Appendix G
USEPA National Pollutant Discharge Elimination System (NPDES) Water Permit Application

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM PERMIT APPLICATION

GULF LANDING LNG REGASIFICATION TERMINAL

Submitted to:

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 6
1445 Ross Avenue
Dallas, Texas 75202-2733

Submitted by:

GULF LANDING LLC
a wholly owned subsidiary of Shell US Gas & Power
1301 McKinney, Suite 700
Houston, Texas 77010

October 2003

Please print or type in the unshaded areas only
(fill-in areas spaced for elite type, i.e., 12 characters/inch).

Form Approved OMB No. 2040-0086 Approval expires 7-31-88

FORM 1 GENERAL

EPA

U.S. ENVIRONMENTAL PROTECTION AGENCY

GENERAL INFORMATION

Consolidated Permits Program

(Read the "General Instructions" before starting.)

1. EPA I.D. NUMBER

%		T/A	C
F			D
1	2 – 13	14	15

LABEL ITEMS

- I. EPA I.D. NUMBER
- III. FACILITY NAME
- V. FACILITY MAILING ADDRESS
- VI. FACILITY LOCATION

PLEASE PLACE LABEL IN THIS SPACE

GENERAL INSTRUCTIONS

If a preprinted label has been provided, affix it in the designated space. Review the information carefully; if any of its is incorrect, cross through it and enter the correct data in the appropriate fill-in area below. Also, if any of the preprinted data is absent *(the area to the left of the label space lists the information that should appear)*, please provide it in the proper fill-in area(s) below. If the label is complete and correct you need not complete Items I, III, V, and VI *(except VI-B which must be completed regardless)*. Complete all items if no label has been provided. Refer to the instructions for detailed item descriptions and for the legal authorizations under which this data is collected.

II. POLLUTANT CHARACTERISTICS

INSTRUCTIONS: Complete A through J to determine whether you need to submit any permit application forms to the EPA. If you answer "yes" to any questions, you must submit this form and the supplemental form listed in the parenthesis following the question. Mark "X" in the box in the third column if the supplemental form is attached. If you answer "no" to each question, you need not submit any of these forms. You may answer "no" if your activity is excluded from permit requirements; see Section C of the instructions. See also, Section D of the instructions for definitions of bold-faced terms.

SPECIFIC QUESTIONS	YES	NO	FORM ATTACHED
A. Is this facility a publicly owned treatment works which results in a discharge to waters of the U.S.? (FORM 2A)		X	
B. Does or will this facility *(either existing or proposed)* include a concentrated animal feeding operation or aquatic animal production facility which results in a discharge to waters of the U.S.? (FORM 2B)		X	
C. Is this a facility which currently results in discharges to waters of the U.S. other than those described in A or B above? (FORM 2C)		X	
D. Is this a proposed facility *(other than those described in A or B above)* which will result in a discharge to waters of the U.S.? (FORM 2D)	X		Form 2 D
E. Does or will this facility treat, store, or dispose of hazardous wastes? (FORM 3)		X	
F. Do you or will you inject at this facility industrial or municipal effluent below the lowermost stratum containing, within one quarter mile of the well bore, underground sources of drinking water? (FORM 4)		X	
G. Do you or will you inject at this facility any produced water or other fluids which are brought to the surface in connection with conventional oil or natural gas production, inject fluids used for enhanced recovery of oil or natural gas, or inject fluids for storage of liquid hydrocarbons? (FORM 4)		X	
H. Do you or will you inject at this facility fluids for special processes such as mining of sulfur by the Frasch process, solution mining of minerals, in situ combustion of fossil fuel, or recovery of geothermal energy? (FORM 4)		X	
I. Is this facility a proposed stationary source which is one of the 28 industrial categories listed in the instructions and which will potentially emit 100 tons per year of any air pollutant regulated under the Clean Air Act and may affect or be located in an attainment area? (FORM 5)		X	
J. Is this facility a proposed stationary source which is NOT one of the 28 industrial categories listed in the instructions and which will potentially emit 250 tons per year of any air pollutant regulated under the Clean Air Act and may affect or be located in an attainment area? (FORM 5)		X	

III. NAME OF FACILITY

c 1 SKIP (15, 16 – 29, 30 – 69)

Gulf Landing LNG Regasification Terminal

IV. FACILITY CONTACT

A. NAME & TITLE *(last, first, & title)*	B. PHONE *(area code & no.)*		
Larry D. Jensen Manager, Regulatory	713	230	3134

V. FACILITY MAILING ADDRESS

A. STREET OR P.O. BOX

1301 McKinney, Suite 700

B. CITY OR TOWN	C. STATE	D. ZIP CODE
Houston	TX	77010

VI. FACILITY LOCATION

A. STREET, ROUTE NO. OR OTHER SPECIFIC IDENTIFIER

Federal Lease Block, West Cameron, Block #213

B. COUNTY NAME

Gulf of Mexico

C. CITY OR TOWN	D. STATE	E. ZIP CODE	F. COUNTY CODE *(if known)*
Off Louisiana Coast	N/A	N/A	N/A

CONTINUED FROM THE FRONT

VII. SIC CODES (4-digit, in order of priority)

	Code	Specify
A. FIRST	4491	Marine Cargo (LNG) Handling Offshore Terminal
B. SECOND	N/A	N/A
C. THIRD	N/A	N/A
D. FOURTH	N/A	N/A

VIII. OPERATOR INFORMATION

A. NAME: Gulf Landing LLC

B. Is the name listed in Item VIII-A also the owner? ☒ YES ☐ NO

C. STATUS OF OPERATOR *(Enter the appropriate letter into the answer box; if "Other", specify.)*

F = FEDERAL M = PUBLIC *(other than federal or state)*
S = STATE O = OTHER *(specify)*
P = PRIVATE

Answer: P *(specify)* N/A

D. PHONE *(area code & no.)*: 713 230 3134

E. STREET OR P.O. BOX: 1301 McKinney, Suite 700

F. CITY OR TOWN	G. STATE	H. ZIP CODE
Houston	TX	77010

IX. INDIAN LAND

Is the facility located on Indian lands?

☐ Yes ☒ No

X. EXISTING ENVIRONMENTAL PERMITS

Permit	C	T	Number
A. NPDES *(Discharges to Surface Water)*	9	N	None
B. UIC *(Underground Injection of Fluids)*	9	U	None
C. RCRA *(Hazardous Wastes)*	9	R	None
D. PSD *(Air Emissions from Proposed Sources)*	9	P	None
E. OTHER *(specify)* N/A	9		None
E. OTHER *(specify)* N/A	9		None

XI. MAP

Attach to this application a topographic map of the area extending to at least one mile beyond property boundaries. The map must show the outline of the facility, the location of each of its existing and proposed intake and discharge structures, each of its hazardous waste treatment, storage or disposal facilities, and each well where it injects fluids underground. Include all springs, rivers and other surface water bodies in the map area. See instructions for precise requirements.

XII. NATURE OF BUSINESS *(provide a brief description)*

See Attachment 1-XII.

XIII. CERTIFICATION *(see instructions)*

I certify under penalty of law that I have personally examined and am familiar with the information submitted in this application and all attachments and that, based on my inquiry of those persons immediately responsible for obtaining the information contained in the application, I believe that the information is true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment.

A. NAME & OFFICIAL TITLE *(type or print)*	B. SIGNATURE	C. DATE SIGNED
A. Y. Noojin, III President, Gulf Landing LLC	A Y Noojin III	10/21/03

COMMENTS FOR OFFICIAL USE ONLY

Please print or type in the unshaded areas only.	**EPA I.D. NUMBER** *(copy from Item 1 of Form 1* Not Applicable	*Form Approved OMB No. 2040-0086 Approval expires 7-31-88*

FORM **2 D** NPDES

EPA

New Sources and New Dischargers Application for Permit to Discharge Process Wastewater

I. Outfall Location

For each outfall, list the latitude and longitude, and the name of the receiving water.

Outfall Number *(list)*	Latitude			Longitude			Receiving Water *(name)*
	Deg	Min	Sec	Deg	Min	Sec	
001	29	13	13.2	93	16	34.5	Gulf of Mexico
002	29	13	16.5	93	16	27.3	Gulf of Mexico
003	29	13	16.5	93	16	27.3	Gulf of Mexico
004	29	13	16.5	93	16	27.3	Gulf of Mexico
005	29	13	16.5	93	16	27.3	Gulf of Mexico
006	29	13	16.5	93	16	27.3	Gulf of Mexico

II. Discharge Date *(When do you expect to begin discharging?)* January 2009

+

III. Flows, Sources of Pollution, and Treatment

A. For each outfall, provide a description of (1) All operations contributing wastewater to the effluent, including process wastewater, sanitary wastewater, cooling water, and stormwater runoff; (2) The average flow contributed by each operation; and (3) The treatment received by the wastewater. Continue on additional sheets if necessary.

Outfall Number	1. Operations Contributing Flow *(list)*	2. Average Flow *(include units)*	3. Treatment *(Description or List Codes from Table 2D-1)*
001	Thermal Water for ORV	136 MGD	4-B Ocean Discharge Through Outfall
002	Deck Drainage Wastewater	0.0058 MGD	1-H Oil/Water Separator 4-A Discharge to Surface Water
003	Uncontaminated Deck Water	0.0209 MGD	4-A Discharge to Surface Water
004	Desalinization Rejected Water	0.0254 MGD	4-A Discharge to Surface Water
005	Treated Sanitary & Domestic Wastewater	0.0075 MGD	2-F Chlorinated Marine Sanitation Device 4-A Discharge to Surface Water
006	Firewater Bypass	0.5035 MGD	4-A Discharge to Surface Water

B. Attach a line drawing showing the water flow through the facility. Indicate sources of intake water, operations contributing wastewater to the effluent, and treatment units labeled to correspond to the more detailed descriptions in Item III-A. Construct a water balance on the line drawing by showing average flows between intakes, operations, treatment units, and outfalls. If a water balance cannot be determined (e.g., for certain mining activities), provide a pictorial description of the nature and amount of any sources of water and any collection or treatment measures.

C. Except for storm runoff, leaks, or spills, will any of the discharges described in Item III-A be intermittent or seasonal?

☐ Yes (*complete the following table*) ☒ No (*go to Item IV*)

Outfall Number	1. Frequency		2. Flow		
	A. Days Per Week (*specify average*)	b. Months Per Year (*specify average*)	a. Maximum Daily Flow Rate (*in mgd*)	b. Maximum Total Volume (*specify with units*)	c. Duration (*in days*)
Not Applicable					

IV. Prouction

If there is an applicable production-based effluent guidelines or NSPS, for each outfall list the estimated level of production (projection of actual production level, not design), expressed in the terms and units used in the applicable effluent guideline or NSPS, for each of the first 3 years of operation. If production is likely to vary, you may also submit alternative estimates (attach a separate sheet).

Year	a. Quantity Per Day	b. Units of Measure	c. Operation, Product, Material, etc. (*specify*)

This project is an offshore liquefied natural gas (LNG) receiving terminal. The LNG will be revaporized and delivered into existing into existing offshore pipelines

CONTINUED FROM THE FRONT	EPA I.D. NUMBER *(copy from Item 1 of Form 1)*	Outfall Number
	Not Applicable	001

V. Effluent Characteristics

A, and B. These items require you to report estimated amounts *(both concentration and mass)* of the pollutants to be discharged from each of your outfalls. Each part of this item addresses a different set of pollutants and should be completed in accordance with the specific instructions for that part. Data for each outfall should be on a separate page. Attach additional sheets of paper if necessary.

General Instructions *(See table 2D-2 for Pollutants)*
Each part of this item requests you to provide an estimated daily maximum and average for certain pollutants and the source of information. Data for all pollutants in Group A, for all outfalls, must be submitted unless waived by the permitting authority. For all outfalls, data for pollutants in Group B should be reported only for pollutants which you believe will be present or are limited directly by an effluent limitations guideline or NSPS or indirectly through limitations on an indicator pollutant.

1. Pollutant	2. Maximum Daily Value *(include units)*	3. Average Daily Value *(include units)*	4. Source *(see instructions)*
Biochemical Oxygen Demand (BOD_5)	<20 mg/L	<20 mg/L	4-Best Professional Estimate
Chemical Oxygen Demand (COD)	<40 mg/L	<40 mg/L	4-Best Professional Estimate
Total Organic Carbon (TOC)	<25 mg/L	<25 mg/L	4-Best Professional Estimate
Total Suspended Solids (TSS)	<20 mg/L	<20 mg/L	4-Best Professional Estimate
Ammonia (as N)	<0.1 mg/L	<0.1 mg/L	4-Best Professional Estimate
Temperature (winter)	3-18°C	3-18°C	4-Best Professional Estimate
Temperature (summer)	10-25°C	10-25°C	4-Best Professional Estimate
pH	6-9 s.u.	6-9 s.u.	4-Best Professional Estimate
Total Residual Chlorine	<0.5 mg/L	<0.5 mg/L	4-Best Professional Estimate
Bromoform	<0.02 mg/L	<0.01 mg/L	4-Best Professional Estimate
Flow	150 MGD	136 MGD	4-Best Professional Estimate

 CONTINUE ON NEXT PAGE

CONTINUED FROM THE FRONT	EPA I.D. NUMBER *(copy from Item 1 of Form 1)*	Outfall Number
	Not Applicable	002

V. Effluent Characteristics

A, and B. These items require you to report estimated amounts *(both concentration and mass)* of the pollutants to be discharged from each of your outfalls. Each part of this item addresses a different set of pollutants and should be completed in accordance with the specific instructions for that part. Data for each outfall should be on a separate page. Attach additional sheets of paper if necessary.

General Instructions *(See table 2D-2 for Pollutants)*
Each part of this item requests you to provide an estimated daily maximum and average for certain pollutants and the source of information. Data for all pollutants in Group A, for all outfalls, must be submitted unless waived by the permitting authority. For all outfalls, data for pollutants in Group B should be reported only for pollutants which you believe will be present or are limited directly by an effluent limitations guideline or NSPS or indirectly through limitations on an indicator pollutant.

1. Pollutant	2. Maximum Daily Value *(include units)*	3. Average Daily Value *(include units)*	4. Source *(see instructions)*
Biochemical Oxygen Demand (BOD_5)	<20 mg/L	<30 mg/L	4-Best Professional Estimate
Chemical Oxygen Demand (COD)	<30 mg/L	<40 mg/L	4-Best Professional Estimate
Total Organic Carbon (TOC)	<40 mg/L	<50 mg/L	4-Best Professional Estimate
Total Suspended Solids (TSS)	<30 mg/L	<45 mg/L	4-Best Professional Estimate
Ammonia (as N)	<0.1 mg/L	<0.1 mg/L	4-Best Professional Estimate
Temperature (winter)	15-35°C	15-35°C	4-Best Professional Estimate
Temperature (summer)	25-45°C	25-45°C	4-Best Professional Estimate
pH	6-9 s.u.	6-9 s.u.	4-Best Professional Estimate
Oil and Grease	<15 mg/L	<15 mg/L	4-Best Professional Estimate
Flow	0.8072 MGD	0.00576 MGD	4-Best Professional Estimate

CONTINUED FROM THE FRONT	EPA I.D. NUMBER *(copy from Item 1 of Form 1)*	Outfall Number
	Not Applicable	003

V. Effluent Characteristics

A, and B. These items require you to report estimated amounts *(both concentration and mass)* of the pollutants to be discharged from each of your outfalls. Each part of this item addresses a different set of pollutants and should be completed in accordance with the specific instructions for that part. Data for each outfall should be on a separate page. Attach additional sheets of paper if necessary.

General Instructions *(See table 2D-2 for Pollutants)*
Each part of this item requests you to provide an estimated daily maximum and average for certain pollutants and the source of information. Data for all pollutants in Group A, for all outfalls, must be submitted unless waived by the permitting authority. For all outfalls, data for pollutants in Group B should be reported only for pollutants which you believe will be present or are limited directly by an effluent limitations guideline or NSPS or indirectly through limitations on an indicator pollutant.

