the near- and far-shore slope intersect is the slope break point.

For the anticipated Harbor Island facility diffuser location, the break was estimated to be at 200 feet from the shoreline (based on bathymetry maps). At the break point, the water depth is approximately 59 ft (the nearshore slope is approximately 30%). The cross -section slope reduces at this break point and the far-shore slope is 4% (between 200-400 ft from the shoreline). These slopes reflect the northern edge of the Corpus Christi Channel. The near- and far-shore slopes are shown in **Figure 3**.

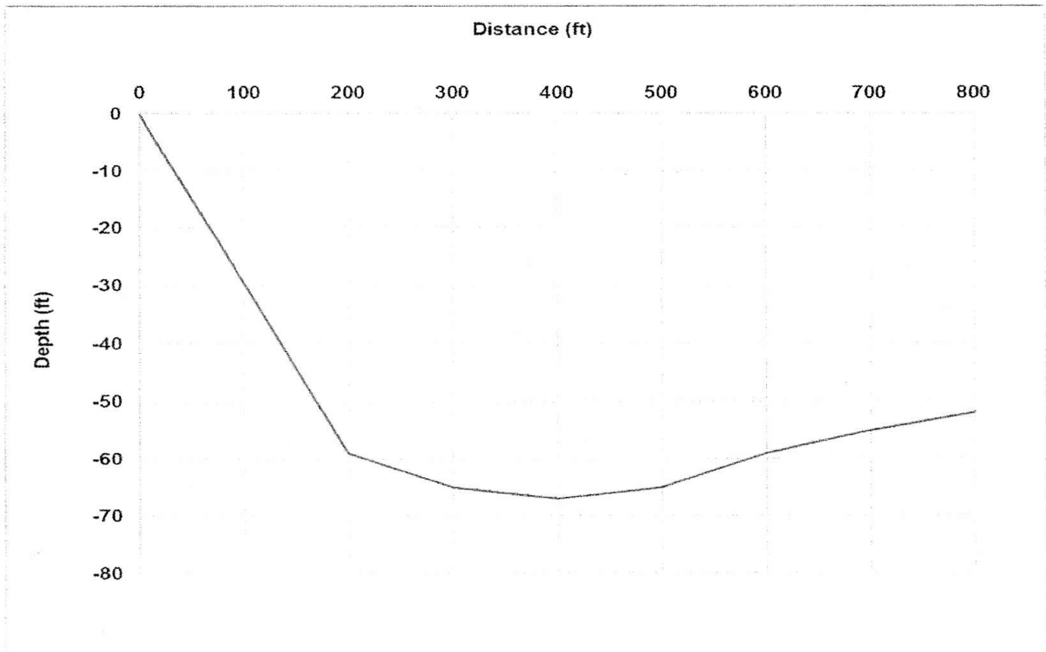

Figure 3: Cross Section Near Proposed Harbor Island Facility Diffuser

2.1.4 Summary of Ambient Conditions

The summary of ambient conditions utilized in modeling, with the ambient densities presented in **Table 1** and **Table 2,** is presented in **Table 3.**

Table 3: Harbor Island Base Scenario for Ambient Parameters

Parameter	Unit	Value	Basis
Wind Speed	m/s	2	TCEQ CORMIX Guidance
Water Velocity	m/s	0.05	TCEQ CORMIX Guidance
Manning Constant (n)	-	0.0183	Calculated based on 0.025 Darcy Constant
Near Shore Bottom Slope (%)		29.5	Bathymetry and COMRIX manual definition on slope
Distance Shoreline to Break	meter	61	Bathymetry and COMRIX manual definition on slope
Far Shore Bottom Slope (%)		4	Bathymetry and COMRIX manual definition on slope

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2.2 General Design Assumptions

To design the outfall system for brine discharge, the relevant literature was reviewed to specify the important design parameters such as diffuser type, discharge velocity, diffuser diameter, and diffuser angles that result in better initial mixing. Shoreline discharge (i.e., absent a diffuser) of negatively buoyant concentrate will result in a density current that runs down the bottom slope. The dilution is very small for this discharge since the resulting density stratification inhibits vertical mixing. Therefore, submerged discharge through pipes and port(s) has been an effective method for discharging brine. The discharge could be through a single port for a small discharge or a multiport diffuser for larger discharges [1-4]. Multiport diffusers have been shown more effective in rapid salinity dilution as the waste stream discharges with high velocity which will allow more rapid initial jet mixing of the plant effluent in the ambient seawater. This rapid mixing provides enhanced initial dilution while having a limited effect on aquatic organisms as the relatively small zone of high velocity gradients occurs near the port and only lower settling velocities occur near the ocean bottom. However, entrained ambient water pulled up from under the upward discharging ports creates some limited potential for scour; therefore, the height of the ports above the sea bed should be considered. In addition, due to the presence of the Ship Channel, appropriate measures should be considered to protect the diffuser and ports.

2.2.1 Diffuser Alignment

Normally with multiport diffuser mixing, it is better if the diffuser is oriented transverse to the ambient current. Transverse co-flowing minimizes the overlapping of individual port plumes. However, for easier installation, the diffuser was assumed parallel to the shore. Therefore, the Gamma angle (diffuser line to Tidal flow) was set to zero in all cases analyzed. Vertical port angle of discharge (Theta) of 60° has been reported as the optimum discharge angle for most brine discharges. This angle was shown to provide maximum rise level of jet trajectory among other tested vertical angles [1-4]. Therefore, a 60° angle was used for brine discharge in all analyses.

The following configuration angles were selected in all of the CORMIX analyses.

- Port Angle from Horizontal (THETA) = 60 degree – The existing literature considered a THETA of 60 degrees to be the optimum angle for most brine discharge cases
- Port Angle to Tidal Flow (SIGMA) = 270 degree – This value is determined to discharge off-shore toward deeper water.
- Diffuser Line to Tidal Flow (GAMMA) = 0 degree – This value is used because the diffuser is placed in parallel to the ambient flow in order to keep the diffuser out of the ship channel.
- Port Angle to Diffuser Line (BETA) = 90 degree – Having selected that alignment (GAMMA=0), then the best port orientation in the x-y plane is perpendicular to the oscillating ambient current.

2.2.2 ZID and Mixing Zones

A mixing zone is defined as a limited area or volume within the coastal water where the impacts to marine life are deemed minimal. This negotiated area or control volume usually is restricted to an area around the outfall where the initial dilution happens. Acute marine criteria are applied at the edge of the zone of initial dilution (ZID), chronic marine criteria are applied at the edge of the aquatic life mixing zone (MZ), and chronic human health protection criteria are applied at the edge of the human heath mixing zone (HH MZ). Applicable mixing zone distances are specified in the TCEQ Procedures to Implement the Texas Surface Water Quality Standards as follows:

- The ZID is defined as a volume within a radius of 50 feet from the point where the discharge enters the receiving water.

- The MZ for this discharge is defined as a volume within a radius of 200 feet from the point where the discharge enters the receiving water.
- The HH MZ is defined as a volume within 400 feet from the point where the discharge enters the receiving water.

Based on the TCEQ modeling guidelines for multi-port diffusers, the ZID and other mixing zones are considered rectangular in shape with an equivalent area to the corresponding specified standard circular mixing zones. As the diffuser is unidirectional with all ports directed off-shore, the equivalent rectangle is shifted to the off-shore side with one side along the axis of the diffuser.

2.2.3 Other Modeling Inputs

The following effluent and diffuser model inputs were varied as described in Section 3:

- Effluent Density
- Discharge Flow
- Discharge Depth
- Diffuser Length
- Number of Ports
- Port Height
- Discharge Velocity
- Port Diameter

3. Mixing Performance Under Varying Conditions

CORMIX analysis was performed under both 40% and 50% permeate recovery at the RO unit, which impacted both effluent density and effluent flow rate. While it is possible that the proposed desalination plant will operate at 50% permeate recovery, 40% permeate recovery is more likely. Given the uncertainty in this operating condition, both conditions were modeled. In the analysis, effluent salinity was assumed to be twice the concentration of ambient for the design condition in which 50% of flow to the RO unit is recovered as permeate. Effluent was approximated as 60% more concentrated in salinity compared with ambient salinity for the 40% permeate recovery operating condition.

The work process for the CORMIX analysis, under both 40% and 50% RO recovery, included five steps. First, the diffuser location was established based on the bathymetry characteristics. Second, different diffuser designs were examined at 50% RO recovery. Third, the selected design was examined under the eight ambient conditions at 50% RO recovery to determine the critical ambient condition. Fourth, for the selected design at the critical ambient condition, the flow rate was changed at 40% RO recovery to evaluate mixing at a lower recovery rate. Fifth, multiple designs were examined at various flow rates (for the critical ambient condition) and at 40% RO recovery to identify achievable mixing performance across a range of flow rates. In analysis steps one and two, the ambient density associated with the 95^{th} percentile temperature and 95^{th} percentile salinity (ρ (T95, S95)) in the summer months was used for the analysis at 50% RO recovery since the critical ambient condition (ambient condition which resulted in poorest mixing) was not identified until step

3. The analysis for 40% RO recovery was thereafter performed for the identified critical ambient condition in steps four and five.