1. Pollutant	2. Maximum Daily Value *(include units)*	3. Average Daily Value *(include units)*	4. Source *(see instructions)*
Biochemical Oxygen Demand (BOD_5)	<35 mg/L	<20 mg/L	4-Best Professional Estimate
Chemical Oxygen Demand (COD)	<40 mg/L	<30 mg/L	4-Best Professional Estimate
Total Organic Carbon (TOC)	<25 mg/L	<40 mg/L	4-Best Professional Estimate
Total Suspended Solids (TSS)	<45 mg/L	<30 mg/L	4-Best Professional Estimate
Ammonia (as N)	<0.1 mg/L	<0.1 mg/L	4-Best Professional Estimate
Temperature (winter)	15-35°C	15-35°C	4-Best Professional Estimate
Temperature (summer)	25-40°C	25-40°C	4-Best Professional Estimate
pH	6-9 s.u.	6-9 s.u.	4-Best Professional Estimate
Oil and Grease	<15 mg/L	<15 mg/L	4-Best Professional Estimate
Flow	2.929 MGD	0.021 MGD	4-Best Professional Estimate

CONTINUE ON NEXT PAGE

CONTINUED FROM THE FRONT	EPA I.D. NUMBER *(copy from Item 1 of Form 1)*	Outfall Number
	Not Applicable	004

V. Effluent Characteristics

A, and B. These items require you to report estimated amounts *(both concentration and mass)* of the pollutants to be discharged from each of your outfalls. Each part of this item addresses a different set of pollutants and should be completed in accordance with the specific instructions for that part. Data for each outfall should be on a separate page. Attach additional sheets of paper if necessary.

General Instructions *(See table 2D-2 for Pollutants)*
Each part of this item requests you to provide an estimated daily maximum and average for certain pollutants and the source of information. Data for all pollutants in Group A, for all outfalls, must be submitted unless waived by the permitting authority. For all outfalls, data for pollutants in Group B should be reported only for pollutants which you believe will be present or are limited directly by an effluent limitations guideline or NSPS or indirectly through limitations on an indicator pollutant.

1. Pollutant	2. Maximum Daily Value *(include units)*	3. Average Daily Value *(include units)*	4. Source *(see instructions)*
Biochemical Oxygen Demand (BOD_5)	<20 mg/L	<20 mg/L	4-Best Professional Estimate
Chemical Oxygen Demand (COD)	<40 mg/L	<40 mg/L	4-Best Professional Estimate
Total Organic Carbon (TOC)	<25 mg/L	<25 mg/L	4-Best Professional Estimate
Total Suspended Solids (TSS)	<20 mg/L	<20 mg/L	4-Best Professional Estimate
Ammonia (as N)	<0.1 mg/L	<0.1 mg/L	4-Best Professional Estimate
Temperature (winter)	3-18°C	3-18°C	4-Best Professional Estimate
Temperature (summer)	10-25°C	10-25°C	4-Best Professional Estimate
pH	6-9 s.u.	6-9 s.u.	4-Best Professional Estimate
Total Residual Chlorine	<0.5 mg/L	<0.5 mg/L	4-Best Professional Estimate
Bromoform	<0.02 mg/L	<0.01 mg/L	4-Best Professional Estimate
Flow	0.0254 MGD	0.0254 MGD	4-Best Professional Estimate

 CONTINUE ON NEXT PAGE

CONTINUED FROM THE FRONT	EPA I.D. NUMBER *(copy from Item 1 of Form 1)*	Outfall Number
	Not Applicable	005

V. Effluent Characteristics

A, and B. These items require you to report estimated amounts *(both concentration and mass)* of the pollutants to be discharged from each of your outfalls. Each part of this item addresses a different set of pollutants and should be completed in accordance with the specific instructions for that part. Data for each outfall should be on a separate page. Attach additional sheets of paper if necessary.

General Instructions *(See table 2D-2 for Pollutants)*
Each part of this item requests you to provide an estimated daily maximum and average for certain pollutants and the source of information. Data for all pollutants in Group A, for all outfalls, must be submitted unless waived by the permitting authority. For all outfalls, data for pollutants in Group B should be reported only for pollutants which you believe will be present or are limited directly by an effluent limitations guideline or NSPS or indirectly through limitations on an indicator pollutant.

1. Pollutant	2. Maximum Daily Value *(include units)*	3. Average Daily Value *(include units)*	4. Source *(see instructions)*
Biochemical Oxygen Demand (BOD_5)	<45 mg/L	<30 mg/L	4-Best Professional Estimate
Chemical Oxygen Demand (COD)	<300 mg/L	<200 mg/L	4-Best Professional Estimate
Total Organic Carbon (TOC)	<50 mg/L	<40 mg/L	4-Best Professional Estimate
Total Suspended Solids (TSS)	<45 mg/L	<30 mg/L	4-Best Professional Estimate
Ammonia (as N)	<5 mg/L	<3 mg/L	4-Best Professional Estimate
Temperature (winter)	30-45°C	30-45°C	4-Best Professional Estimate
Temperature (summer)	30-45°C	30-45°C	4-Best Professional Estimate
pH	6-9 s.u.	6-9 s.u.	4-Best Professional Estimate
Total Residual Chlorine	<1.0 mg/L	<1.0 mg/L	4-Best Professional Estimate
Fecal Coliform (colonies/100 ml)	<400 cols.	<200 cols.	4-Best Professional Estimate
Oil and Grease	<15 mg/L	<15 mg/L	4-Best Professional Estimate
Flow	0.0075 MGD	0.0075 MGD	4-Best Professional Estimate

CONTINUE ON NEXT PAGE

CONTINUED FROM THE FRONT	EPA I.D. NUMBER *(copy from Item 1 of Form 1)*	Outfall Number
	Not Applicable	006

V. Effluent Characteristics

A, and B. These items require you to report estimated amounts *(both concentration and mass)* of the pollutants to be discharged from each of your outfalls. Each part of this item addresses a different set of pollutants and should be completed in accordance with the specific instructions for that part. Data for each outfall should be on a separate page. Attach additional sheets of paper if necessary.

General Instructions *(See table 2D-2 for Pollutants)*
Each part of this item requests you to provide an estimated daily maximum and average for certain pollutants and the source of information. Data for all pollutants in Group A, for all outfalls, must be submitted unless waived by the permitting authority. For all outfalls, data for pollutants in Group B should be reported only for pollutants which you believe will be present or are limited directly by an effluent limitations guideline or NSPS or indirectly through limitations on an indicator pollutant.

1. Pollutant	2. Maximum Daily Value *(include units)*	3. Average Daily Value *(include units)*	4. Source *(see instructions)*
Biochemical Oxygen Demand (BOD_5)	<20 mg/L	<20 mg/L	4-Best Professional Estimate
Chemical Oxygen Demand (COD)	<40 mg/L	<40 mg/L	4-Best Professional Estimate
Total Organic Carbon (TOC)	<25 mg/L	<25 mg/L	4-Best Professional Estimate
Total Suspended Solids (TSS)	<20 mg/L	<20 mg/L	4-Best Professional Estimate
Ammonia (as N)	<0.1 mg/L	<0.1 mg/L	4-Best Professional Estimate
Temperature (winter)	15-35°C	15-35°C	4-Best Professional Estimate
Temperature (summer)	25-40°C	25-40°C	4-Best Professional Estimate
pH	6-9 s.u.	6-9 s.u.	4-Best Professional Estimate
Flow	0.5035 MGD	0.5035 MGD	4-Best Professional Estimate
Total Residual Chlorine	<1 mg/L	<0.5 mg/L	4-Best Professional Estimate

CONTINUED FROM THE FRONT	EPA I.D. NUMBER *(copy from Item 1 of Form 1)*	
	Not Applicable	001, 002, 003, 004, 005, and 006

C. Use the space below to list any of the pollutants listed in Table 2D-3 of the instructions which you know or have reason to believe will be discharged from any outfall. For every pollutant you list, briefly describe the reasons you believe it will be present.

1. Pollutant	2. Reason for Discharge
Not Applicable – No pollutants listed in Table 2 D-3 are expected in the discharge.	

VI. Engineering Report on Wastewater Treatment

A. If there is any technical evaluation concerning your wastewater treatment, including engineering reports or pilot plant studies, check the appropriate box below.

☒ Report Available ☐ No Report

B. Provide the name and location of any existing plant(s) which, to the best of your knowledge, resembles the production facility with respect to production processes, wastewater constituents, or wastewater treatments.

Name	Location
Port Pelican	Gulf of Mexico, Vermilion Block 140

EPA I.D. NUMBER *(copy from Item 1 of Form 1)*
Not Applicable

VII. Other Information

Use the space below to expand upon any of the above questions or to bring to the attention of the reviewer any other information you feel should be considered in establishing permit limitations for the proposed facility. Attach additional sheets if necessary.

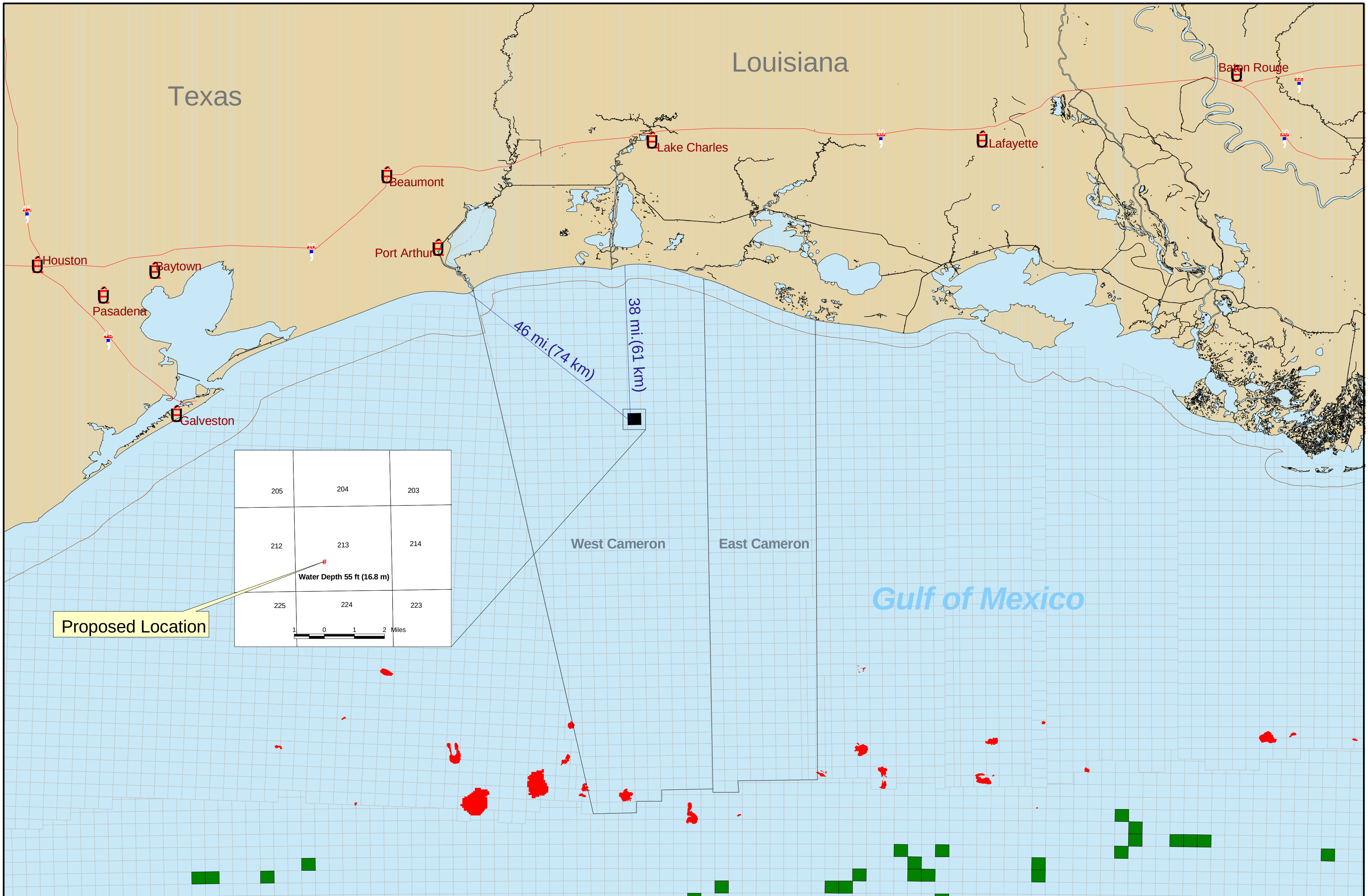
Please see the following Attachments:

Figure 1 – Location Map,
Figure 2 – General Layout of Facility,
Figure 3 – Main Operation and Discharge Flow Diagram,
Figure 4 – Other Supporting Operations and Minor Discharges Flow Diagram,
Attachment 1-XII – Descriptions for the nature of business,
Attachment 2D-III – Descriptions for each outfall,
Attachment 2D-VII.1 – Free Chlorine in Wastewater, and
Attachment 2D-VII.2 – Cool Water Outfall Analysis.

VIII.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A. Name and Official Title *(type or print)*	B. Phone No.
A. Y. Noojin, III President, Gulf Landing LLC	(713) 230-3525
C. Signature A. Y. Noojin III	D. Date Signed 10/21/03



LEGEND

West Cameron (WC) Block 213
City
State - Federal Boundary
MMS Lease Block
Interstate Highway
Known Chemosynthetic Block
Known Topographic Feature

N W E S
Scale
20 0 20 40 Miles

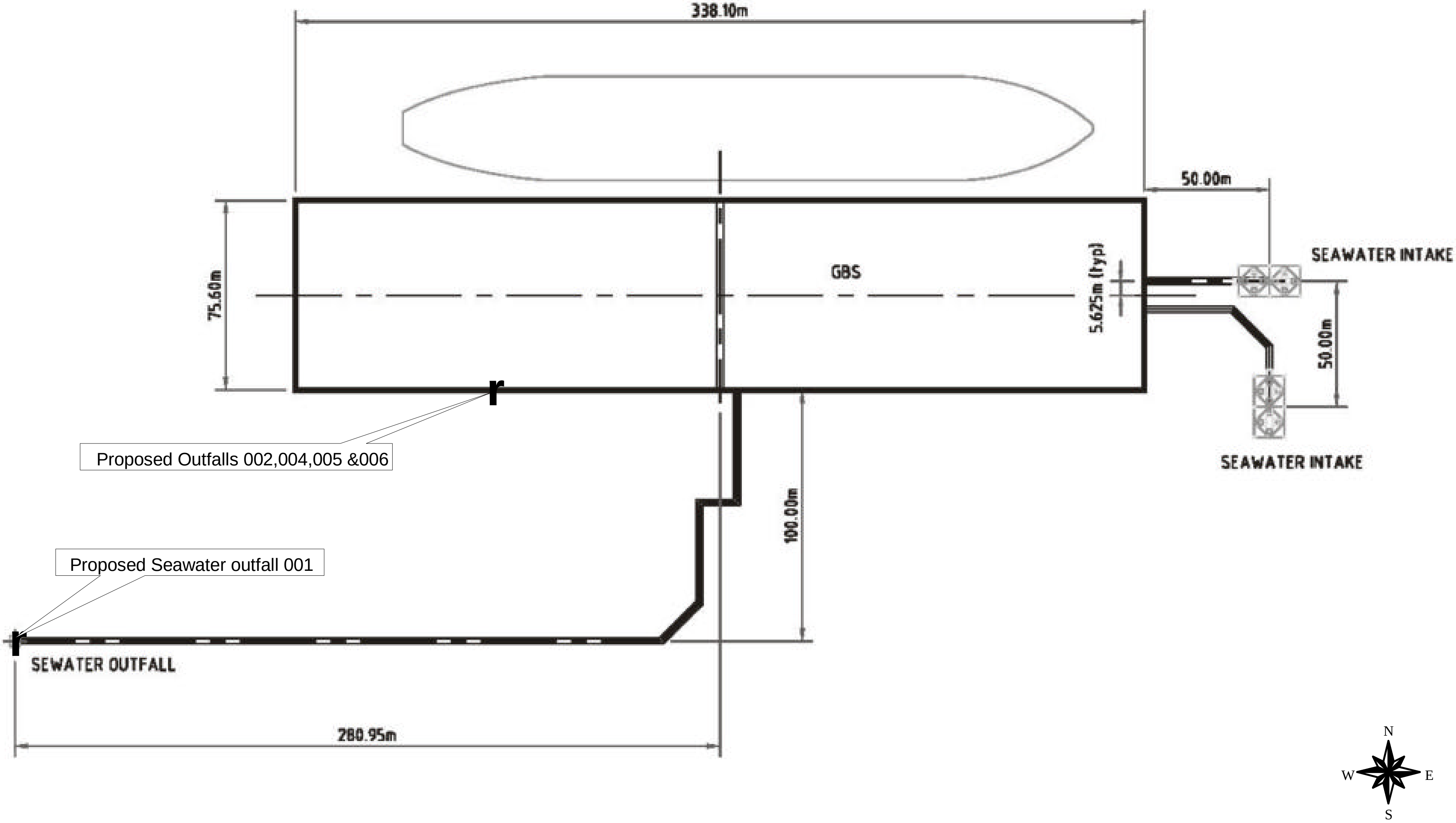
ecology and environment
International Specialist in the Environment
Baton Rouge, Louisiana

Figure 1

Proposed Location and Vicinity Map

Gulf Landing LNG Terminal

West Cameron Block 213



r **Proposed outfalls locations subject to changes according to final design.**

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Baton Rouge, Louisiana

Figure 2

General Layout of Facility

Gulf Landing LNG Terminal

West Cameron Block 213

Figure 3
Gulf Landing Offshore LNG Terminal
West Cameron 213, Gulf of Mexico
Main Operation and Discharge Flow Diagram

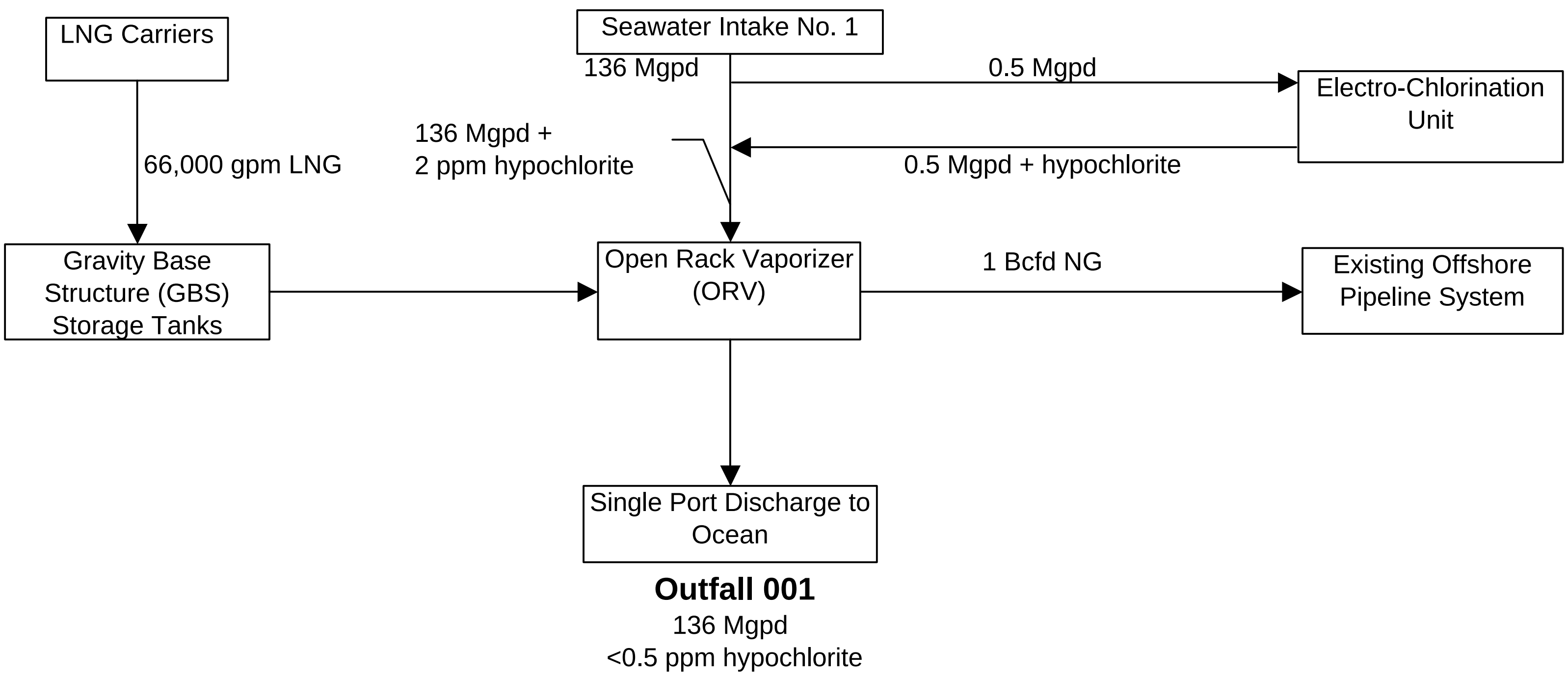
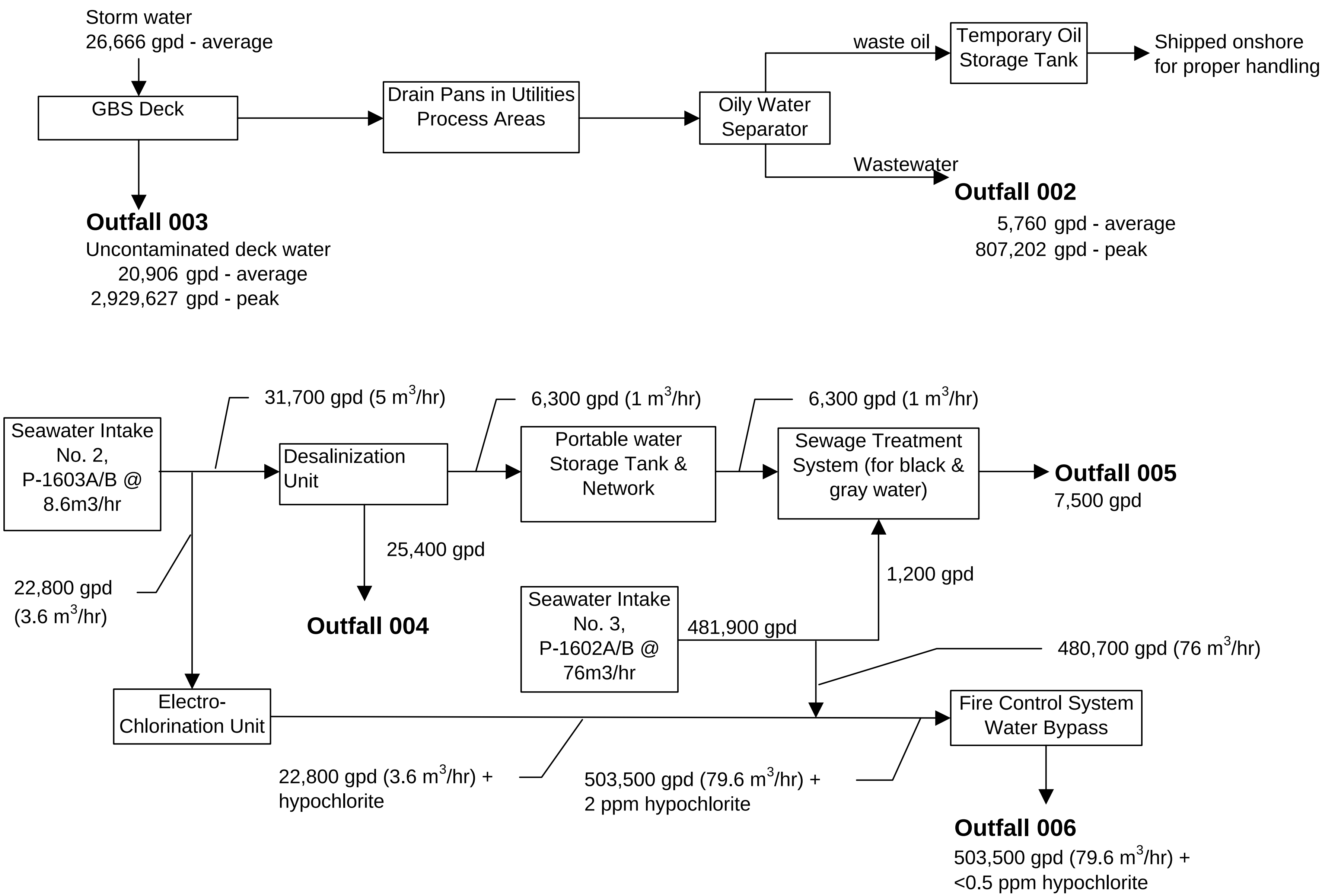


Figure 4
Gulf Landing Offshore LNG Terminal
West Cameron 213, Gulf of Mexico
Other Supporting Operations and Minor Discharges Flow Diagrams



NPDES PERMIT APPLICATION – FORM 1
GULF LANDING LNG TERMINAL

Attachment 1-XII - Nature of Business

Gulf Landing LLC proposes to construct, own and operate a liquefied natural gas (LNG) terminal located in Block 213 in the West Cameron (WC 213) area in the Gulf of Mexico offshore Louisiana. This location is approximately 38 miles (61 kilometers [km]) offshore at water depth of approximately 55 feet (17 meters) and is adjacent to an existing shipping fairway serving the Calcasieu River and area ports. The location of the terminal is shown on Figure 1.

The main structures of the proposed offshore LNG terminal consist of two concrete gravity base structures (GBS), and a berth for breasting, mooring, and unloading a LNG carrier. The GBS contains and supports features including LNG unloading and vapor return arms, LNG storage tanks, LNG in-tank pumps, unloading and normal boil-off gas (BOG) compressor, LNG send-out pumps, vaporizers, sales gas heaters, fiscal meters, utility systems, venting and flaring, and general facilities. An accommodation module is also provided for 60-person living quarters at the west end of the facility's western GBS. The general layout of the terminal is shown on Figure 2.

The terminal is designed to handle a nominal receiving capacity of 7.7 million tonnes per year of LNG. This equates to a nominal vaporization capacity of 1 billion cubic feet daily (bcfd; 2,000 cubic meters per hour [m^3/h]). The vaporization system is designed for a peak capacity of 1.2 bcfd (2,400 m^3/h) in order to supply peak demand needs. Re-gasified LNG will be transported onshore through up to five new takeaway pipelines, which will be constructed to connect the terminal to existing offshore pipeline infrastructure in the area.

The terminal provides seven basic functions:

- LNG carrier berthing,
- LNG carrier offloading,
- LNG storage,
- LNG vaporization,
- Gas metering and export,
- Power generation and other utilities, and
- Personnel quarters.

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Attachment 2D-III.A - Outfalls Descriptions

Outfall 001

The proposed flow rate (approximately 136 million gallons per day [mgpd]) at this outfall is the largest at this facility. Seawater will be used as thermal heating water to vaporize the liquefied natural gas (LNG) from the storage tanks through an open rack vaporizer (ORV). Seawater will be continuously pumped from the ocean to the top of the ORV and cascaded down the ORV where LNG is moved through internally and vaporized. Sodium hypochlorite will be injected continuously at a dosing of 2 parts per million (ppm) equivalent chlorine at the suction of the seawater intake to prevent marine growth. Every 8 hours, a shock dosing to an equivalent chlorine concentration of 5 ppm for 1 hour will be applied,while the continuous dosing will be stopped. The treated seawater will flow through independent lines to the top of ORV and then collected at the bottom by a drain pan. Water collected will then be discharged through Outfall 001. The seawater will be discharged through a single port structure at the seafloor at a maximum temperature differential of 18º F (10º C) cooler than the ambient seawater temperature. The proposed location of the discharge is approximately 150 meters to the southwest corner of the gravity base structure (GBS) facility as shown in Figure 2. A flow diagram for the process is presented in Figure 3. A study of the mixing of the cool water from this outfall and the receiving waters in Gulf of Mexico has been performed using United States Environmental Protection Agency (EPA) accepted computer models. Results of this study are presented in Attachment 2D-VII.2.

Seawater Intake for ORV Operations

The seawater for the ORV operations will be delivered at a rate of approximately 21,500 m^3/hr or 5.7 million gallons per hour (mgph) via four high capacity pumps. Due to the considerable pumping rate at the intake structures, design requirements in Regulations Addressing Cooling Water Intake Structures for New Facilities (40 Code of Federal Regulations [CFR] Parts 9, 122, et al.) under the National Pollutant Discharge Elimination System (NPDES) Rules have been considered, although the water is used for heating instead of cooling. The intake structures for the facility have been designed to minimize the potential impacts in respect to impingement and entrainment. There will be two intake cages located to the east side of the GBS (as shown in Figure 2) and each intake cage will contain eight intake ports. The designed water intake velocity for the intake ports is less than 0.15 meters per second (m/s; <0.5 feet per second [ft/s]) to minimize the potential impact of impingement. These intake ports will be located approximately 5.7 meters above the seafloor and will be covered with a 0.64-centimeter (cm; 0.25-inch [in]) mesh screen to minimize potential entrainment.

Outfall 002

Wastewater from the utility areas that include power generation, boil-off gas compressor, emergency diesel generator, diesel day tank, and diesel loading area where there is a potential for the presence of (non LNG) liquid hydrocarbons will be contained within skid drain pans. These drain pans can collect rainwater, machine wash down wastewater, or other fluids in the areas. Machine wash down will not generally occur during a storm event. The drains would be routed to a Coalescer Plate Interceptor (CPI) type oily water separator. The CPI separator will be a compact, single stage, gravity-type vessel using a coalescer plate pack principle of separation. The oily water will gravity drain into the separator where the majority of the oil will separate in the gravity stage below the oil chamber into which it will rise and collect. The water will flow through a multi-stage plate pack, which will encourage the remaining oil droplets to coalesce and rise through the pack to the oil chamber. Oil will be pumped via a closed drain header to a storage tank. From here it will be pumped into portable tote tanks for transport to shore for recycle or proper disposal. Clean water will exit the rear end of the unit to an overboard discharge connection at Outfall 002. A flow diagram presenting the process is shown in Figure 4. Capacitance probes will be fitted to detect the oil level in the oil chamber, controlling the pump to give fully automatic operation. A 15-ppm oil-content meter will be installed on the water outlet to prevent oil discharges to the sea if any of the separation or monitoring systems should fail. Based on limited local rainfall data at present, the peak rainfall for sizing of the CPI separator is based on 2 inch per hour (in/hr) of rainfall for 20 minutes that would yield approximately 24,500 gallons per storm event. The peak daily rainfall recorded in Louisiana yielded 22 inches in 24 hours that is equivalent to 0.92 in/hr, which could result approximately 807,000 gallons per day (gal/day) at this discharge Outfall 002.

Outfall 003

Uncontaminated rainfall drainage from the deck outside the utility areas will be routed overboard for discharge through this outfall. The average daily discharge is estimated at approximately 21,000 gal/day from the deck area of the GBS and expected to be intermittent. This outfall is presented in the flow diagram in Figure 4.