3.1 Step 1: Establish Diffuser Location

The diffuser location for the Harbor Island facility is proposed to be placed at 300 ft from the shoreline on the south side of Harbor Island and east of the Ferry (**Figure 4**). The water depth at the proposed location is approximately 63 ft. Since the change in water depth between 300-600 ft from the shoreline is insignificant, if the diffuser is placed in any location east-west or north south at this range, the results of CORMIX analysis would be expected to be similar. Thus, the study evaluated mixing performance at one location relative to the shoreline.

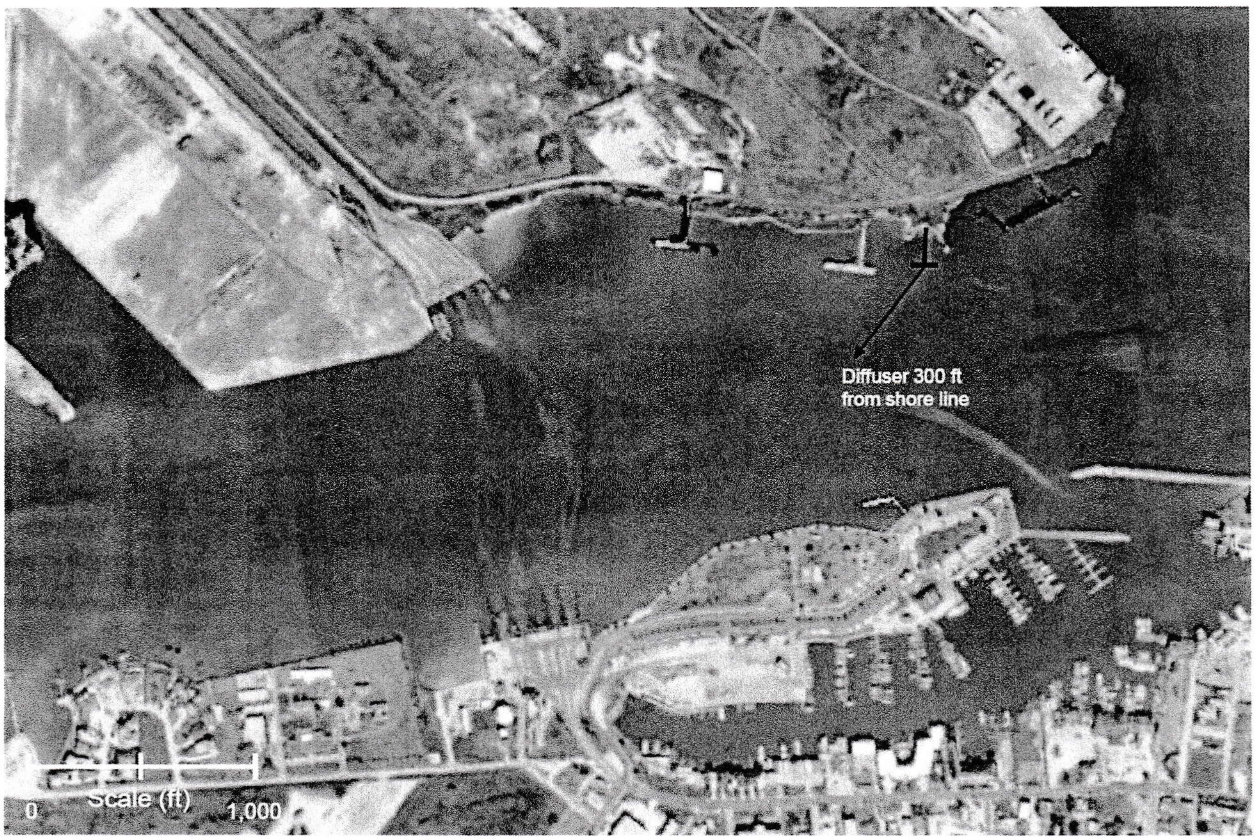

Figure 4: Proposed Location for Harbor Island Facility Diffuser

3.2 Step 2: Diffuser Design at 50% RO Recovery

For the selected diffuser location and a design production rate of 50 MGD (66 MGD effluent at 50% RO Recovery), different diffuser design alternatives were tested (Alternatives 1-5 in **Table 4**) using the 95% condition for temperature and salinity. In the analysis of design alternatives, the discharge depth and diffuser angles were kept constant. Design parameters that vary in different alternatives include:

- Discharge Velocity
- Port Height
- Number of Ports
- Number of Ports Per Riser
- Port Diameter
- Diffuser Length

For the Harbor Island facility, design Alternative 1 represents the initial run alternative with a discharge velocity of 11 ft/s, port height of 12.6 ft, and port diameter of 12 inches. These design parameters were varied in other design alternatives (i.e., Alternatives 2-5) to access impact on mixing performances at the ZID as shown in **Table 4**. The results of the alternatives analysis, summarized in **Table 4**, showed that increasing port height (Alternative 2) has no effect on the dilution. In Alternative 3, the number of ports was decreased, and accordingly, diffuser length was reduced compared to the initial alternative. The results showed similar effluent concentration at ZID and increase in effluent concentration at MZ compared with Alternative 1. In Alternative 4, the number of ports was decreased to six with port diameters of 18 inches (and subsequent diffuser length of 82 ft). The results showed similar effluent concentration at ZID and increase in effluent concentration at MZ compared with Alternative 1. In Alternative 5, parameter values from Alternatives 2 and 4 were combined, resulting in similar performance as Alternative 3. Based on the effluent percentage at ZID all of the configurations show similar performance. Hence, Alternative 3 was selected for further analysis in the subsequent steps. **Table 5** provides a summary of effluent percentages at the boundaries of the three mixing zones.

Table 4: Design Alternative for Harbor Island Plant Diffuser at 50% RO Recovery

Design Alternative ID	Discharge Depth (ft)	Discharge Velocity (ft/s)	Port Height (ft)	# of Port	Riser Spacing (ft)	Port Diameter (inch)	Diffuser Length (ft)	# of Ports Per Riser	Variation	Effluent at ZID (%)
1	63	11	12.6	12	16.4	12	82	2	Base	1.01
2	63	11	15.75	12	16.4	12	82	2	Port height increase	1.01
3	63	13	12.6	10	16.4	12	65.6	2	Higher discharge velocity/ Less ports/Shorter diffuser	1.01
4	63	11	12.6	6	16.4	18	98.4	2	Larger Port Diameter	1.01
5	63	13	15.75	10	16.4	12	65.6	2	Higher discharge	1.01

								velocity, higher port height	

Table 5: Effluent Percentages at Mixing Zone Boundaries for Different Design Alternatives in Harbor Island Plant Diffuser at 50% RO Recovery

Design Alternative	Effluent Percentage at ZID, MZ and HH Mixing Zones (%)		
	ZID	MZ	HH
1	1.01	0.534	0.467
2	1.01	0.536	0.467
3	1.01	0.575	0.504
4	1.01	0.541	0.472
5	1.01	0.575	0.504

3.3 Step 3: Analysis at Different Ambient Conditions

Since the most limiting combination of effluent receiving water conditions cannot be reliably predicted in advance of running the model, a range of modeling scenarios were performed in order to determine protective effluent dilution. Due to seasonal variability in the effluent density, eight standard effluent/ambient density combinations were analyzed (**Table 1**) at 66 MGD effluent flow rate for 50% RO recovery in accordance with the TCEQ modeling guidelines in **Attachment A**.

In considering the effect of stratification in these analyses, the salinity and temperature values at the top and bottom of the water column were paired. Given the available ambient data set from the TCEQ, the top depth was based on salinity data at a depth of 0.3 meters. The bottom depths were based on 12.19 meters. The average density differences between the top and bottom of the water column at these depths were calculated to be 0.01 kg/m^3 for Harbor Island. Because the differences in density are less than 0.1 kg/m^3, stratification does not need to be considered in the model in accordance with CORMIX guidance.

Table 6 shows the effluent percentages for different ambient cases for diffuser design Alternative 3 at 50% RO permeate recovery. The largest percent effluent at each of the three mixing zone boundaries was observed during summer conditions at the 95th percentile of temperature and 5th percentile of salinity, making this set of conditions the critical ambient condition.