Outfall 004

This outfall is for the discharge of excess/reject water from the desalination system on board the GBS at this facility. The desalination system will consist of 2 x 50% reverse osmosis (RO) water purifiers to produce potable water from seawater. Seawater will be pumped from the ocean and feed into the units to produce portable water for the facility. The purifiers are designed to process a total of approximately 31,700 gallons of seawater per day and produce about 6,300 gal/day of purified portable water. About 80% of the seawater feeding the units (25,400 gal/day) will be rejected through the process and discharged through this outfall into Gulf of Mexico. The portable water will be collected in a storage tank and distributed on demand. The process is illustrated in a flow diagram in Figure 4. The salinity of the discharge water from the purifiers will be approximately 0.04 parts per trillion (ppt).

Outfall 005

This outfall is for the discharge of wastewater from the sewage treatment unit that services the facility. The facility is designed to accommodate a normal operating crew of 30 with additional capacity of 30 persons for other services. The sewage treatment system will be a United States Coast Guard (USCG) approved marine sanitation device that consists of a sewage treatment unit, a tablet chlorinator, and a hydraulic macerator. The sewage treatment unit will process the blackwater and greywater sewage from the bathrooms in the quarters building (toilets, showers and hand basins). During maintenance of the sewage treatment unit, the blackwater from the quarters building will bypass the treatment unit and flow through the tablet chlorinator. The chlorinator will contain chlorine tablets that dissolve into the wastewater and kill the bacteria. The hydraulic macerator will contain baffle plates inside, with pressurized seawater jets directed at the baffles. The seawater jets will break up solids in the wastewater stream before it is discharged overboard. The treated water discharge from the sewage treatment unit will be approximately 7,500 gal/day and will contain a maximum of 1 milligrams per liter (mg/L) of total residual chlorine at the discharge (see Figure 4).

Outfall 006

This outfall is for the discharge of water associated with the facility fire protection system. Firewater pumps draw seawater from the Gulf of Mexico for the fire protection system (see Figure 4 for the flow scheme). In order to control marine growth throughout the system, sodium hypochlorite is added to the seawater at an average concentration of 2 ppm with a maximum concentration of 5 ppm for water circulating in the system. Firewater is discharged at an estimated rate of 503,500 gal/day with a concentration of less than 0.5 ppm hypochlorite at this outfall.

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Attachment 2D-VII.1 – Free Chlorine in Wastewater

Sodium hypochlorite will be injected at several seawater intake pump basins to control marine growth for the pump systems (such as thermal water for the open rack vaporizer [ORV] operations and seawater for the fire control system) at this facility. Chlorination is also used for the sewage treatment unit. The following provides general background information on the chlorine chemical reactions with wastewater. However, as it described below, it is difficult to evaluate the rate of decay for free chlorine when it is injected in the seawater.

When Cl_2 (g) is dissolved in water then the two aqueous species of chlorine are HOCl (hypochlorous acid) and OCl^- (hypochlorate ion). Toxicity of HOCl is far greater (in the order of 100-1000 times) than OCl^-. However, the fraction of HOCl increases with decreasing pH. At a near neutral pH value (~ 7.0) and a temperature of 0° C, 90% of free residual chlorine is HOCl. At the same pH but temperature of 20° C, the percentage of HOCl decreases to 80%. Furthermore, if the discharge water contains dissolved ammonia, free chlorine residual reacts extremely fast with ammonia to form chloramines. In any event, both HOCl and OCl^- are highly unstable. Under all pH-pe (electron activity or oxidation-reduction potential) conditions of natural water, Cl^- is the most stable form. This is due to the strong oxidizing property of chlorine. Free chlorine in the form of HOCl and OCl^- has the oxidation state of (+1). It oxidizes water (and the dissolved ions in it such as ammonia) and itself is reduced to chloride in which its oxidation state is (-1). Consequently, the rate of decay of free chlorine or the rate of conversion of Cl(+1) to Cl(-1) is extremely fast.

Furthermore, the rate of decay also depends on salinity, temperature, and pH. Thus, the aquatic chemistry of dissolved chlorine is highly complex. For this reason, no good estimate of the rate of decay of free chlorine is available in the literature. This is normally assessed from a study of the specific system under consideration. Without such data, modeling the fate and transport of free chlorine residual into a water body is not quite meaningful.

The United States Environmental Protection Agency (EPA 1985) notes that "The complexity of the reactions of chlorine in fresh and salt water makes it important that studies of the effects of chlorine on aquatic organisms be appropriately designed and that concentrations of TRC (total residual chlorine) or CPO (chlorine-produced oxidants) be adequately measured. Because the half-lives of TRC and CPO are short in most waters, usually tests must be flow-through and the concentrations must be measured often enough to demonstrate that substantial reduction in concentration is not occurring. Also, the measurements must usually be performed using a method (e.g., amperometric, idometric, or potentiometric titration, or DPD) that measures TRC or CPO and not just one or more components, such as free, but not combined chlorine."

Reference

USEPA, January 1985, Ambient Water Quality Criteria for Chlorine, Office of Water, EPA 440/5-84/030.

Attachment 2D-VII.2 – Cool Water Outfall Analysis

Analysis of Cool Water Outfall, Base Case Gulf Landing LNG Gasification Project Offshore Louisiana

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Executive Summary

The Gulf Landing LNG facility will discharge cooled sea water during operation. This report is an analysis of the behavior of the cool water plumes from this facility. The base case, analyzed here, is a continuous discharge of 20,000 m^3/hr having a temperature deficiency of 10°C (18°F) and a hyprochloride concentration of 0.5 ppm. The temperature deficiency is the ambient sea water temperature minus the temperature of water discharged by the LNG facility. Two outfall configurations were investigated: a single port and a diffuser. The single port is 2.55 m in diameter, oriented vertically upward. Its mouth is 3 m above the sea bed and is expected to be incorporated in a 3 m tall concrete structure on the sea floor. The diffuser has 25 ports, each 0.3049 m (12 inch) in diameter, spaced at 4 m intervals, making a total diffuser length of 96 m. The diffuser ports are also 3 m above the sea floor.

The U.S. EPA's CORMIX model (version 3.2) was used for this analysis, supplemented by the Offshore Operators Committee discharge model where necessary. Visitation probability and far-field dilution models developed at Brandsma Engineering were also used.

Ambient conditions used in the analysis were set based on currents and hydrographic conditions measured in the nearby region. No *in situ* measurements were available. Current speeds exceeded 90, 50 and 10% of the time were estimated to be 0.03, 0.097 and 0.218 m/s, respectively. Hydrographic measurements indicated that ambient density gradients ranged from 0.0 kg/m^3/m (unstratified) to about 0.19 kg/m^3/m (strongly stratified). The strong stratification was due almost entirely to the formation of a halocline, little temperature variation was observed in individual temperature profiles.

The single port creates an unstable mixing region featuring near-field instabilities and full vertical mixing. This mixed region will restratify and form a dense cool water layer on the sea floor, probably within 200 m or so of the discharge port. In slow currents, the vertically mixed region near the discharge can collapse and spread in all directions (up to 400 m upstream). A persistent lens of cool water will form on the sea floor with thicknesses ranging from 1.5 m to 2.0 m. Temperature deficiencies at a distance of 100 m are 1°C or less on the sea floor. Hyprochloride concentrations are expected to be 0.05 ppm or less on the sea floor.

The diffuser does an excellent job of mixing the cool water with the ambient sea water, under most conditions, so that a pool of water slightly cooler than the surrounding ambient water occupies much of the water column and is widespread in the area around the diffuser. The diffuser plume fills the water column near the diffuser and occupies the lower 1/3 to 2/3 of the water column at a distance of 500 m. Upstream intrusions of the cool water lens of about 300 m are possible in slow currents. Temperature deficiencies of 0.1 to 0.6°C are reported at distances of 100 m and up. Corresponding hyprochloride concentrations are expected to be 0.005 to 0.03 ppm.

Occasionally, when fast currents flow parallel to the diffuser, the diffuser will perform poorly and provide little dilution. If the diffuser axis is oriented north-south, this is expected about 1.6 percent of the time. The temperature deficiency predicted when this occurs is about 6°C and the resulting cool water plume thickness will be less than 1 m. The persistence of such events is expected to be 12 hours or less.

Distributions of the probability of cool water released from the outfall visiting any location around the outfall within a certain travel time horizon were calculated. All available near bottom currents measured at LATEX site 20 were used for this analysis. The distributions can be represented by closed contours surrounding the outfall. As the travel time horizon increases, the contours expand. For a travel time horizon of 36 hours, the 20% visitation probability contour extends approximately 3000 m east and west of the outfall and approximately 2000 m north and south of the outfall. This means that there is a 20% probability that the cool water plume will visit the intake location within 36 hours after discharge during a year's operation of the LNG facility (assuming the intake is located less than 2000 m away from the outfall).

The far-field model (using all available near bottom data from LATEX site 20) predicted the distribution around the outfall of maximum temperature deficiencies expected during one year's operation of the LNG facility.

For the single port outfall, maximum temperature deficiencies in a small area near the outfall of more than 2.4°C were reported. Near the outfall, maximum temperatures declined rapidly in the first few hundred meters of distance from the outfall and more slowly thereafter. A significant area may see maximum temperature deficiencies exceeding 1°C. These maximum temperature deficiencies will be restricted to a 1.5 to 2 m thick layer on the sea floor.

The far-field distributions of maximum temperature deficiencies of cool water discharged from the diffuser exhibit an almost uniform maximum temperature deficiency of about 0.5°C within 4000 m of the outfall. This maximum temperature deficiencies occur in the lower 1/3 to 2/3 of the water column. In effect, the diffuser creates large plumes of water slightly cooler than the ambient water and these plumes wander about near the discharge, decaying very slowly, and in combination covering the entire area within 4 km of the outfall during one year's operation. This means that entrainment of diluted cool water from the diffuser into the sea water intake will occur regularly during one year's operation of the facility. The temperature deficiency, however, will be much less than yearly fluctuations of the natural ambient temperature expected at the Gulf Landing site.

A mid-water depth is recommended for the intake cage when a single port outfall is used. This would also work with a diffuser. The horizontal separation between the intake and the outfall should be as large as practicable and not less than 200 m.

Both the single port and diffuser configurations reduce the temperature deficiency ΔT to 1.1°C or less at a 100 m distance from the discharge under most ambient conditions. Roughly 1.6% of the time the diffuser will allow ΔT=6°C at the 100 m distance. For comparison, the World Bank criterion for thermal discharges from power plants is $\Delta T < 3°C$ at a 100 m.

The report concludes with a caveat that computer models are approximate, especially for conditions postulated for the Gulf Landing outfall. Careful laboratory experiments remain the best way to predict plume behavior under such conditions.

1 Introduction

The Gulf Landing facility to gasify liquified natural gas (LNG) offshore Louisiana is in the design stage. The thermal energy to gasify the LNG is to be extracted from ambient sea water. The by-product of this process will be cooled sea water that is to be discharged from the facility. This report investigates the behavior of cool water plumes from two possible outfall configurations, a single-port aimed vertically upward and a horizontal diffuser. The volume flux of cooled sea water will be 20,000 m^3/hr for the "base" case. The discharged sea water is expected to be 10.0°C (18°F) cooler than the ambient sea water. The facility will discharge cool water continuously throughout the year. The discharged cool sea water will also contain hyprochloride at a concentration of 0.5 ppm.

This report provides an assessment, based on computer modeling, of the nature and extent of the cool water plumes expected when the gasification facility is operating. The plume temperatures are expressed as temperature deficiencies, the difference between the ambient water temperature and the cooler plume temperature. The following subjects are covered:

- description of the data used for modeling, consisting of the discharge and ambient conditions,
- description of the modeling methods,
- presentation of the results for the distribution of temperature deficiencies and hyprochloride concentrations,
- discussion and recommendations.

2 Modeling Data

Modeling data was obtained from e-mail messages and attachments sent by Continental Shelf Associates, Inc.

2.1 Bathymetry

The preliminary location of the facility is in the West Cameron lease area, block 213. The water depth is approximately 55.8 ft (17 m) and the sea floor is relatively flat, owing to its location on the continental shelf.

2.2 Currents

No current measurements are available *in situ*. However, data from a study, LATEX, sponsored by the U.S. Minerals Management Service is available at a location near the Gulf Landing facility (Shell, Preliminary Oceanographic Criteria document). Site 20 of the LATEX study lies about 35 nautical miles west of Gulf Landing. Owing to the similarity of water depth, distance offshore and coastal configuration, the Site 20 data are considered to be representative of conditions at Gulf Landing.

Measurements were taken at depths of 3 and 12 m in water 14 m deep. The upper meter was deployed from 5/31/92 to 11/30/94. The lower meter was deployed from 4/13/92 to 11/30/94. Despite periods of missing data, the quantity of data provided allowed for calculation of reliable statistics.

Modeling reported in this document is based on the Site 20 data. The marginal distributions from the joint distribution tables for current speed and direction reported in Shell's "Preliminary Oceanographic Criteria" document were used to prepare plots of current speed vs. probability of exceedance (**Figure 1**) and of current direction vs. probability[1] (**Figure 2**). The curves show the statistics for the individual periods of good data records. There is considerable variation exhibited in these figures, making the selection of representative current conditions difficult.

An estimate of the cumulative marginal distributions of current speed and direction for the entire measurement period was undertaken. The joint distribution tables for currents, contained in the "Preliminary Oceanographic Criteria" document give the percentage of the sample times that each speed and direction band in the tables occurred. The number of days in each measurement period was reported. Therefore the number of , say, hourly measurements that fall within a certain band of speed or direction for a single measurement period can be computed as the product of the number of days in the period, the percentage of measurements in the band and the number of hours in a day. This calculation was made for the marginal distributions of speed and direction in each joint distribution table. The measurement counts thus obtained were summed for each speed and direction band in the marginal distributions, divided by the total number of measurement counts and multiplied by 100%. The results were cumulative distributions of current speed (**Figure 3**) and current direction (**Figure 4**).

Subsequent to the work described in the previous paragraph, the data files for the top and bottom meters at LATEX site 20 were made available. Cumulative joint probability distributions of current speed and direction were prepared from this data, as shown in **Tables 1 and 2**.

Examination of **Figures 1 and 3** shows a considerable difference in speeds between the upper and lower meters. Owing to the outfall discharging cool water near the sea floor, currents from the lower meter were used for modeling.

Usual practice for picking current speeds to use for modeling effluent discharge is to use the speeds exceeded 10%, 50% and 90% of the time. The speed exceeded 90% of the time is the 10 percentile speed. Consulting the "Bot, All Data" curve in **Figure 3**, this speed is 3.0 cm/s. Using the same curve, the speed exceeded 50% of the time (the median or 50 percentile speed) is 9.7 cm/s. The speed exceeded 10% of the time (the 90 percentile speed) is 21.8 cm/s. These three current speeds were used for modeling.

[1] In oceanographic usage, current direction is the direction the current flows <u>toward</u>.

Examination of **Figure 4** shows that there is not a lot of variation of direction probability for the currents measured at the lower meter (in contrast to the upper meter, for which a tendency to westward flow is evident). There is a small tendency of the bottom currents to flow towards the west.