Table 6: Effluent Percentage and Concentration at the Three Mixing Zones for Design Alternative 3 and 50% RO Permeate Recovery at Different Ambient Conditions

Ambient	Effluent at ZID (%)	Ambient Salinity (ppt)	Effluent Salinity (ppt)	ZID (ppt)	Percentage Above Ambient
Summer, (T_5, S_5)	1.440	22.90	45.8	23.56	2.88%
Summer, (T_5, S_{95})	1.00	38.76	77.52	38.84	2.00%

Summer, (T_{95}, S_5)	**1.450**	**22.90**	**45.8**	**23.56**	**2.90%**
Summer, (T_{95}, S_{95})	1.010	38.76	77.52	39.54	2.02%
Winter, (T_5, S_5)	1.260	26.70	53.4	27.37	2.52%
Winter, (T_5, S_{95})	1.030	35.63	71.25	36.36	2.06%
Winter, (T_{95}, S_5)	1.280	26.70	53.4	27.38	2.56%
Winter, (T_{95}, S_{95})	1.040	35.63	71.25	36.37	2.08%

Ambient	Effluent at MZ (%)	Ambient Salinity (ppt)	Effluent Salinity (ppt)	MZ (ppt)	Percentage Above Ambient
Summer, (T_5, S_5)	0.687	22.90	45.8	23.21	1.37%
Summer, (T_5, S_{95})	0.574	38.76	77.52	39.20	1.15%
Summer, (T_{95}, S_5)	**0.689**	**22.90**	**45.8**	**23.22**	**1.38%**
Summer, (T_{95}, S_{95})	0.575	38.76	77.52	39.21	1.15%
Winter, (T_5, S_5)	0.641	26.70	53.4	27.04	1.28%
Winter, (T_5, S_{95})	0.581	35.63	71.25	36.04	1.16%
Winter, (T_{95}, S_5)	0.646	26.70	53.4	27.04	1.29%
Winter, (T_{95}, S_{95})	0.586	35.63	71.25	36.04	1.17%

Ambient	Effluent at HH (%)	Ambient Salinity (ppt)	Effluent Salinity (ppt)	HH (ppt)	Percentage Above Ambient
Summer, (T_5, S_5)	0.599	22.9	45.8	23.17	1.20%
Summer, (T_5, S_{95})	0.503	38.76	77.52	39.15	1.01%
Summer, (T_{95}, S_5)	**0.601**	**22.9**	**45.8**	**23.18**	**1.20%**
Summer, (T_{95}, S_{95})	0.504	38.76	77.52	39.15	1.01%
Winter, (T_5, S_5)	0.561	26.7	53.4	27.00	1.12%
Winter, (T_5, S_{95})	0.509	35.625	71.25	35.99	1.02%
Winter, (T_{95}, S_5)	0.565	26.7	53.4	27.00	1.13%
Winter, (T_{95}, S_{95})	0.513	35.625	71.25	35.99	1.03%

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3.4 Step 4: Test the Selected Diffuser Design under Different Discharge Flow Rates at 40% RO Recovery

In this step, the design Alternative 3 selected in Step 2 (determined based on RO recovery of 50% under critical ambient condition) was tested under a range of target product and corresponding discharge flow rates at 40% RO recovery. All the runs in this section were conducted at the critical ambient condition (Summer, (T_{95}, S_5)) with the ambient and effluent density of 1012.49 kg/m3 and 1029.45 kg/m3, respectively. These runs evaluated different plant capacities for the previously determined diffuser design alternative, now for the RO recovery of 40%. For effluent flow ranging from 38 MGD (20 MGD product water) to 96 MGD (50 MGD product water), the analysis showed that good mixing (ZID: 1.75% - 1.92%) can be achieved only for discharge flows between 38 MD (20 MGD product water) and 54 MGD (28 MGD product water) at critical ambient condition. **Figure 5** shows discharge flow vs. ZID for the specified diffuser design alternative. The variations in the ZID percentages under different discharge flow rates is significantly influenced by the "flow class" as defined by the CORMIX model. The flow classification from the CORMIX manual is demonstrated in **Attachment C.** The model results for each model run is shown in **Table 7** along with the flow class.

Table 7: Effluent Percentage and Concentration at the Three Mixing Zones for Design Alternative 3 at Different Discharge Flow Rates for 40% RO Recovery

Plant Capacity(MGD)	Discharge Flow (MGD)	Condition	Effluent at ZID (%)	Ambient Salinity (ppt)	Effluent Salinity(ppt)	ZID (ppt)	Percentage above Ambient	Flow Class
50	96	RO 40%	7.71	22.9	36.64	25.72	12.34%	MNU8
40	76	RO 40%	8.37	22.9	36.64	25.97	13.39%	MNU8
35	67	RO 40%	8.8	22.9	36.64	26.12	14.08%	MNU8
30	57	RO 40%	24.7	22.9	36.64	31.95	39.52%	MNU9
28	54	RO 40%	1.92	22.9	36.64	23.60	3.07%	MNU3
25	48	RO 40%	1.87	22.9	36.64	23.59	2.99%	MNU3
20	38	RO 40%	1.75	22.9	36.64	23.54	2.80%	MNU3

Plant Capacity	Discharge Flow (MGD)	Condition	Effluent at MZ (%)	Ambient Salinity (ppt)	Effluent Salinity(ppt)	MZ (ppt)	Percentage above Ambient	Flow Class
50 MGD	96	RO 40%	5.46	22.9	36.64	24.90	8.74%	MNU8
40 MGD	76	RO 40%	6.1	22.9	36.64	25.14	9.76%	MNU8
35 MGD	67	RO 40%	6.5	22.9	36.64	25.28	10.40%	MNU8
30 MGD	57	RO 40%	13.1	22.9	36.64	27.70	20.96%	MNU9

28 MGD	54	RO 40%	0.734	22.9	36.64	23.17	1.17%	MNU3
25 MGD	48	RO 40%	0.704	22.9	36.64	23.16	1.13%	MNU3
20 MGD	38	RO 40%	0.624	22.9	36.64	23.13	1.00%	MNU3

Plant Capacity(MGD)	Discharge Flow (MGD)	Condition	Effluent at HH (%)	Ambient Salinity (ppt)	Effluent Salinity(ppt)	HH (ppt)	Percentage above Ambient	Flow Class
50	96	RO 40%	4.44	22.9	36.64	24.53	7.10%	MNU8
40	76	RO 40%	4.99	22.9	36.64	24.73	7.98%	MNU8
35	67	RO 40%	5.34	22.9	36.64	24.86	8.54%	MNU9
30	57	RO 40%	6.59	22.9	36.64	25.31	10.54%	MNU9
28	54	RO 40%	0.633	22.9	36.64	23.13	1.01%	MNU3
25	48	RO 40%	0.606	22.9	36.64	23.12	0.97%	MNU3
20	38	RO 40%	0.535	22.9	36.64	23.10	0.86%	MNU3