Table 1
Cumulative Distribution (Percent) of Current Speed and Direction, Top Meter LATEX Site 20

SPEED (cm/s)	Direction (degrees)								TOTAL
	N	NE	E	SE	S	SW	W	NW	
5	0.48	0.35	0.34	0.34	0.43	0.42	0.44	0.39	3.18
10	1.26	1.05	0.70	0.77	1.06	1.13	1.26	1.17	8.40
15	1.79	1.48	1.08	1.02	1.11	1.65	2.11	1.97	12.20
20	1.78	1.54	1.38	1.19	0.96	1.78	3.20	2.55	14.38
25	1.27	1.29	1.36	0.87	0.83	2.00	4.13	2.10	13.85
30	1.15	1.18	0.95	0.70	0.63	1.87	3.73	1.68	11.90
35	0.60	0.86	0.87	0.45	0.55	1.55	3.51	1.19	9.59
40	0.40	0.60	0.42	0.26	0.44	1.17	3.00	1.13	7.43
45	0.34	0.54	0.55	0.20	0.24	0.91	2.36	0.75	5.89
50	0.26	0.25	0.40	0.15	0.09	0.95	2.07	0.57	4.74
55	0.14	0.21	0.22	0.07	0.05	0.65	1.33	0.33	3.01
60	0.07	0.07	0.17	0.04	0.02	0.51	0.87	0.19	1.93
65	0.07	0.03	0.19	0.04	0.01	0.37	0.71	0.11	1.53
70	0.04	0.03	0.11	0.01	0.02	0.20	0.46	0.04	0.91
75	0.03	0.02	0.09	0.00	0.00	0.12	0.27	0.01	0.54
80	0.01	0.00	0.05	0.01	0.01	0.04	0.15	0.00	0.28
85	0.03	0.00	0.01	0.00	0.01	0.04	0.08	0.00	0.17
90	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.06
95	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
100	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
TOTAL	9.72	9.49	8.87	6.13	6.48	15.38	29.73	14.20	100.00

Table 2
Cumulative Distribution of Current Speed and Direction, Bottom Meter LATEX Site 20

SPEED (cm/s)	Direction (degrees)								TOTAL
	N	NE	E	SE	S	SW	W	NW	
5	2.10	2.75	2.95	2.38	1.87	1.98	2.27	2.31	18.61
10	3.72	5.04	4.79	4.03	3.91	3.77	4.19	3.42	33.24
15	2.36	3.83	3.01	2.88	3.43	3.00	4.58	2.21	25.3
20	0.96	1.33	1.18	1.16	1.80	1.49	3.03	1.09	12.03
25	0.23	0.53	0.63	0.58	0.87	0.79	2.11	0.52	6.25
30	0.10	0.22	0.27	0.15	0.32	0.27	1.30	0.15	2.79
35	0.04	0.18	0.14	0.04	0.07	0.08	0.56	0.04	1.15
40	0	0.04	0.04	0.02	0.04	0.03	0.25	0.01	0.43
45	0	0.03	0	0.01	0.01	0	0.09	0	0.14
50	0	0.01	0	0	0.01	0	0.03	0	0.05
55	0	0	0	0	0	0	0.01	0	0.01
TOTAL	9.51	14.33	13.01	11.24	12.33	11.43	18.42	9.74	100

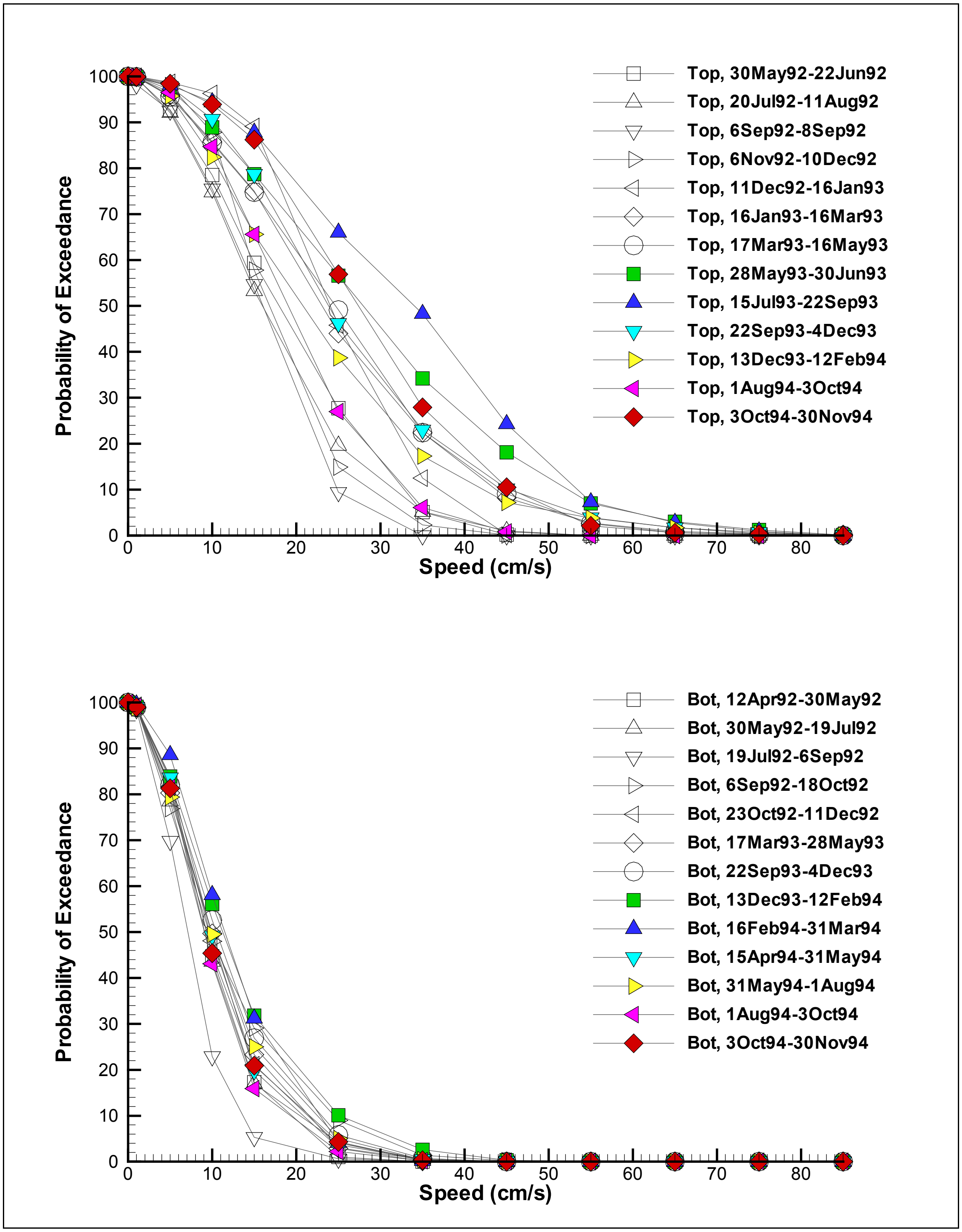

Figure 1. Current speed vs. probability curves for individual measurement periods. The upper frame represents measurements 3 m below the surface. The lower frame represents measurements 12 m below the surface (2 m above the sea floor).

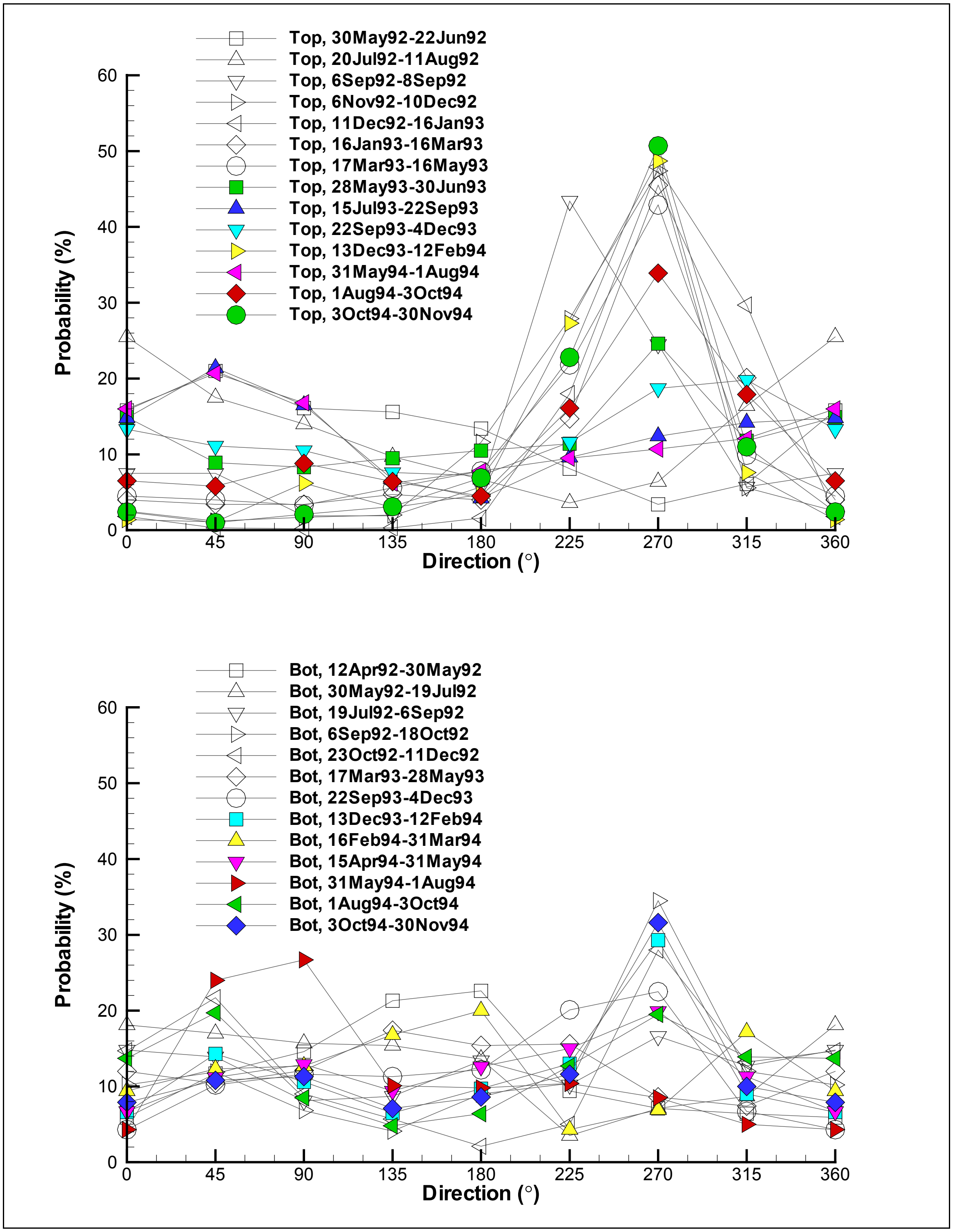

Figure 2. Current direction vs. probability curves for individual measurement periods. The upper frame represents measurements 3 m below the surface. The lower frame represents measurements 12 m below the surface (2 m above the sea floor).

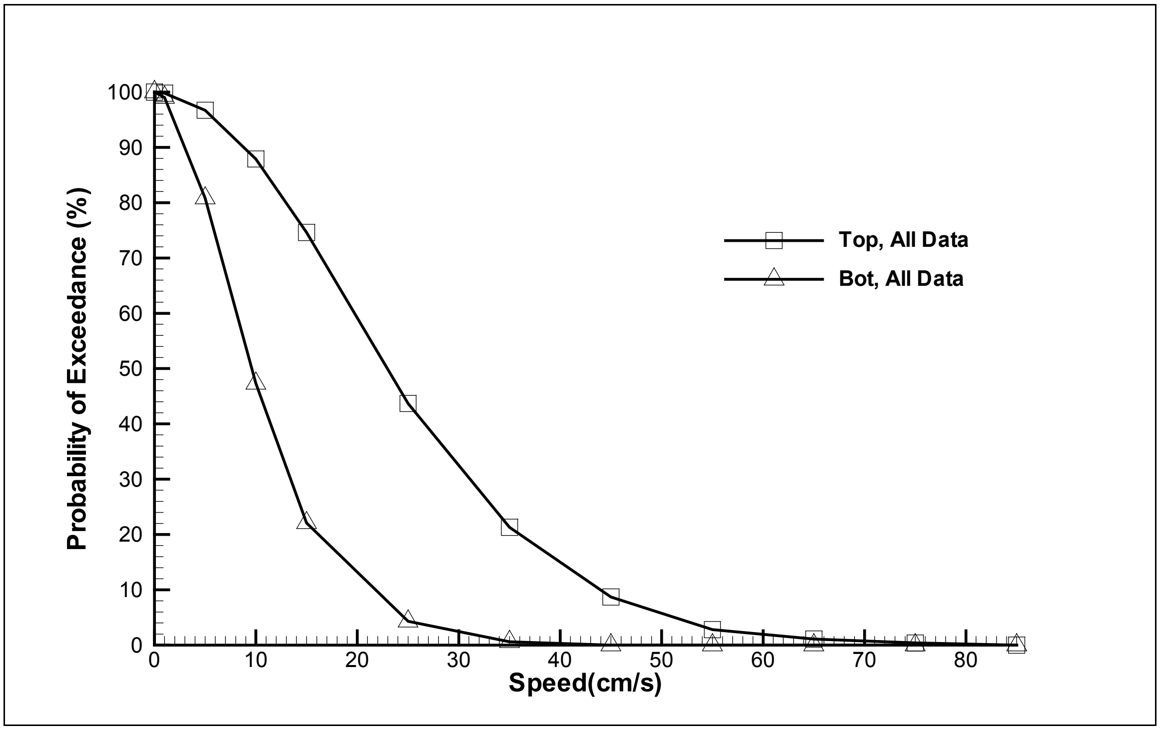

Figure 3. Current speed vs. probability curves for all measurement periods, combined.

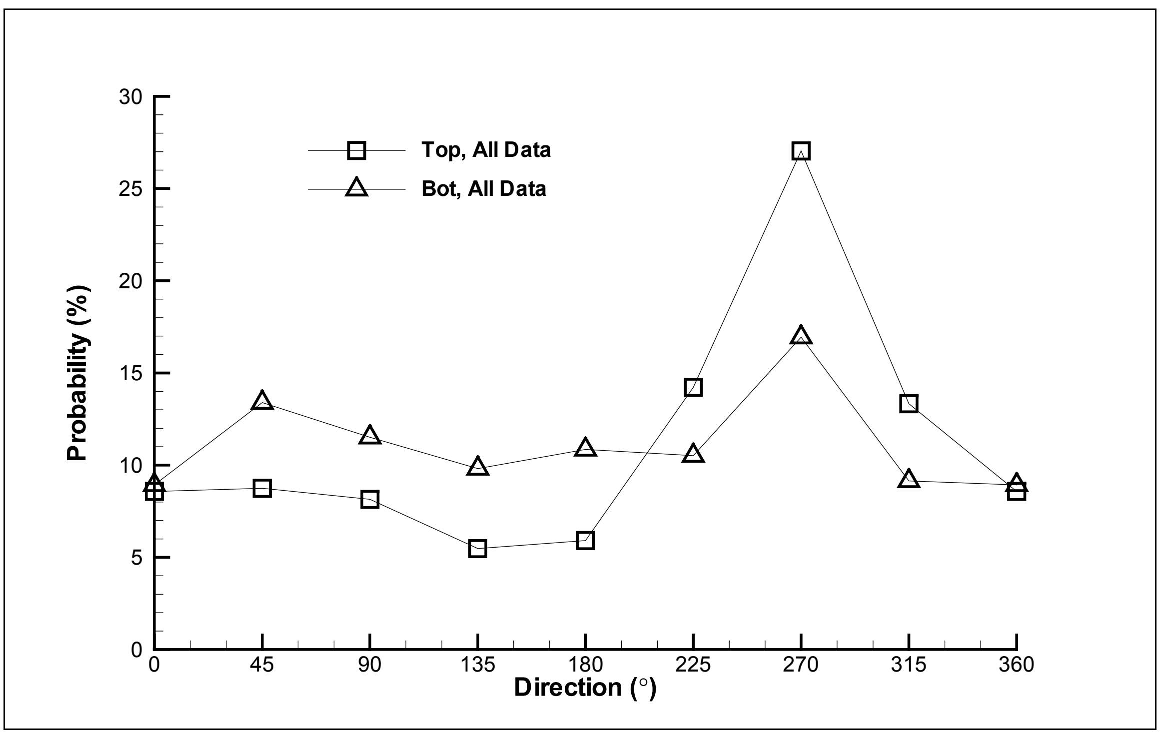

Figure 4. Current speed vs. probability curves for all measurement periods, combined.