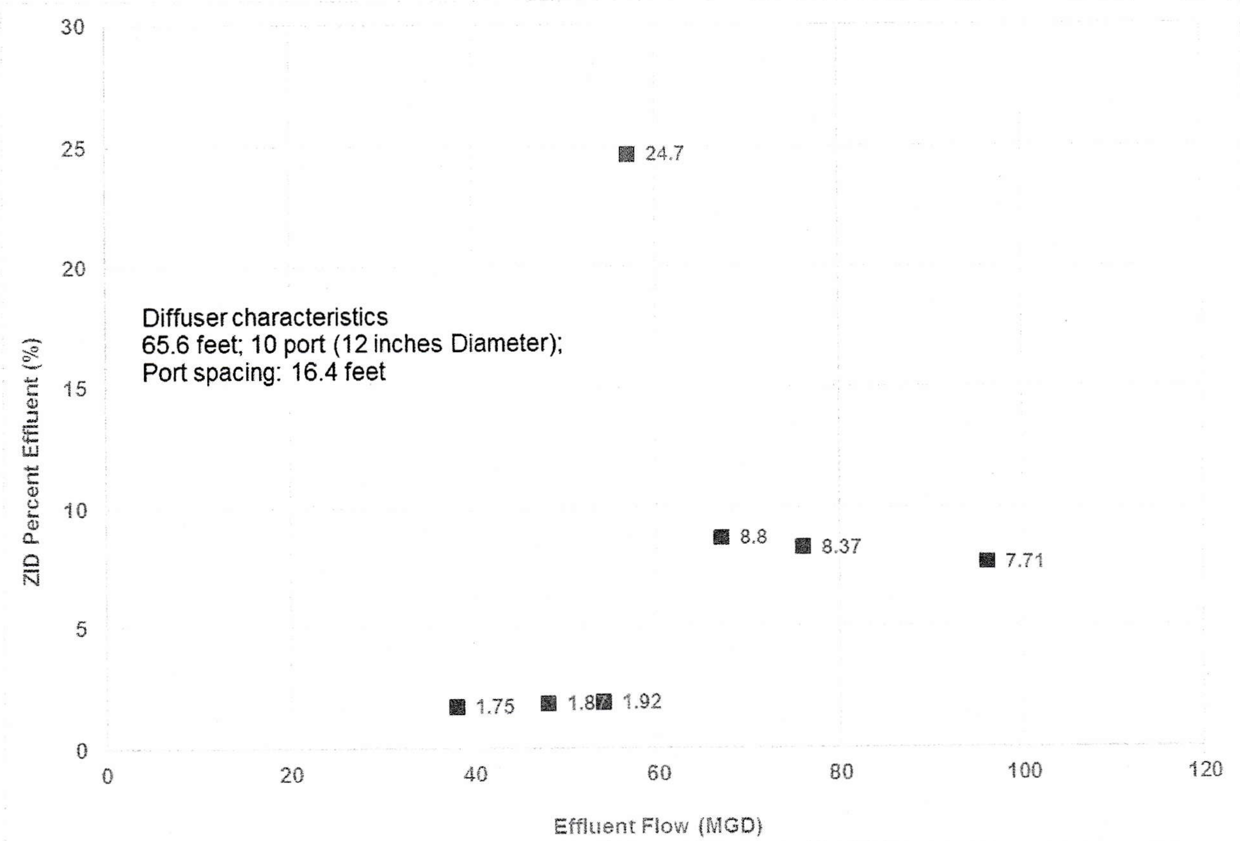

Figure 5: Discharge Flow vs. ZID Percent Effluent for the Specified Diffuser Design Alternative

3.5 Step 5: Diffuser Design Change at 40% RO Recovery Under Different Flow Rates

In this step, diffuser design features were modified to examine whether good mixing can be achieved for a plant capacity of 50 MGD (at 40% RO recovery). Different design alternatives were tested as shown in **Table 8**. This analysis showed that increasing the diffuser diameter leads to better mixing. Design alternative H6 yields a good mixing performance with ZID= 2.25%, MZ=0.94%, and HH=0.8% as shown in **Table 9.** Hence, a diffuser with the following properties would achieve the target mixing performance: **111.5 feet diffuser with 10 ports (24 inches diameters), 2 ports per riser, riser spacing 27.8 feet.**

Table 8: Design Alternatives for 50 MGD Plant at 40% RO Recovery

Design for Flow	Design	Discharge Velocity (ft/s)	Discharge Depth	Port Height (ft)	Number of Port	Port Spacing (ft)	Port Diameter (inches)	Diffuser Length (ft)	Number of Port Per Riser	Variation	Effluent at ZID (%)
50 MGD	H1	18.73	63	12.6	10	16.4	12	65.6	2	Base	8.37

50 MGD	H2	18.73	63	12.6	10	16.4	12	147.6	1	Single port per riser	6.58
50 MGD	H3	4.72	63	12.6	10	16.4	24	65.6	2	Port diameter increased	2.27
50 MGD	H4	4.72	63	12.6	10	24.6	24	98.4	2	Port diameter increased/port spacing increased to 7.5 meter	2.11
50 MGD	H5	4.72	63	12.6	10	26.248	24	104.992	2	Port diameter increased/port spacing increased to 8 meters	2.09
50 MGD	**H6**	**4.72**	**63**	**12.6**	**10**	**27.8885**	**24**	**111.554**	**2**	**Port diameter increased/port spacing increased to 8.5 meters**	**2.06**
50 MGD	H7	4.73	63	12.6	16	16.4	14	114.8	2	Port diameter increased+ number of ports increased	2.25
50 MGD	H8	4.73	63	12.6	22	16.4	16.18	164	2	Port diameter increased/port spacing increased to 8.5 meter	2.08

Table 9: Effluent Percentages and Concentrations at the Three Mixing Zones for 50 MGD Plant at Different Design Alternatives with 40% RO Recovery

Design	Plant	Discharge Flow	Condition	Effluent at ZID (%)	Ambient Salinity (ppt)	Effluent Salinity(ppt)	ZID (ppt)	Percentage above Ambient	Flow Class
H1	50 MGD	96MGD	RO 40%	8.37	22.9	36.64	25.97	13.39%	MU8
H2	50 MGD	96MGD	RO 40%	6.58	22.9	36.64	25.31	10.53%	MU9
H3	50 MGD	96MGD	RO 40%	2.27	22.9	36.64	23.73	3.63%	MU3
H4	50 MGD	96MGD	RO 40%	2.11	22.9	36.64	23.67	3.38%	MU3
H5	50 MGD	96MGD	RO 40%	2.09	22.9	36.64	23.67	3.34%	MU3
H6	**50 MGD**	**96MGD**	**RO 40%**	**2.06**	**22.9**	**36.64**	**23.65**	**3.30%**	**MU3**
H7	50 MGD	96MGD	RO 40%	2.25	22.9	36.64	23.72	3.60%	MU3
H8	50 MGD	96MGD	RO 40%	2.08	22.9	36.64	23.66	3.33%	MU3

Design	Plant	Discharge Flow	Condition	Effluent at MZ (%)	Ambient Salinity (ppt)	Effluent Salinity(ppt)	MZ(ppt)	Percentage above Ambient
H1	50 MGD	76MGD	RO 40%	6.1	22.9	36.64	25.14	9.76%
H2	50 MGD	76MGD	RO 40%	4.58	22.9	36.64	24.58	7.33%

H3	50 MGD	76MGD	RO 40%	1.14	22.9	36.64	23.32	1.82%
H4	50 MGD	76MGD	RO 40%	0.921	22.9	36.64	23.24	1.47%
H5	50 MGD	76MGD	RO 40%	0.888	22.9	36.64	23.23	1.42%
H6	**50 MGD**	**76 MGD**	**RO 40%**	**0.86**	**22.9**	**36.64**	**23.22**	**1.38%**
H7	50 MGD	76MGD	RO 40%	0.937	22.9	36.64	23.24	1.50%
H8	50 MGD	76 MGD	RO 40%	0.77	22.9	36.64	23.18	1.23%

Design	Plant	Discharge Flow	Condition	Effluent at HH (%)	Ambient Salinity (ppt)	Effluent Salinity(ppt)	HH (ppt)	Percentage above Ambient
H1	50 MGD	76 MGD	RO 40%	4.99	22.9	36.64	24.73	7.98%
H2	50 MGD	76 MGD	RO 40%	4.59	22.9	36.64	24.58	0.82%
H3	50 MGD	76 MGD	RO 40%	0.98	22.9	36.64	23.26	0.82%
H4	50 MGD	76 MGD	RO 40%	0.789	22.9	36.64	23.19	0.82%
H5	50 MGD	76 MGD	RO 40%	0.761	22.9	36.64	23.18	0.82%
H6	**50 MGD**	**76 MGD**	**RO 40%**	**0.735**	**22.9**	**36.64**	**23.17**	**1.18%**
H7	50 MGD	76 MGD	RO 40%	0.802	22.9	36.64	23.19	0.82%
H8	50 MGD	76 MGD	RO 40%	0.66	22.9	36.64	23.14	1.06%

The design alternative obtained from the previous step was tested under different discharge flow rates for RO recovery of 40%. The analysis results, shown in **Table 10**, Show that good mixing can be achieved for discharge flow rates of 67 MGD (35 MGD product water) to 96 MGD (50 MGD product water). **Figure 6** shows discharge flow vs. ZID percent effluent for the specified diffuser design alternative. The variations in the ZID percentages under different discharge flow rates is significantly influenced by the "flow class" as defined by the CORMIX model. The flow class for each model run is shown in **Table 10.**

Table 10: Effluent Percentages at the Three Mixing Zones for Design Alternative H6 at Different Flow Rate at 40% Recovery

Design	Plant	Discharge Flow (MGD)	Condition	Effluent at ZID (%)	Ambient Salinity (ppt)	Effluent Salinity(ppt)	ZID (ppt)	Percentage above Ambient	Flow Class
H6	50 MGD	96	RO 40%	2.06	22.9	36.64	23.65	3.30%	MNU3
H6	40 MGD	76	RO 40%	1.91	22.9	36.64	23.60	3.06%	MNU3
H6	35 MGD	67	RO 40%	1.82	22.9	36.64	23.57	2.91%	MNU3

H6	30 MGD	57	RO 40%	22.18	22.9	36.64	31.03	35.49%	MNU1
H6	28 MGD	54	RO 40%	22.43	22.9	36.64	31.12	35.89%	MNU1
H6	25 MGD	48	RO 40%	22.6	22.9	36.64	31.18	36.16%	MNU1
H6	20 MGD	38	RO 40%	23.5	22.9	36.64	31.51	37.60%	MNU1

Design	Plant	Discharge Flow (MGD)	Condition	Effluent at MZ (%)	Ambient Salinity (ppt)	Effluent Salinity(ppt)	MZ (ppt)	Percentage above Ambient
H6	50 MGD	96	RO 40%	0.86	22.9	36.64	23.22	1.38%
H6	40 MGD	76	RO 40%	0.753	22.9	36.64	23.18	1.20%
H6	35 MGD	67	RO 40%	0.7	22.9	36.64	23.16	1.12%
H6	30 MGD	57	RO 40%	16.48	22.9	36.64	28.94	26.37%
H6	28 MGD	54	RO 40%	16.56	22.9	36.64	28.97	26.50%
H6	25 MGD	48	RO 40%	16.63	22.9	36.64	28.99	26.61%
H6	20 MGD	38	RO 40%	17	22.9	36.64	29.13	27.20%

Design	Plant	Discharge Flow (MGD)	Condition	Effluent at HH (%)	Ambient Salinity (ppt)	Effluent Salinity(ppt)	HH (ppt)	Percentage above Ambient
H6	50 MGD	96	RO 40%	0.735	22.9	36.64	23.17	1.18%
H6	40 MGD	76	RO 40%	0.642	22.9	36.64	23.14	1.03%
H6	35 MGD	67	RO 40%	0.596	22.9	36.64	23.12	0.95%
H6	30 MGD	57	RO 40%	12.8	22.9	36.64	27.59	20.48%
H6	28 MGD	54	RO 40%	12.8	22.9	36.64	27.59	20.48%
H6	25 MGD	48	RO 40%	12.8	22.9	36.64	27.59	20.48%
H6	20 MGD	38	RO 40%	12.6	22.9	36.64	27.52	20.16%

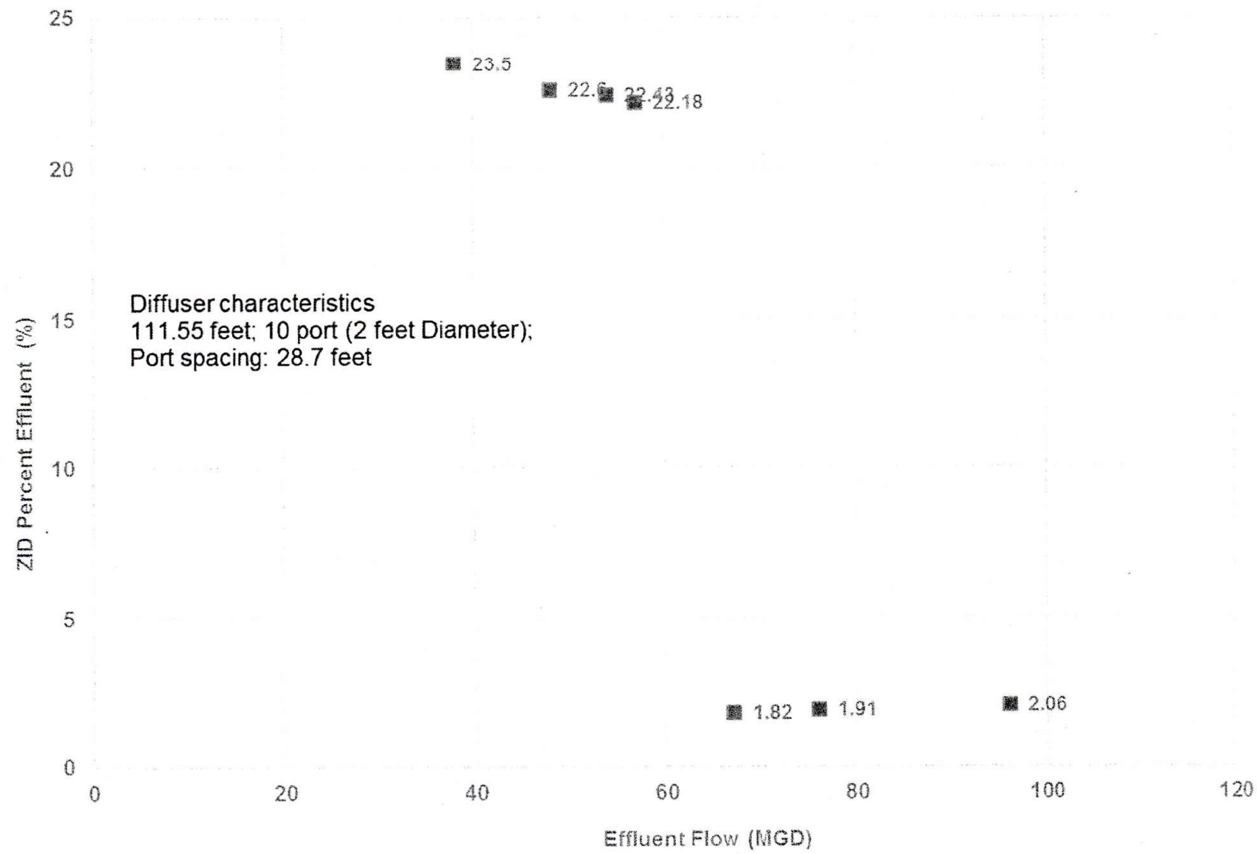

Figure 6: ZID Percent Effluent vs. Effluent Discharge Rate for the Specified Design Alternative at 40% RO Recovery

4. Summary and Conclusions

Conclusions from this modeling study include the following:

- Based on the modeling, the critical ambient condition for effluent mixing (ambient conditions which yield poorest mixing) occur at the 95th percentile of temperature and 5th percentile of salinity for the summer data.
- Significantly better effluent mixing is predicted by the model for 50% RO recovery than for 40% RO recovery for varying diffuser designs. This difference is likely due to the increased density of the effluent at higher salinity.
- At 40% RO recovery, mixing performance varied widely depending on diffuser design for effluent flows ranging from 38 MGD (20 MGD product water) to 96 MGD (50 MGD product water) at critical ambient conditions. Good mixing performance could be achieved for flows within this range (1.75% to 2.06% at the ZID, 0.7% to 0.86 at the aquatic life mixing zone, and 0.535% to 0.735 at the human health

mixing zone) but necessitated changes in the diffuser design. The performance for a given diffuser design varied significantly depending on the flow rate.

- A critical factor in achieving good mixing is the flow profile, which is referred to in the CORMIX model as "flow class". Mixing performance changes significantly when the flow class changes.
- Across the range of flows modeled at 40% RO recovery, effluent targets of 2.5% at the ZID, 1 % at the aquatic life mixing zone, and 0.80 % at the human health mixing zone can readily be achieved with an appropriately designed diffuser.
- For a production rate of 50 MGD, yielding an estimated effluent flow rate of 96 MGD at the critical ambient condition and 40% RO recovery rate, a diffuser with the following properties would achieve the target mixing performance: 111.5 feet diffuser with 10 ports (24 inches diameter), 2 ports per riser, riser spacing 27.8 feet.
- The Port of Corpus Christi proposes to implement a diffuser which will achieve the target mixing performance at the selected design production rate and at the 40% RO recovery rate. Modeling suggests that if the RO recovery rate is increased, mixing performance for the selected design should improve.

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5. References

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ATTACHMENT A

Mixing Analysis Using CORMIX

Mixing Analyses Using CORMIX

Introduction

Detailed site-specific mixing analyses are an alternative to using default effluent percentages for developing permit requirements. The use of effluent diffusers and/or the strategic orientation of outfall pipes can enhance mixing of wastewater effluent with receiving waters and increase critical dilutions (reduce effluent percentages) used to develop permit conditions. The model most commonly used to design diffusers and evaluate mixing near outfalls is CORMIX. This model requires a substantial amount of information on the ambient receiving water conditions, detailed discharge and diffuser configuration information, and knowledge of regulatory mixing zone shapes and sizes. This document outlines the specific information needed to construct or review a CORMIX model and provides standardized methods for developing and interpreting critical cases.

In general, mixing should be evaluated under both summer and winter temperature conditions and at different combinations of effluent and receiving water densities. This is necessary because the most limiting combination of effluent and receiving water conditions cannot be reliably predicted prior to running the model. The highest effluent percentages at the edge of the aquatic life mixing zone and the zone of initial dilution (ZID) will be used to determine water-quality-based permit limits for the protection of aquatic life. Likewise, the highest effluent percentage at the edge of the human health mixing zone will be used to determine water-quality-based permit limits for the protection of human health.

Ambient Data

Widths and Depths

For bounded receiving waters (streams, rivers, and other narrow channels), the application should include information regarding water body width and depth near the proposed discharge location. For unbounded receiving waters (lakes, bays, wide tidal rivers), the application should include information on depths in the vicinity of the discharge point (200 foot radius for lakes, 400 foot radius for bays or wide tidal rivers).

Velocity

Streams and Rivers. In flowing water bodies, use velocity calculated from the 7Q2 flow, the average width, and the average depth. If necessary, dilution estimates for human health protection can be developed using velocity calculated from harmonic mean flow. Calculate the 7Q2 and harmonic mean flows using methods outlined in the most current version of the *Procedures to Implement the Texas Surface Water Quality Standards*. Calculate the average width and depth using the data provided by the applicant.