2.3 Hydrography

Ambient salinity and temperature profiles can have an effect on effluent plumes. Changes in salinity and temperature with depth can create density gradients within the water column. The interaction of ambient density gradients with effluent density influences the vertical motion of effluent plumes.

Texas A&M University has sponsored oceanographic cruises that measured hydrographic profiles near the Gulf Landing site. Data from cruises 92G04 and 92G10 was plotted (**Figure 5**). The bottom frame of **Figure 5** shows the density[2] profiles corresponding to the measured temperatures and salinities. The bottom frame exhibits both unstratified and strongly stratified conditions. Stratification is expressed as $d\sigma_t / dy$, which ranges from 0.0 for unstratified conditions to about 0.2 for the maximum stratification.

The ambient water density for the unstratified case was taken to be σ_t=20 (based on Station 10, Cruise 92G10).

As shown in **Figure 5**, most density variations were due to salinity variations, so a composite of the two greatest salinity gradients were used to establish conditions for maximum stratification conditions. The composite maximum salinity gradient was approximately 0.25 ppt/m. Stratified conditions develop when the surface salinity is reduced by rainfall or river flows. This has implications for operation of the gasification facility. Assume that water for the gasification plant intakes comes from mid-depth in the water column, and assume the surface water has a salinity of 30 ppt. With the maximum gradient, the salinity at the sea floor (17 m below the surface) will be 34.25 ppt. The salinity at mid-depth will be 32.125 ppt. In the absence of cooling, the water, discharged near the sea floor, will be buoyant and try to rise towards the surface. Assume a water temperature that is the average of observed temperatures at stations 1-4 of cruise 92G04 (when salinity gradients were observed), 19°C. The calculated sea water densities at the surface and bottom are then 21.205 and 24.449 sigma-t units (1021.205 and 1024.449 kg/m^3). The corresponding density gradient is 0.191 kg/m^3/m (also σ_t/m).

If the water from mid-depth is cooled 10.0°C, so its temperature is 9.0°C, its density will be 24.868 sigma-t units and it will be slightly heavier than the surrounding ambient water when it exits the discharge ports.

The unstratified case (density = 1020 kg/m^3) and the stratified case (surface density = 1021.205 kg/m^3, bottom density = 1024.449 kg/m^3) were both used for modeling.

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[2] Oceanographers express sea water density in Sigma-t (σ_t) units. Sigma-t = 1000 (1 – density), where density is in g/cm^3. If density is given in kg/m^3, the corresponding Sigma-t = density – 1000.

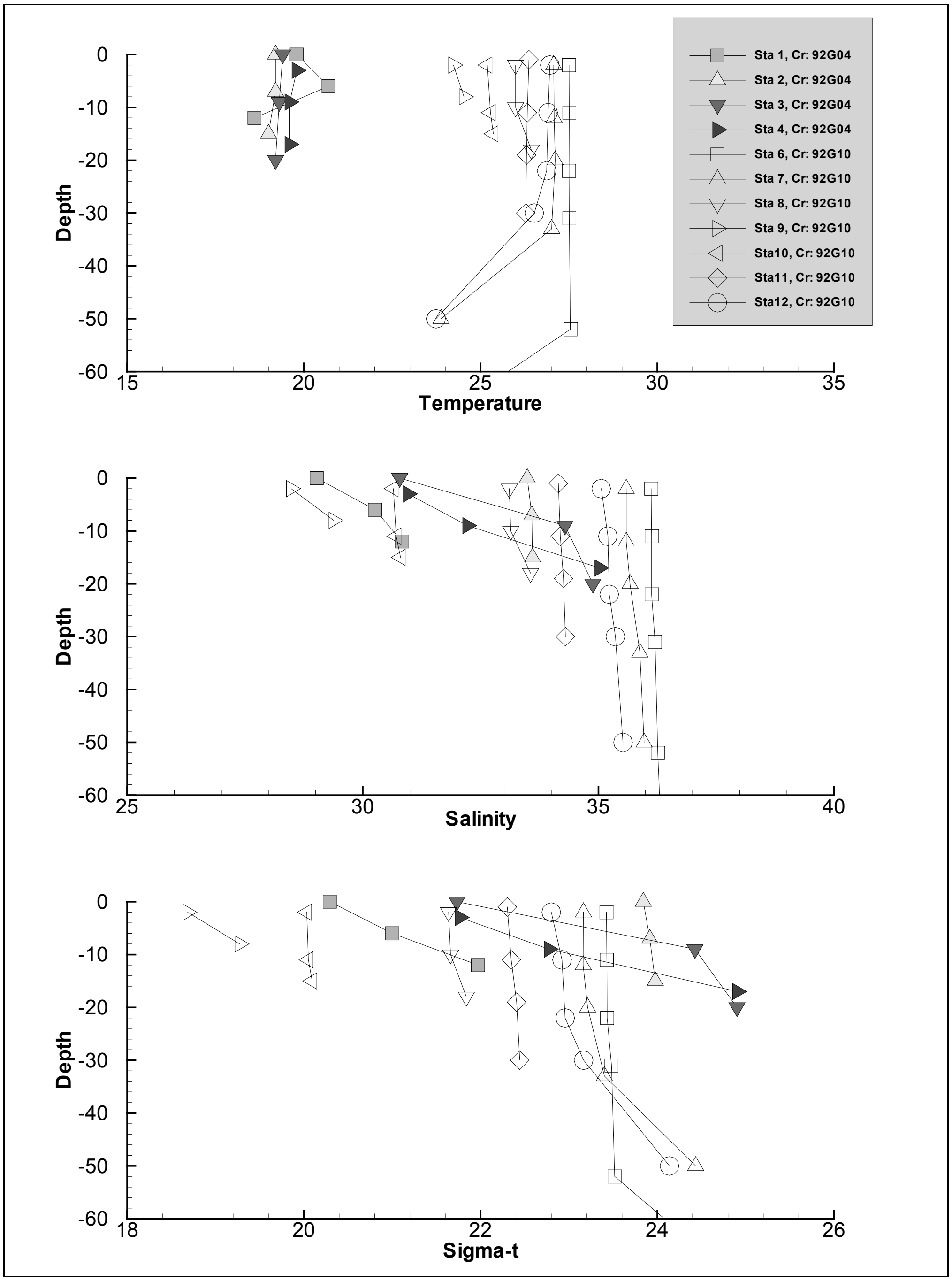

Figure 5. Temperature and salinity profiles measured near the Gulf Landing site. The sigma-t profiles in the plot frame at the bottom of the figure were computed from the temperature and salinity profiles.

2.4 Tides

Tidal fluctuations were not considered in this study. The variation in water depths due to the approximately 1 m difference between highest and lowest astronomical tides (a 6% variation of total depth) is not expected to significantly effect the results of this study.

2.5 LNG Warming Water System

The gasification facility is identified as a gravity based system (GBS) and is expected to employ seven sea water lift pumps that will draw their water from an intake cage located at an elevation in the water column that is yet to be determined. The water is to be continuously discharged through two 1.8 m (72 inch) discharge lines. At the end of the discharge lines, there will be one of two possible outfall configurations. One is a horizontal diffuser up to 100 m long (the length comes from a layout sketch). The other is an outfall structure containing a single upward directed port 2.55 m in diameter (area equivalent to two 1.8 m lines). The intake cage is to be located southeast of the facility. The outfall is to be located to the southwest of the facility.

In the base case considered in this report, the sea water flow rate is expected to be 20,000 m^3/hr (5.56 m^3/s). The discharged sea water will be 10°C (18°F) cooler than its temperature at the intake cage.

2.6 Outfall Configurations

It is necessary to select a location of the outfall with respect to the gasification facility and to select the outfall configuration. Under unstratified ambient conditions, the cool water plume will sink to the sea floor and form a cool water layer there. Under stratified conditions, the cool water plume may rise or sink, possibly forming a layer within the water column. In order to take advantage of the dilution capability of the site, it is best to place the outfall just above the sea floor and aim the discharge ports upward. This may result in some disturbance of the surface water in the immediate vicinity of the outfall. Given the tendency of the cooled sea water to sink, no significant interaction with the sea surface is expected. A location near the sea floor is also best for the safety of vessels operating in the area.

Aiming the discharge ports strongly upward is necessary to avoid a phenomenon called Coanda attachment, wherein effluent plumes discharged near solid boundaries attach themselves to the boundaries. The attachment occurs because effluent plumes try to entrain ambient water into themselves. The presence of a nearby solid boundary creates a sort of vacuum between the plume and the boundary and the plume is sucked over to the boundary. To avoid this the ports should be aimed 45 to 90 degrees above horizontal. Normally, one would try to aim the ports in the downcurrent direction[3]. For the Gulf Landing location, however, no strong directional trend is evident for currents near the sea floor (**Figure 4**). The highest probability is for the ambient current to flow westward. Therefore an outfall location west of the gasification facility is preferred. If other considerations preclude a location to the west, other directions would work just about as well.

[3] Plumes from ports aimed towards the ambient current tend to be blown back to the port and thus reduce the effective dilution achievable from the port.

The discharge ports should be aimed vertically upward to prevent effluent plumes being blown back onto themselves by an adverse current. This applies to the single port and horizontal diffuser configurations.

2.6.1 Single Port Outfall

The single port configuration will be contained in an X by X by X concrete block, where X is 3 to 4 m. As suggested above, the orientation should be vertically upward. The port diameter, 2.55 m, is calculated to provide an area equivalent to that of two 1.8 m discharge lines. The port height above the sea floor is set to 3 m, the assumed height of the concrete block.

2.6.2 Horizontal Diffuser

A sketch from Shell GS suggested that the horizontal diffuser could be 100 m long. The configuration envisioned for the diffuser is a set of vertical riser pipes attached to a horizontal diffuser manifold. In order to use a standard pipe size for risers, a port diameter of 0.3049 m (12 inches) was selected. The port area is 0.073 m^2. In order to provide good initial mixing and to keep sediment from entering the outfall, a minimum port exit velocity of 3.0 m/s was selected. A discharge coefficient of 1.0 was assumed for the risers (no flow constriction at the ends of the risers). The total port area required is 5.56 $m^3/s/3.0\ m/s = 1.8533\ m^2$. The total number of ports required is 1.8533/0.073 = 25.4, say 25. There are then 24 intervals between ports and if we set the spacing at 4 m, the total length of the diffuser is 96 m. A rule of thumb is that the total port area should be 1/3 to 2/3 of the cross-sectional area of the diffuser manifold. A manifold 2.44 m (96 inches) in diameter will make the port area/manifold area ratio = 0.396. The last configuration item is the height of the ports above the sea floor, and this was set to 3.0 m.

3 Modeling Procedure and Tools

3.1 Dilution of Waste Water Discharged to the Ocean

There are three sources of energy to drive the dilution of wastewater discharged to the ocean: the initial momentum of the wastewater, the initial buoyancy (positive or negative) of the wastewater, and the natural turbulent eddies of the ocean. The initial momentum is governed by the speed at which the wastewater exits the discharge structure, whether it be a single open pipe or a multi-port diffuser. The initial buoyancy is governed by differences in concentrations of dissolved solids and temperature between the wastewater and the receiving ocean water. These differences lead to differences in the densities of the wastewater and ambient sea water. If the wastewater is denser than the surrounding sea water, it sinks; if it is lighter than sea water, it rises. The combined influence of momentum and buoyancy drives the wastewater plume to move through the ambient receiving water. As the plume does so, it rapidly entrains the ambient water and this creates strong mixing and results in rapid dilution. When the momentum and buoyancy of the plume are dissipated (because of mixing with the ambient receiving water, possible interaction with ambient density gradients, and possible interaction with the surface or sea floor) the only remaining energy for mixing comes from oceanic turbulence. At this point, dilution continues, but at a slower rate.

In many cases, the initial dilution of a wastewater plume can be effected by outfall design that takes advantage of the initial buoyancy and is configured to provide the optimal amount of initial momentum. Design changes can have a noticeable effect in the far-field only when the volume flux of effluent is a small fraction of the volume flux of ambient water flowing by the diffuser. The ratio of the two volume fluxes can be estimated by dividing the effluent volume flux by the product of the diffuser length, the water depth and the current speed.

For the diffuser in the 10 percentile current established in section 2.3, the ambient volume flux is 96 m x 17 x 0.03 = 49 m^3/s, and the flux ratio is 5.56/49 = 0.113. The cool water volume flux is about 11% of the ambient volume flux. For the 50 and 90 percentile speeds, the ratio is 0.035 and 0.016. All these flux ratios are low enough that design changes to the diffuser should be reflected in far-field dilution results.

Considering the single port, the plume width at the end of initial dilution will be roughly 10 m and it will occupy the full water depth, 17 m. So the ambient volume flux for the 10 percentile current is 10 x 17 x 0.03 = 5.1 m^3/s. The volume ratio is 5.56/5.1 = 1.09. For the 50 and 90 percentile currents, the volume ratio is 0.34 and 0.15, respectively. These ratios suggest that changes in the size and orientation of the single port will be noticeable in the far-field only at the higher current speeds expected at the facility.

The combination of a cool water effluent that wants to sink, the injection of the effluent upward at high velocity into a relatively shallow water column, and the large volume flux of that effluent in comparison with the ambient volume flux will lead to instability, recirculation and re-entrainment in the region near the outfall (**Figure 6**). As illustrated in the figure, the region surrounding the outfall will be subject to strong vertical fluid motions and the cool water effluent will be mixed throughout the water column. Much of this mixing will involve the re-entrainment of previously discharged cool water and this will reduce the effective dilution. Because of the negative buoyancy of the cool water, it will spread upstream under the slower current speeds expected at the site. At some distance from the outfall, the water column will restratify and the cool water plume will form a layer on the sea floor. This layer will be exhibited as a large, persistent region of somewhat depressed temperatures. The cool water discharge from the Gulf Landing facility will behave in this way.

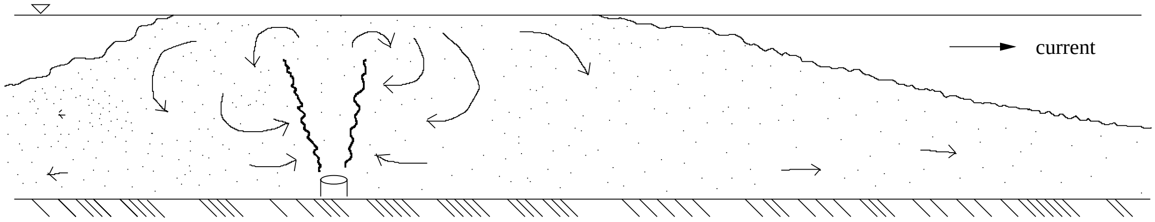

Figure 6. Unstable flow pattern for cool water effluent.

3.2 Approach

CORMIX version 3.2 was used to model the cool water plumes originating from a single port and from a 96 m horizontal diffuser under selected ambient conditions, three current speeds and stratified and unstratified ambient sea water density profiles. The diffuser performance was checked for currents flowing at angles of 90, 45 and 0 degrees measured from the diffuser axis.

The CORMIX modeling results were supplemented by detailed dynamic plume results from the CORJET subsystem of CORMIX, where possible. There were three cases that CORJET failed to run and for these cases, the OOC model was used to compute the dynamic plume. The dynamic plume results were used to add some detail to the results reported in CORMIX prediction files. In some conditions, the effluent flow is a significant fraction of the ambient flow and this leads to unstable conditions involving the full water column. The CORMIX session reports report this behavior, but it is not shown in the associated prediction file.

The output of the CORMIX system provides numeric results describing gross plume behavior and some unsatisfactory plume graphics. The dynamic plume results and CORMIX prediction file results were combined to provide plan and elevation views of boundaries and maximum temperature deficiencies as a function of down-current distance.

The physical dilution predicted by CORMIX can be applied to hyprochloride concentrations as well as temperature deficiencies. The hyprochloride concentration within the cool water plume at some distance from the discharge point (or time in steady currents) is calculated as the initial concentration divided by the dilution factor.

The longer term behavior of the cool water plume is also of interest, as the efficiency of the gasification process may be reduced if previously discharged, diluted cool water is taken into the sea water intake. So it would be helpful to estimate the probability that aged cool water from a previous discharge time will revisit the outfall location. It would also be helpful to estimate the maximum temperature deficiency that might be expected at any particular location measured from the outfall.

3.2.1 Probability of Cool Water Lens Impingement on Intake Cage

There has been some previous work on this question. Brandsma and Smith (1996) addressed the question of a plume revisiting the point of discharge for a produced water outfall in the central Gulf of Mexico in open water 82 m deep. They concluded that water packets returned to the discharge location sufficiently to allow temporary reductions of effective dilution only about 3.6 percent of the time for which current records were available. This estimate was based on progressive vector calculations from current meter records. Another study in the central Gulf (Science Applications International, 1989) found a water packet return probability of 6 percent.

The visitation probabilities for the Gulf Landing facility are expected to be higher because the currents in the area are expected to be weak, with lack of a strong directional trend. Shell's "Preliminary Oceanographic Criteria" document gave mean current component speeds of 1.1 cm/s south and 0.6 cm/s west at LATEX mooring 20 near the sea floor. The cool water plume will rest on the sea floor.

It is possible to calculate visitation probabilities around the outfall site. This is done by setting up a grid around the outfall location and counting the number of times a cloud of diluted effluent overlays each cell of the grid. This requires a time series of current speed and direction at the outfall. Clouds released from the outfall and advected by the currents measured at the outfall are allowed to travel to some limiting time following release, the time horizon. Whenever a cloud contacts a grid cell, the visitation count for that cell is incremented. Division of the count in each cell by the total number of clouds released yields the visitation frequency for that cell. This is the probability of finding a cloud that has traveled for the time horizon or less at the cell. Given an initial dilution and cloud size, the maximum concentration for a specified travel time can also be calculated. Minimum dilutions, maximum tracer concentrations or maximum temperature deficiencies can be recorded. Details of this process are in sections 3.5 and 3.6.

3.3 Offshore Operators Committee (OOC) Model

The OOC model was used to simulate the initial cool water plume behavior for the single port outfall and for a single port of the diffuser. The model was developed by Brandsma and Sauer (1983) under sponsorship of the Offshore Operators' Committee (OOC) and simulates the unsteady, three-dimensional behavior of offshore effluent plumes discharged from a single port outfall. The model has been continuously improved since its original release. The present version is 2.5.6 (October, 2002). The effluent may be drilling mud or cuttings or produced water. The model predicts effluent concentration distributions in the water column and the initial deposition distribution of particulates on the sea floor. The model has been validated in laboratory (Policastro, 1983; Brandsma et al., 1992) and field experiments (O'Reilly et al., 1989; Smith et al., 1994). A complete re-validation, using 681 model runs, has been completed recently (Brandsma, in press). The model has been used by government and industry to estimate the likely behavior and fate of drilling mud, cuttings, and produced water discharged in the marine environment. A description of the produced water aspects of the model can be found in Brandsma, et al. (1992). A more general mathematical description is in Brandsma and Smith (1999).

Appendix A provides additional information on the OOC model.

3.4 Cornell Mixing Zone Expert System (CORMIX)

The CORMIX system (Doneker and Jirka, 1990; Jirka et al, 1996) was used to analyze the cool water plumes issuing from the single port and diffuser outfall configurations. The CORMIX system and documentation is available through the U.S. EPA's Center for

Exposure Assessment Modeling (http://www.epa.gov/ceampubl/products.htm). See **Appendix B** for an overview.

3.5 Visitation Probability Model

One of the questions to be answered in this investigation is "How frequently might a cool water lens visit the intake cage location when the Gulf Landing facility is operated for a year?" In order to answer the question, it is necessary to calculate plume trajectories and growth for selected travel time horizons. In other words, we want to know where effluent plumes might travel within a time horizon of 3, 6, 9, 12 hours, etc.

The visitation probability model (and the far field dilution model described in the next section) are based on the ideas of Koh (1988), Roberts (1999), Roberts and Sternau (1997) and Koh (1971). This model is used to summarize where diluted effluent (of any concentration) is likely to travel within a specified time horizon during one year's operation of the outfall. The modeling technique requires that a continuous current record exists. The necessary data was collected at the lower meter of Site 20 of the LATEX project (DiMarco et al, 1997), beginning on 12 April 1992 and ending on 30 November 1994 (a span of 962 days). The available data consists of 32481 readings of east and north current speed components, taken at 0.5 hour intervals. This is equivalent to 70.3% data recovery.

The calculation is performed on a two-dimensional grid of contiguous, square cells surrounding the point of discharge. The cell size is constant throughout the grid. The point of discharge is located in the center of the grid. An array to record the number of cloud visits to each cell is initialized to all zeros. For a specific time horizon, the probability that an effluent plume will exist at any time within each grid cell is calculated using all available current data. Plume trajectories are calculated beginning at each half hour of the current record and ending at the start time plus the time horizon. The clouds are tracked as the ambient current advects them. Clouds are tracked until their age equals the time horizon. The diameter of each cloud as a function of travel time was calculated using the four-thirds power law of oceanic dispersion (Fischer et al, 1979) and the initial cloud size predicted by the CORMIX model. This is the lateral horizontal dimension of the continuous plume after initial dilution (at the end of the near-field calculations). Clouds may initially be smaller than a single grid cell and ultimately grow to span many cells.

The following calculations were conducted starting at each half hour of the current record and proceeding to the time horizon. The coordinates of the cloud of effluent were initialized to the point of discharge. The cloud was then advected at each time step using:

$$\begin{aligned} x &= x + u\Delta t \\ y &= y + v\Delta t \end{aligned} \qquad (1)$$

where (x,y) are the cloud coordinates, u is the east current velocity component, and v is the north current velocity component, and Δt is the time step. For this application, a half hour time step was used. The current components *u* and *v* change every half hour. The cloud size at any time step was calculated using (after Koh, 1971):

$$\sigma = \sigma_o (1 + 4^{4/3} \frac{2}{3} \frac{A_L T}{\sigma_o^{2/3}})^{1.5} \quad (2)$$

where σ represents the horizontal standard deviation of the cloud at any time, σ_o represents the initial standard deviation, A_L represents the dissipation parameter associated with the four-thirds power law, and *T* represents the travel time, or age, of the cloud. *T* is the summation of the individual time steps. The initial standard deviation, σ_o, is one-fourth of the plume width predicted by the CORMIX model after initial dilution. Equations (1) and (2) give the position and size of the effluent cloud at any time. The position and size are used to determine grid cells occupied by the cloud. The visitation counter in each cell occupied by the cloud is incremented.

The calculations described above are repeated until the cloud reaches the travel time horizon. The whole process is repeated for the next entry in the current record and successive entries up to the end of the current record, less the time horizon. At the end of all these calculations, the visitation count in each cell is divided by the total number of clouds released in the calculation. This is product of the number of time steps included in the time horizon and the number of entries in the current record, less the number of entries that fit within the time horizon. The result is a two-dimension distribution of probabilities that particular cells would be visited by diluted effluent in the time period covered by the current data record. The distribution can be multiplied by 100 to express the probabilities in percent. Contour plots of the visitation probability distributions for various time horizons were prepared.

3.6 Far-field Dilution Model

The ideas in the previous section were incorporated in a far field dilution model. A calculation of instantaneous concentrations was added based on the ideas of Roberts and Sternau (1997) and Csanady(1973). The far-field dilution at the center of any grid cell is calculated by:

$$S_f = 2\left[erf\left(\frac{\frac{L}{2} + d}{\sqrt{2}\sigma} \right) + erf\left(\frac{\frac{L}{2} - d}{\sqrt{2}\sigma} \right) \right]^{-1} \quad (3)$$

where S_f = far-field dilution, *L* = initial plume width (after initial dilution), *d* = distance of the cloud from the grid cell center, σ = the standard deviation of the concentration distribution calculated with (2). *erf* represents the standard error function. The ultimate dilution at any location is the product of the near and far field dilutions, $S = S_n S_f$. The concentration at the center of any grid cell is then:

$$C = \frac{C_o}{S_n S_f} \qquad (4)$$

where C_o is the initial effluent concentration or temperature deficiency and S_n is the near field dilution predicted by the CORMIX model. Concentrations are assigned to each cell in which a cloud is present, depending on the position of the cell with respect to the cloud center.

The far field model operates in the same way as the visitation probability model. An outer loop sequences through entries in the current record from beginning to end. An inner loop calculates the position and size of effluent clouds released at each time in the current record until each cloud's travel time horizon is reached. Cloud dilutions are calculated at each time step and corresponding concentrations are observed in each cell visited by the cloud. The maximum concentrations seen at each grid cell are recorded.

The far field dilution model produces a two-dimensional distribution of maximum concentrations associated with clouds whose age is the time horizon or less. The distribution can be plotted to show maximum concentration isolines for a given travel time horizon.

Far field dilution was calculated for the initial plume sizes and dilutions found for each ambient condition for the single port and diffuser configurations. Travel time horizons of 3, 6 and 12 hours were used. Six runs of the far field model were made for each outfall (3 current speeds and 2 stratifications). Contour plots of the resulting distributions were prepared. The distribution of maximum temperature deficiency was very similar at 3, 6 and 12 hour time horizons and showed a central peak centered on the outfall. The outer edges of the distributions extended further as the time horizon increased, but the central peaks did not change significantly. Therefore the results were consolidated to show a single distribution of maximum temperature deficiency reported for any ambient condition for the single port outfall. A similar distribution of maxima was prepared for the diffuser.

4 Results

To avoid cluttering up the text, figures for this section appear at the end of the report, following the References section.

4.1 Base Case Flow Discharged from Single Port Outfall

4.1.1 Single Port Outfall in Unstratified Conditions

The base case is a 20,000 m^3/hr flow. The single port is 2.55 m in diameter, aimed vertically upward, 3 m above the sea floor (top of concrete outfall structure).

Figures 7, 8 and 9 show, plan and elevation views of the predicted plume boundaries and the maximum temperature deficiency predicted as a function of downcurrent distance. **Figures 7-9** are for unstratified conditions and current speeds of 0.03, 0.097 and 0.218 (the 10, 50 and 90 percentile speeds). Because of the large horizontal scale and small vertical scale of the plume, the elevation views are distorted by a 20:1 vertical exaggeration.

The plume in **Figure 7** reaches the surface and creates an unstable mixing region near the discharge featuring near-field instabilities and full vertical mixing (elevation view). This mixed region will restratify and form a dense cool water layer on the sea floor, probably within 100 m or so of the discharge port. Because of the slow current the vertically mixed region near the discharge can collapse and spread in all directions. This leads to an upstream impingement of almost 400 m. There is a small, "C" shaped figure at X = 0. This represents the dynamic plume impinging on the sea surface and then falling back. This is the region of near-field instability.

The middle frame of **Figure 7** shows that a lens of cool water about 1.5 m thick is formed on the sea floor. Unfortunately, CORMIX is incapable of predicting the details of the restratification transition from the region of full vertical mixing near the discharge point to the lens. Lens formation is probably complete within 100-200 m of the point of discharge.

The bottom frame of **Figure 7** shows the temperature deficiency (depression of temperature from ambient) as a function of down-current distance. This shows that the cool water lens created under these conditions has a relatively uniform temperature. The temperature deficiency decreases from the initial $\Delta T = 10°C$ at the point of discharge (X=0) to less than 1°C within 50 m of the discharge, within the region of full vertical mixing. Once the cool water lens is formed on the sea floor, its temperature deficiency changes only slowly. A lens temperature deficiency of 1°C, corresponds to a 10:1 dilution, so hyprochloride concentration can be expected to be about 0.05 ppm on the sea floor.

When the current speed is increased to 0.097 m/s (the median speed), the dynamic plume still impinges on the surface, but the upstream impingement of the cool water lens is only about 20 m (**Figure 8**). The spreading cool water lens is much narrower than in Figure 7. The middle frame of **Figure 8** shows a region of instability and full vertical mixing near the point of discharge. This restratifies into a layer about 2 m thick 100 m downcurrent. From here down-current the layer gradually thins. The bottom frame of **Figure 8** shows a rapid decline of temperature deficiency and the formation of a layer with $\Delta T = 1°C$. As in Figure 7 the lens temperature deficiency is equivalent to a 10:1 dilution, so the hyprochloride concentration will be about 0.05 ppm on the sea floor.

When the current speed is increased again to 0.218 m/s (the 90 percentile speed), there is no upstream spreading of the cool water lens (**Figure 9**). The dynamic plume and region of instability and full vertical mixing still occupies the entire water column near the point of discharge. The cool water lens on the sea floor forms a much narrower plume in the faster current. The elevation view (middle frame of **Figure 9**) shows that the entire water column is occupied out to a distance of about 40 m. Restratification occurs between 40 and 200 m down-current. By 500 m the cool water lens has stabilized at a thickness of about 1.6 m. The temperature deficiency declines swiftly as a function of distance down-current from the point of discharge. By 100 m, the temperature deficiency is less than ΔT = 1°C. Here again, a cool water lens with relatively stable thickness and temperature deficiency is formed. Hyprochloride concentrations on the sea floor will be about 0.05 ppm.

4.1.2 Single Port Outfall in Maximum Stratification

Figures 10, 11 and 12 show the results for a single port outfall operating at 10, 50 and 90 percentile current speeds with the water column exhibiting maximum stratification. The overall behavior of the plumes from the single port in maximum stratification do not differ significantly from the unstratified conditions in **Figure 7 to 9**. A stable cool water lens of ΔT = 1°C, from 1.5 to 2 m thick forms on the sea floor. With the 10:1 dilution implied by the ΔT, hyprochloride concentrations can be expected to be 0.05 ppm on the sea floor.

4.1.3 Single Port Performance Summary

Temperature deficiency, plume thickness on the sea floor and plume half-width predictions are summarized in **Table 3** for distances 100 and 500 m downcurrent of the single port outfall. The table shows that temperature deficiencies at the two distances are not very sensitive to changes in current speed and the ambient density gradient. Plume widths are sensitive at both distances. Plume thicknesses are sensitive at the 100 m distance, and less so at the 500 m distance.

Table 3
Summary of Plume Behavior from Single Port Outfall for Base Case (20,000 m^3/hr, ΔT = 10°C)

Current		Density Gradient (σ_t/m)	Distance = 100 m			Distance = 500 m		
Speed (m/s)	Per-centile		ΔT (°C)	Plume Thick-ness (m)	Plume Half-Width (m)	ΔT (°C)	Plume Thick-ness (m)	Plume Half-Width (m)
0.030	10	0.0	1.04	0.94	627.8	0.71	1.53	858.3
0.097	50	0.0	1.06	2.00	134.1	0.83	1.29	266.1
0.218	90	0.0	0.92	4.13	33.4	0.61	1.65	125.9
0.030	10	0.19	1.05	0.97	605.6	0.73	1.54	829.4
0.097	50	0.19	1.09	2.00	131.4	0.85	1.29	260.9
0.218	90	0.19	1.11	3.34	34.5	0.73	1.42	123.2

4.1.4 Single Port Sensitivity to Discharge Changes

In order to quantify the sensitivity of plumes issuing from single port to changes in the discharge rate and effluent temperature deficiency, a few CORMIX simulations were prepared. As **Table 3** shows that the temperature deficiency results are insensitive to changes of current speed and ambient density, only the 50 percentile current speed and unstratified condition were used. **Table 4** compares the results for the base case (20,000 m^3/hr at $\Delta T = 10°C$) with a 20,000 m^3/hr discharge at $\Delta T = 5°C$, 3,000 m^3/hr at $\Delta T = 10°C$ and 3,000 m^3/hr at $\Delta T = 5°C$. Reducing the temperature deficiency of the base case reduces the ΔT's reported at 100 and 500 m by about half, as one would expect. The lateral spread of the plume is also reduced a bit because the density difference between the plume and the surrounding ambient water is reduced and this reduces the force driving plume spreading. Reducing the discharge rate to 3,000 m^3/hr makes smaller plumes but increases the ΔT at 100 m. This increase is attributed to the 0.16 m/s exit velocity associated with the 3,000 m^3/hr rate. The plume, in effect, falls over the edge of the discharge pipe structure and lands on the sea floor. As a result, dilution by active entrainment of ambient fluid is quite limited. By the time the 3000 m^3/hr plume has reached the 500 m distance there is little temperature difference between it and the base case, but the plume dimensions are significantly smaller, as would be expected.