Lakes, Bays, and Wide Tidal Rivers. In lakes or tidal water bodies, the applicant may provide velocity information. Otherwise, assume a small velocity, but large enough so that the model does not predict dilutions greater than the limiting dilution. An ambient velocity of zero may be used to obtain results in the near field only.

Wind Speed

Use a wind speed of 2 m/s unless the applicant provides site-specific information that demonstrates the wind speed should be greater.

Density

Good characterization of ambient density is an extremely important component of the mixing analysis. Therefore, an effort should be made to maximize the use of available data in order to develop meaningful statistics.

Select the appropriate SWQM station or stations and extract the following parameters:

Parameter	Code
Temperature	00010
Conductivity	00094
Salinity	00480

Generally there is more conductivity data than salinity data available. If paired salinity and conductivity data are available, develop a regression (2nd order usually fits better than linear) for salinity as a function of conductivity. Use the regression equation to calculate salinity for those conductivity measurements without a corresponding reported salinity in order to bolster the salinity data set. If paired salinity and conductivity data are not available, use the conductivity values to calculate salinity from the following equations:

S(ppt) = 0.000589 × conductivity (μmhos/cm) (for conductivities < 17,000)
S(ppt) = (0.000682 × conductivity)-1.7 (μmhos/cm) (for conductivities ≥ 17,000)

Determine the 5th and 95th percentile temperatures and salinities, and calculate the density for each combination of temperature and salinity: $\rho(T_5, S_5)$, $\rho(T_5, S_{95})$, $\rho(T_{95}, S_5)$, and $\rho(T_{95}, S_{95})$. These percentiles need to be developed for both summer (June, July, and August) and winter (December, January, and February) seasons if the effluent exhibits seasonal density variation. Use the resulting salinities along with their corresponding temperatures to calculate densities using the following equation:

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

where:

$\rho_{s,t,o}$	=	water density (kg/m3 or g/cm3)
T	=	water temperature (°C)
S	=	water salinity (ppt)

For some estuarine outfall locations, density stratification can have an important influence on mixing characteristics. To determine whether stratification should be factored into the analysis, a detailed evaluation of density profile data should be performed. For each date where profile data is available, calculate the density at each point in the water column and calculate the overall density difference from surface to bottom or to a depth equal to the average depth near the outfall, whichever is less. According to CORMIX guidance, if the density changes by more than 0.1 kg/m3 from surface to bottom, stratification should be considered in the model analysis. If the density does not change this much, the water column can be considered unstratified. If the water column routinely exhibits stratification (more than 10% of the time), use the calculated surface-to-bottom density differences to determine the median density difference ($\Delta\rho_{median}$) to use later in the analysis.

Discharge Data

Diffuser Design and Orientation

The application should include drawings or schematics of the diffuser and its orientation relative to the receiving water. Distances and angles should be clearly marked. If not, contact the applicant and request this information.

Effluent Flow

Run the model using the following effluent flows as applicable:

- Existing permitted flow (renewal or amendment)
- Proposed permitted flow (new or amendment)
- Most recent two-year median monthly average flow (renewal or amendment)

Effluent Density

The application should include effluent temperature and salinity information along with calculated effluent densities (ρ_{eff}). When running the model, be sure to maintain the seasonal relationship between ambient and effluent densities; that is, do not model a winter effluent density with a summer ambient density.

Mixing Zone Definition

Single-port Diffusers

For single-port diffuser discharges to saltwater bodies or freshwater lakes, effluent percentages will need to be determined at the intersection of the plume centerline with the radial mixing zone distances given in Table 1, where:

$$D = \sqrt{X^2 + Y^2}$$

and where: D = distance from outfall
X = CORMIX x-coordinate of plume centerline
Y = CORMIX y-coordinate of plume centerline

For discharges to flowing freshwater streams or rivers, effluent percentages will need to be determined in the x-coordinate direction at the upstream and downstream longitudinal distances given in Table 1.

Table 1. Standard regulatory mixing zone distances for various types of water bodies.

Water Body Type		ZID (m)	MZ (m)	HH MZ (m)
Wide Tidal River, Bay, Estuary		15.24*	60.96*	121.92*
Narrow Tidal River (width < 400')	upstream	6.10	30.48	30.48
	downstream	18.29	91.44	91.44
Freshwater Lake		7.62*	30.48*	60.96*
Freshwater Stream	upstream	6.10	30.48	30.48
	downstream	18.29	91.44	91.44

* Radial distance from outfall.

Multiport Diffusers

For multiport diffuser discharges, the ZID and both mixing zones typically will be rectangular in shape and equal in area to the standard ZID and mixing zone sizes. The ZID and mixing zones may be centered on or aligned along the diffuser barrel. The position of the ZID and mixing zones relative to the diffuser will depend on two things:

1) the nature of the receiving water (tidally reversing or one-direction flow)
2) the orientation of the diffuser ports to the receiving water current.

A schematic depicting the configuration of the mixing zones relative to the multiport diffuser should be drawn to aid in the interpretation of model results.

Model Scenarios

Since the most limiting combination of effluent and receiving water conditions cannot be reliably predicted in advance of running the model, a range of modeling scenarios should be performed in order to determine protective effluent dilutions. For consistency, set the model up to predict percent effluent.

For effluents with relatively constant density year round, the following standard effluent/ambient density combination model runs should be performed for **each effluent flow case**:

- $\rho_{eff} / \rho(T_5, S_5)$
- $\rho_{eff} / \rho(T_5, S_{95})$
- $\rho_{eff} / \rho(T_{95}, S_5)$
- $\rho_{eff} / \rho(T_{95}, S_{95})$

For effluents with seasonal density variation, the following standard effluent/ambient density combination model runs should be performed for **each effluent flow case:**

Winter Conditions

- $\rho_{eff} / \rho(T_5, S_5)$
- $\rho_{eff} / \rho(T_5, S_{95})$
- $\rho_{eff} / \rho(T_{95}, S_5)$
- $\rho_{eff} / \rho(T_{95}, S_{95})$

Summer Conditions

- $\rho_{eff} / \rho(T_5, S_5)$
- $\rho_{eff} / \rho(T_5, S_{95})$
- $\rho_{eff} / \rho(T_{95}, S_5)$
- $\rho_{eff} / \rho(T_{95}, S_{95})$

If stratification was determined to be a routine characteristic of the receiving waters, further model scenarios will need to be run and evaluated. The stratification model case(s) should be developed from the most critical case(s) identified from the standard cases described previously. For each standard case that produced a critical dilution estimate (max. % effluent) for any mixing zone type (ZID, MZ, HH MZ), rerun the critical standard case(s) after adjusting the ambient density in the following manner:

$$\rho_{surface} = \rho_{standard} - (0.5 \times \Delta\rho_{median})$$
$$\rho_{bottom} = \rho_{standard} + (0.5 \times \Delta\rho_{median})$$

Choose the Stratification Type A (linear stratification) model setting for all stratification case scenarios.

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ATTACHMENT B

Reported Corpus Christi Bay Ambient Properties

Reported Corpus Christi Bay Ambient Properties

Corpus Christi Bay is bordered on the North by Redfish Bay; on the south by the upper Laguna Madre; on the east by Mustang Island; and on the west by the City of Corpus Christi. The Corpus Christi Bay System has a total area of 124,796 acres with 127 miles of shoreline. The largest bay in this system is Corpus Christi Bay, which covers 95,997 acres.

The diurnal tide within Corpus Christi Bay has a typical range of approximately 3 ft along the coast, but the tidal amplitude is significantly reduced through the Aransas Pass inlet channel and lower portion of the ship canal, resulting in a typical tidal range of only approximately 1 ft in the main part of Corpus Christi Bay, including the proposed La Quinta site discharge location. There has been a seasonal component to the Corpus Christi Bay water level over the past 20 years, with the lowest average water level of approximately 0.3 ft NAVD during January and the high of approximately 1.4 ft during October.

Corpus Christi Bay is a relatively shallow bay with uniform depth (Nelson, 2012). Stratification is typically absent or small in shallow bays with mixing mechanisms. Ward and Armstrong (1997) state that there is no increase in salinity along the ship channel relative to the bay outside of the ship channel due to density currents. Salinity is variable, but the average is relatively constant over the Bay with a gradient transverse to the axis of the Bay. The salinity is typically highest near the southeast corner of the Bay near Laguna Madre. A hyper-saline gravity current originating in Oso Bay and extending into Corpus Christi Bay has been observed (Nelson, 2012). Nelson attributes the limited stratification observed within Laguna Madre and Oso Bay to be caused by winds, rather than other possible processes producing stratification. Ward and Armstrong (1997) state that the average weak stratification is relatively uniform and typically less than 0.5 parts per thousand (ppt) per meter (ppt/m) nearly everywhere and less than 0.3 ppt/m across half of the Corpus Christi Bay system. [1]

General circulation is described by the Texas Parks and Wildlife Department's Sea Center web page as being counter clockwise along the shoreline with a prevailing wind from the southeast being a primary factor for the circulation.

References:

1. http://www.cbbep.org/publications/virtuallibrary/CCBNEP-23.pdfTCEQ. 2017, updated daily. Surface Water Quality Monitoring Information System, May 22, 1969 – May 11, 2017. Compiled by Data Management & Analysis Team. Austin, Texas USA. Data Request ID 322

ATTACHMENT C

Flow Classes Definition by COMRIX

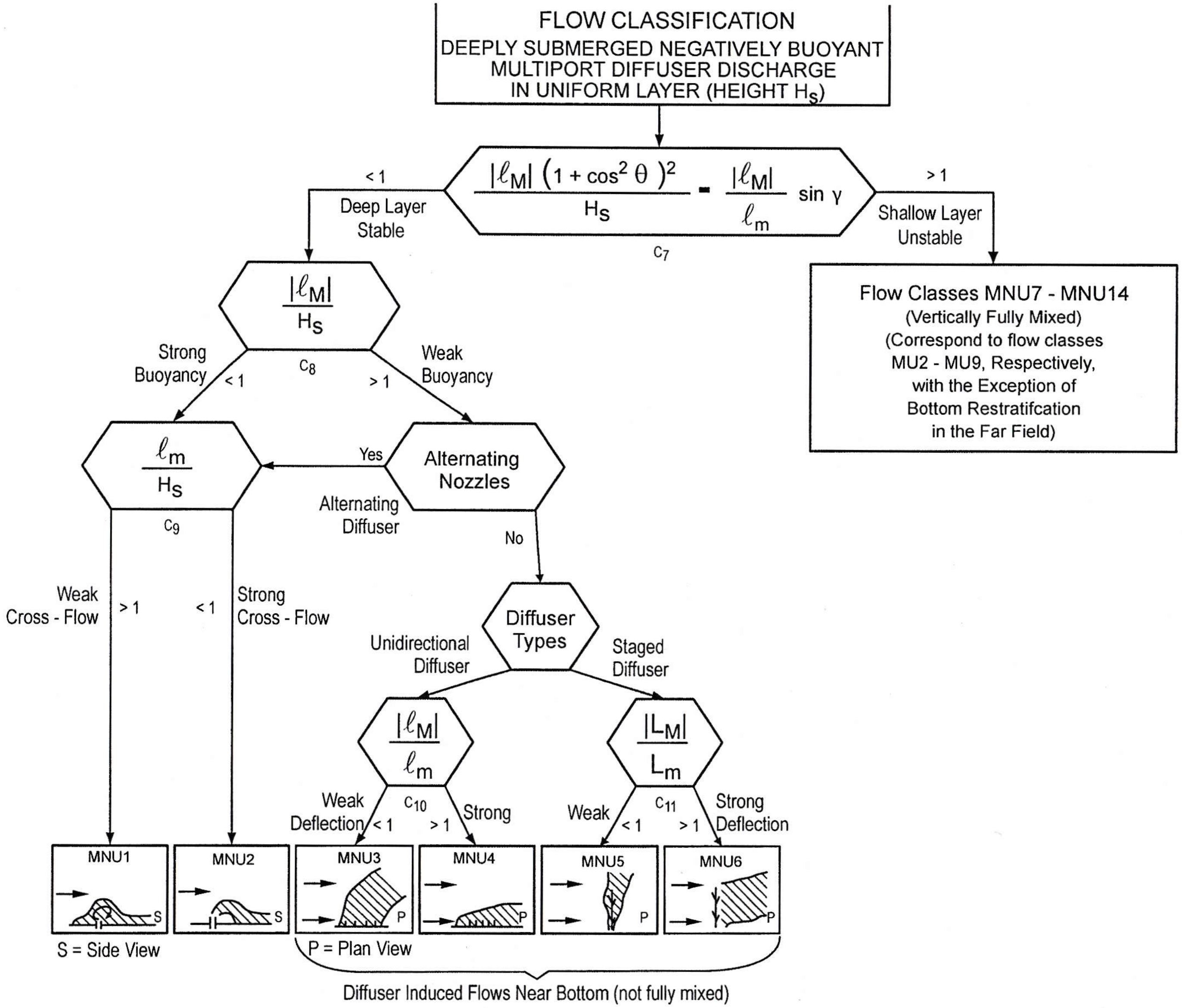

Figure A.7.a *CORMIX2 Classification: Behavior of negatively buoyant multiport diffuser discharges in uniform ambient layer flow (Flow classes MNU)*

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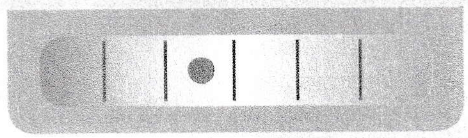
APPENDIX B

EPA Salinity Variation Q&A

FOCUS QUESTION 6:

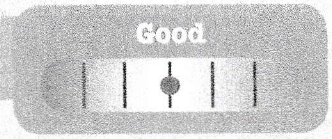
Are freshwater inflows adequate to maintain a healthy bay system?

What was measured: Freshwater inflows and Corpus Christi Bay system salinity levels



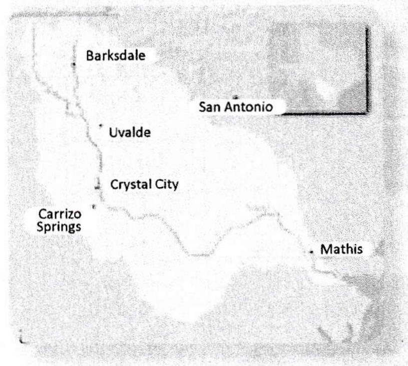
Answer: Maybe, because the freshwater inflows have been altered and managed. Studies are underway to determine the health of the bays and estuaries based on inflows and salinity.

INDICATOR #18: Quantity and timing of freshwater inflows.
Condition/Trend: Good/Stable



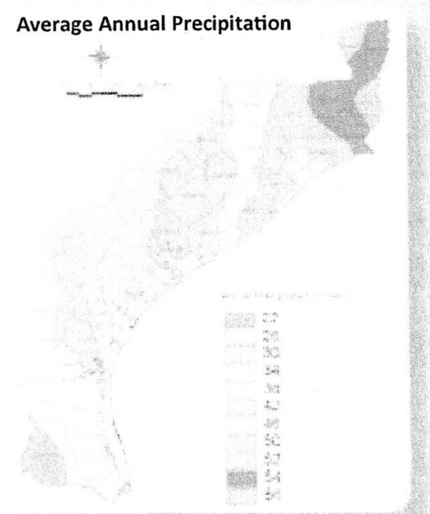
I. BACKGROUND

The flow of freshwater into a bay system from its watershed (drainage areas to a particular body of water) helps to ensure that necessary salinity, nutrient, and sediment loading are adequate in order to maintain productivity of economically and ecologically important species. Sources of freshwater inflows entering into the bays and estuaries consist of rain, groundwater, and the largest contributor, surface water from rivers and streams. The characteristic natural community living in and around the Texas Coastal Bend bay system is largely defined by the volume, timing, location, and quality of freshwater inflows.



Nueces River Watershed

The Nueces River is one of the largest contributors of freshwater into our local bays and estuaries. Because of the altered freshwater inflows into Nueces Bay due to the Choke Canyon and Lake Corpus Christi Reservoirs, it is necessary to regulate inflows with "pass through" requirements that allow a certain amount of freshwater flow into the Nueces River each month.



The City of Corpus Christi is responsible for distributing water to all necessary users and consumers, as well as ensuring all target pass through requirements to the Nueces Estuary are met. The Nueces River Authority (NRA), a governmental organization created in 1935, works closely with the City of Corpus Christi to preserve, protect, and develop surface water resources including flood control, irrigation, navigation, water supply, wastewater treatment, and water quality control within the Nueces River Basin.

II. CONCERNS

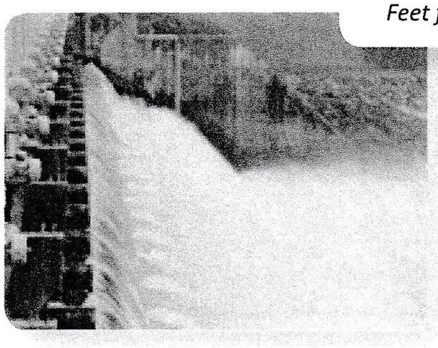
Natural fluctuations in freshwater inflows into the bay can have an immense impact on organisms within the bay system. For example, if a long drought persists and creates a situation of very little freshwater inflow into the bay, it may cause hypersaline (high salt) conditions that in turn affect bay shrimp catches which need a certain salinity range in order to mature in healthy numbers. On the other extreme, there may be an abundance of freshwater inflow after an extended heavy rain event that causes eutrophication (high nutrient conditions), triggers large algal blooms that deplete oxygen and light within the water column, and negatively effects fish and plants living in the bays.

III. LOCAL FRESHWATER INFLOW LEVELS

When looking at the distribution of freshwater inflow into the Coastal Bend bays, there is a definite trend of less rain from north to south. While scientific work continues to determine the amount and location of monthly inflows needed, recommendations were made in 1991 that developed the current target levels of annual freshwater inflows to the bay system. Since the "pass through targets" attempt to mimic the natural freshwater inflow cycle into the Corpus Christi Bay system, there is a greater chance of maintaining a healthy estuary for fish and wildlife, as well as its human inhabitants.

Pass Through Targets (AcFt)				
Month	Capacity<=70%	40%<= Capacity<=70%	30%<= Capacity<=40%	Capacity<=30%
January	2,500	2,500	1,200	0
February	2,500	2,500	1,200	0
March	3,500	3,500	1,200	0
April	3,500	3,500	1,200	0
May	25,500	23,500	1,200	0
June	25,500	23,000	1,200	0
July	6,500	4,500	1,200	0
August	6,500	5,000	1,200	0
September	28,500	11,500	1,200	0
October	20,000	9,000	1,200	0
November	9,000	4,000	1,200	0
December	4,500	4,500	1,200	0

Choke Canyon/Lake Corpus Christi Reservoirs pass through targets measured in Acre Feet for the Nueces River which the City of Corpus Christi is required to follow:



Wesley Seale Dam

Freshwater Inflow
- Quantity
- Timing
- Quality

→

Estuarine Conditions
- Salinity
- Sediment
- Dissolved Material
- Particulate Material

→

Estuarine Resources
- Species Composition, Abundance, Distribution
- Primary and Secondary Production

Freshwater Inflow cause and effect diagram.

IV. REFERENCES

- Asquith, W. H., Mosier, J.G., and P.W. Bush. 1997. Status, Trends, and Changes in Freshwater Inflows to Bays Systems in the Corpus Christi Bay National Estuary Program Study Area. Corpus Christi Bay National Estuary Program. 48 pp.
- City of Corpus Christi. 2007. Frequently Asked Questions About Water Related Issues In Corpus Christi. http://www.cctexas.com/?fuseaction=main.view&page=2841
- Nueces River Authority. 2007. Basin highlights report. Report prepared in cooperation with the Texas Commission on Environmental Quality Clean Rivers Program. Corpus Christi, 82 pp.

INDICATOR #19: Bay salinity levels (within desired target ranges).

Condition/Trend: Good/Stable

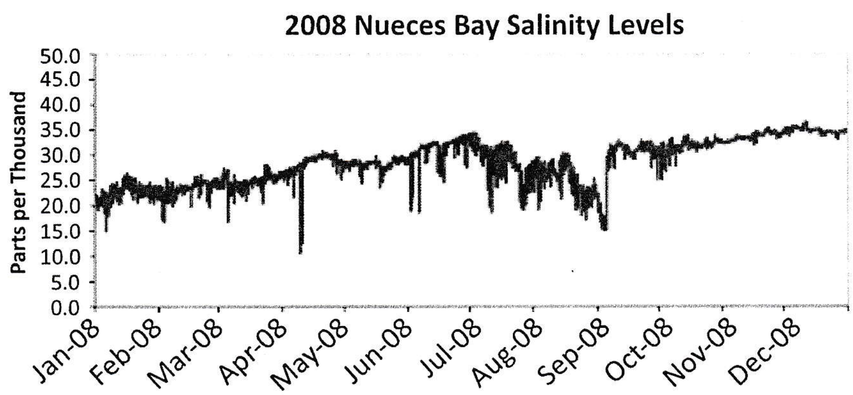
Improvement Needed

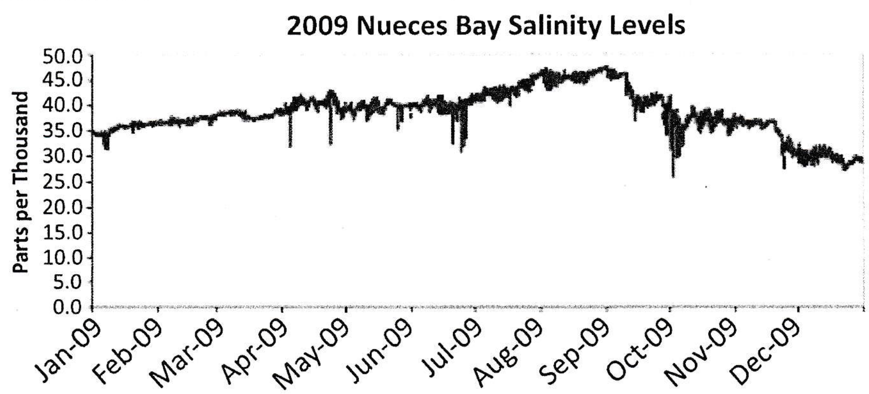
I. BACKGROUND

Salinity is a measure of how much sea salt is contained in a unit of water. The Gulf of Mexico coastal seawater is relatively constant at about 35 parts sea salt per thousand parts water by weight. Salinity of freshwater is near zero. Therefore, most of the salinity variations in the estuary are responses to river inflow, evaporation and mixing by winds and ocean tides.

The ability of resource agencies to manage fish, wildlife and freshwater supplies to the Corpus Christi Bay estuary requires an integrated knowledge of the relations between the organisms and their environment. The salinity of the water, and particularly its seasonality patterns, affect which aquatic species can survive. In short, salinity is a fundamental property of the estuary that determines its biological characteristics.

The Texas Water Development Board has been recording salinity levels since 1987 for the various bays around the Coastal Bend. The Conrad Blucher Institute's Division of Nearshore Research at Texas A&M University-Corpus Christi maintains salinity monitoring stations within the Corpus Christi Bay system and posts a salinity relief check page that is updated daily. The site can be accessed at http://lighthouse.tamucc.edu/Salinity/HomePage.





II. CONCERNS

Management of the freshwater supply is complicated in part because Lake Corpus Christi's freshwater supply serves two major purposes: human consumption and salinity control. When freshwater runoff from the Nueces Watershed is scarce, as in dry years, a proportionally greater amount of available freshwater from the estuary is needed for human use as well as for salinity control.

In order to relieve some salinity stress from within the estuary, salinity pass through targets were developed, based on historical salinity levels, in attempts to mimic natural salinity levels within the bay system. In simple terms, if salinity is too high, freshwater is released to lower salinity levels. When salinity is too low, the City of Corpus Christi gets a Salinity Relief Credit which allows for less freshwater pass through entering into the bay system, allowing salinity levels a chance to increase back to normal levels.

III. LOCAL LEVELS

Salinity gradients along the Texas Coastal Bend bays from the upper to lower regions are a normal feature. Salinity measured within each bay system such as the San Antonio Bay may be as low as zero parts per thousand (ppt), while values as high as 70 ppt may occur in Baffin Bay and the Upper Laguna Madre.

The Corpus Christi Bay system, which receives runoff from urban areas in addition to Nueces River inflow, experiences lower average salinities than the southern region of the Coastal Bend area with an average salinity in 2008 of around 28 ppt compared to an average salinity of 39 ppt in 2009 for Nueces Bay. Optimum salinity ranges vary for the Corpus Christi Bay system depending on proximity to the river and season, but in general, salinities can be between 1 to 30 ppt. By keeping salinities within this target range, fish, wildlife, and plants will be less stressed and more productive.

The City of Corpus Christi receives 500 acre feet per month return flow credit for all return flows into Nueces Bay and possibly one of the following: up to half of the monthly target from flows exceeding the freshwater inflow requirement of the previous month or the salinity relief credit when the salinity in Nueces Bay is low.

Salinity Relief Credit Chart

Months	Salinity Lower Bounds	Salinity Upper Bounds	Reduction for Average Salinity		
			5 psu below SUB	10 psu below SUB	15 psu below SUB
January	5	30	25%	50%	75%
February	5	30	25%	50%	75%
March	5	30	25%	50%	75%
April	5	30	25%	50%	75%
May	1	20	0%	25%	75%
June	1	20	0%	25%	75%
July	2	25	25%	50%	75%
August	2	25	25%	50%	75%
September	5	20	0%	25%	75%
October	5	30	0%	25%	75%
November	5	30	25%	50%	75%
December	5	30	25%	50%	75%

Measuring salinity using a refractometer.

IV. REFERENCES

- City of Corpus Christi. 2007. Frequently Asked Questions About Water Related Issues In Corpus Christi. http://www.cctexas.com/?fuseaction=main.view&page=2841
- Conrad Blucher Institute – Division of Nearshore Research. 2010. Nueces Bay Salinity. http://lighthouse.tamucc.edu/Salinity/HomePage