Table 4
Sensitivity of Plumes from Single Port Outfall to Changes in Flow Rate and Temperature for Current Speed = 0.097 m/s and Zero Density Gradient (Unstratified)

Discharge Rate (m3/hr)	Initial Temperature Deficiency (°C)	Distance = 100 m			Distance = 500 m		
		ΔT (°C)	Plume Thick-ness (m)	Plume Half-Width (m)	ΔT (°C)	Plume Thick-ness (m)	Plume Half-Width (m)
20,000	10.0	1.06	2.00	134.1	0.83	1.29	266.1
20,000	5.0	0.59	2.00	121.2	0.45	1.29	248.8
3,000	10.0	2.95	0.30	48.4	0.87	0.40	119.0
3,000	5.0	1.40	0.30	44.2	0.38	0.50	111.5

4.2 Base Case Flow Discharged from Diffuser

4.2.1 Diffuser in Unstratified Conditions

Figures 13, 14, and 15 show the plume from the 96 m diffuser in unstratified conditions at 10, 50 and 90 percentile current speeds. The current direction is perpendicular to the diffuser axis.

Consider **Figure 13**, showing the plume in the slowest current speed, 0.03 m/s. In the plan view frame, the comb-like area on the left depicts individual plumes from the 25 ports, prior to merging. After merging and before the merged plume impinges on the sea floor, the plume is represented by two lines. Impingement on the sea floor and formation of a cool water lens there is depicted by the sudden widening of the plume. The elevation view in the middle frame of **Figure 13** shows that the diffuser plume occupies most of the water column and the merged plume is mixed through a large fraction of the water column. A cool water lens with a very low temperature deficiency, about 0.1°C, will be formed (bottom frame). The corresponding hyprochloride concentration will be 0.005 ppm.

Figure 14 shows the effect of increasing the current speed to 0.097 m/s (50 percentile). As there is little change between **Figures 13 and 14**, the change of speed has little effect.

Figure 15 shows the effect of increasing the current speed to 0.218 m/s (90 percentile). The plume is significantly narrowed and plumes from individual ports travel a greater distance before merging. The temperature deficiency in the cool water lens is reduced to about 0.06°C and the corresponding hyprochloride concentration will be about 0.003 ppm. The thickness of the cool water lens is increased somewhat, compared to **Figures 13 and 14**.

4.2.2 Diffuser in Maximum Stratification

Figures 16, 17 and 18 show the effects of the maximum ambient density stratification on the diffuser plumes.

In the plan view of **Figure 16**, the line of diffuser plumes can be seen at X=0. The plume from each port impinges on the surface and creates an unstable vertically mixed region along the diffuser (plan and elevation views). This well-mixed region restratifies and forms a cool water lens on the sea floor. Because of the slow current, the lens is able to intrude about 300 m upstream and spread widely downstream. The lens thickness is about 4 m and its temperature deficiency is about 0.05°C. The hyprochloride concentration is expected to be 0.003 ppm.

Figure 17 shows the diffuser plume for maximum stratification and the 50 percentile current speed. Compared to the unstratified case (**Figure 14**), the width of the cool water lens on the sea floor is narrow, the lens is thinner, and its temperature deficiency is higher (about 0.15°C). The hyprochloride concentration will be about 0.008 ppm.

Figure 18 shows the diffuser plume for maximum stratification and 90 percentile current speed. The cool water lens occupies much of the water column and the temperature deficiency is 0.1°C. The hyprochloride concentration for this case will be 0.005 ppm.

4.2.3 Diffuser Performance Summary

Plume behavior of the diffuser with currents flowing perpendicularly to it was discussed in the previous two sections. **Table 5** summarizes the plume properties (temperature deficiency, plume thickness on the sea floor and plume half-width) predicted for perpendicular currents.

Table 5
Summary of Plume Behavior from 96 Meter Diffuser for Base Case (20,000 m^3/hr, ΔT = 10°C) and Currents Flowing Perpendicular to Diffuser

Current		Density Gradient (σ_t/m)	Distance = 100 m			Distance = 500 m		
Speed (m/s)	Per-centile		ΔT (°C)	Plume Thick-ness (m)	Plume Half-Width (m)	ΔT (°C)	Plume Thick-ness (m)	Plume Half-Width (m)
0.030	10	0.0	0.09	15.8	197.6	0.08	10.4	350.2
0.097	50	0.0	0.09	15.8	200.9	0.08	10.3	358.8
0.218	90	0.0	0.06	16.8	130.7	0.05	12.7	195.8
0.030	10	0.19	0.46	3.3	506.9	0.30	3.9	783.9
0.097	50	0.19	0.16	13.2	137.0	0.13	7.8	284.0
0.218	90	0.19	0.11	14.9	76.8	0.09	9.8	139.4

As shown in Figure 2, currents can be expected to flow in all directions. To check the diffuser performance under varying current directions, two additional sets of base case CORMIX simulations (as summarized in Table 3) were prepared. One set assumed a current flowing at an angle of 45° with respect to the diffuser axis and one set assumed a current flowing at an angle of 0° with respect to the diffuser axis (parallel). **Tables 6 and 7** summarize the plume properties predicted by these additional sets of model runs.

Table 6
Summary of Plume Behavior from 96 Meter Diffuser for Base Case (20,000 m^3/hr, ΔT = 10°C) and Currents Flowing 45° from Diffuser Axis

Current		Density Gradient (σ_t/m)	Distance = 100 m			Distance = 500 m		
Speed (m/s)	Per-centile		ΔT (°C)	Plume Thick-ness (m)	Plume Half-Width (m)	ΔT (°C)	Plume Thick-ness (m)	Plume Half-Width (m)
0.030	10	0.0	0.46	2.4	676.2	0.28	3.6	925.3
0.097	50	0.0	0.09	15.6	198.2	0.08	10.2	355.9
0.218	90	0.0	0.06	16.8	129.7	0.05	12.7	194.7
0.030	10	0.19	0.50	3.1	501.2	0.32	3.8	776.4
0.097	50	0.19	0.16	13.0	135.2	0.13	7.6	282.2
0.218	90	0.19	0.11	14.8	76.4	0.09	9.7	138.8

Table 7
Summary of Plume Behavior from 96 Meter Diffuser for Base Case
(20,000 m^3/hr, ΔT = 10°C) and Currents Flowing 0° from Diffuser Axis

Current		Density Gradient (σ_t/m)	Distance = 100 m			Distance = 500 m		
Speed (m/s)	Per-centile		Δ*T* (°C)	Plume Thick-ness (m)	Plume Half-Width (m)	Δ*T* (°C)	Plume Thick-ness (m)	Plume Half-Width (m)
0.030	10	0.0	0.60	2.0	646.4	0.35	3.0	882.2
0.097	50	0.0	0.48	5.6	106.2	0.37	2.8	272.8
0.218	90	0.0	5.9	0.6	37.6	2.79	0.4	125.3
0.030	10	0.19	0.63	2.6	480.3	0.40	3.1	744.0
0.097	50	0.19	0.56	5.6	91.2	0.43	2.9	235.4
0.218	90	0.19	6.00	0.6	34.2	2.84	0.4	104.8

A review of **Tables 5, 6 and 7** shows that the diffuser performance degrades as currents depart from flowing perpendicularly to the diffuser. The poor performance for a 90 percentile current flowing parallel to the diffuser stands out. For this current, the temperature deficiency at 100 m is about 6°C and the *ΔT* at 500 m is about 2.8°C. The corresponding dilution factors are 1.7 and 3.6 and the corresponding hydrochloride concentrations are 0.3 and 0.14 ppm. Apart from this one poor performance, the maximum temperature deficiency at 100 m for any other current and either density gradient is 0.63°C. The corresponding dilution factor is 15.9 and the corresponding hyprochloride concentration is 0.03 ppm. When the current flows parallel to the diffuser, at any speed, the plume thickness on the sea floor is predicted to be 0.6 to 5.6 m at the 100 m distance and 0.4 to 3.1m at the 500 m distance. So poor diffuser performance is accompanied by a thinner plume on the sea floor.

By definition, the poor performance of the diffuser for 90 percentile currents flowing parallel can only occur significantly less than 10 percent of the time. For current speeds in the 90-th percentile and up, **Table 2** shows that the current direction is east-west 50.2% of the time. So it would be best to orient the diffuser axis north-south. Currents in the 90-th percentile and up flow north-south 15.6% of the time. So the probability of both a 90+ percentile current speed and north-south flow is 1.56%. So the diffuser will provide adequate dilution almost all the time, but occasional episodes of very low dilution can be expected.

4.2.4 Diffuser Sensitivity to Discharge Changes

Changes of discharge rate and effluent temperature can effect diffuser performance. **Table 8** compares the results for the base case (20,000 m^3/hr at Δ*T* = 10°C) with a 20,000 m^3/hr discharge at Δ*T* = 5°C, 3,000 m^3/hr at Δ*T* = 10°C and 3,000 m^3/hr at Δ*T* =

5°C. The 50 percentile current flowing perpendicular to the diffuser and a zero density gradient were used for these sensitivity tests. Reducing the temperature deficiency of the base case reduces the *ΔT*'s reported at 100 and 500 m by about half, as one would expect. Because the temperature deficiency is so small, the decrease in it from the 100 m to 500 m distances is masked by the two digit precision for temperatures. The lateral spread of the plume from 100 to 500 m is also reduced because the reduced temperature deficiency reduces the force driving plume spreading. Reducing the discharge rate to 3,000 m^3/hr makes smaller plumes but increases the *ΔT* at 100 m. This increase is attributed to the 0.45 m/s exit velocity associated with the 3,000 m^3/hr rate. The plume only travels upward a short way before falling over and landing on the sea floor. As a result, dilution by active entrainment of ambient fluid is reduced. The plume dimensions are significantly reduced at the lower rate.

Table 8
Sensitivity of Diffuser Plume to Changes in Flow Rate and Temperature for Current Speed = 0.097 m/s Flowing 90° to Diffuser and Zero Density Gradient (Unstratified)

Discharge Rate (m3/hr)	Initial Temperature Deficiency (°C)	Distance = 100 m			Distance = 500 m		
		Δ*T* (°C)	Plume Thick-ness (m)	Plume Half-Width (m)	Δ*T* (°C)	Plume Thick-ness (m)	Plume Half-Width (m)
20,000	10.0	0.09	15.8	200.9	0.08	10.3	358.8
20,000	5.0	0.04	16.2	208.6	0.04	11.3	345.4
3,000	10.0	0.19	2.9	79.0	0.12	2.0	175.7
3,000	5.0	0.08	3.6	74.5	0.05	2.5	161.0

4.3 Visitation Probability Distribution

This section addresses the likelihood of a packet of water released from the outfall visiting locations near the outfall during one year of operation. As observed previously, the currents are not particularly strong and the current direction near the sea floor has a fairly uniform distribution around the compass. This means that a packet of water released from the outfall will tend to meander around the outfall, rather than being strongly advected away from it.

Figures 19 to 23 show the distribution of visitation probabilities surrounding the outfall (0,0). These results demonstrate that as the time allowed for a water packet to travel increases, the probability that the packet will visit locations near the outfall increases too. In other words cool water lenses will be frequent visitors to the intake cage location, wherever it is located. These results were calculated using the method described in section 3.5.

4.4 Far-Field Advection and Distribution of Maximum Temperature Deficiency

The calculations described in section 3.6 produced the results shown in **Figures 24 and 25** which are both plotted to the same scales.

Figure 24 shows the distribution of maximum temperature deficiencies predicted around the single port outfall. Temperature deficiencies of more than 2.4°C were reported in a small area near the outfall. Near the outfall, maximum temperatures decline rapidly in the first few hundred meters of distance from the outfall and more slowly thereafter. A significant area may see temperature deficiencies exceeding 1°C.

It is very important to make two points regarding **Figure 24**. First, the figure does not depict an instantaneous distribution of maximum temperature deficiency (ΔT), but only the maximum ΔT expected to be observed at each point during one year's operation of the facility. Second, the maximum temperature deficiencies depicted will occur in a thin layer on the sea floor. The plume from the single port outfall is not expected to be present in the middle and upper water column except very near the outfall.

Figure 25 shows the distribution of maximum temperature deficiency expected from the 25 port diffuser when it is operating properly under most conditions. The rather startling uniformity of this distribution is an artifact of the mixing efficiency of the diffuser. Because of the diffuser, the initial conditions for the far field dilution calculation were plume widths of about 100 m and near field dilution factors from 17.6 to 61 (initial ΔT = 0.6 to 0.2°C). The diffuser fulfills its function by spreading the cool water effluent over a wide area and over much of the water column. The resulting large areas and low ΔT lead to a very slow decay of temperature deficiency with travel time and distance. This figure suggests that visits of diluted cool water to the sea water intake are going to occur during one year's operation of the plant.

As mentioned previously the diffuser will perform poorly when fast currents flow parallel to the diffuser. A figure showing the distribution of maximum possible temperature deficiency when the diffuser is operating poorly and producing plumes with ΔT = 6°C was not included because it would be highly misleading. This is mainly because the episodes of poor performance will be limited by the persistence of fast currents. The LATEX site 20 data for the lower meter indicate that the persistence of currents at 90-th percentile and greater is 12 hours or less. As the far-field model covers one year of facility operation, providing a figure showing large ΔT over a wide area for a source that has a very short duration is not appropriate.

4.5 Uncertainties

The currents measured at the bottom meter of LATEX site 20 were used for modeling because the cool water plumes spend most of their time on the sea floor. Near the outfall, however, the plumes briefly occupy most or all the water column. The data recorded at LATEX site 20 show that the near surface and near bottom meters rarely recorded identical current directions. Speeds at the near surface meter are significantly higher than at the near bottom meter. Thus there will normally be both speed and directional shear. As CORMIX only allows a uniform spatial distribution of currents, it is necessary to pick single current speeds for modeling. In reality, the cool water plume will be subjected to the speed and directional shear. This is likely to cause the initial mixing to be somewhat higher than predicted by CORMIX because the speed and directional shears will tend to "shred" the plume more before it falls back to the sea floor.

When the water column is stratified so that there are an upper and lower density layer, separated by a pycnocline, the speed and directional shear is likely to be mostly restricted to the pycnocline. When the water column is well mixed, any speed or directional shear is likely to be distributed over a much larger portion of the water column.

5 Discussion and Recommendations

The results reported here are not likely to change significantly if the location of the outfall is changed such that small variations of water depth occur.

Two caveats are in order. First, as mentioned above, computer models have a tough time dealing with the discharge conditions described in this report. Careful laboratory experiments remain the best way to deal with such flows. Second, every CORMIX session report ends with these words:

> "REMINDER: The user must take note that HYDRODYNAMIC MODELING by any known technique is NOT AN EXACT SCIENCE. Extensive comparison with field and laboratory data has shown that the CORMIX predictions on dilutions and concentrations (with associated plume geometries) are reliable for the majority of cases and are accurate to within about +-50% (standard deviation). As a further safeguard, CORMIX will not give predictions whenever it judges the design configuration as highly complex and uncertain for prediction."

The CORMIX model results presented in this report indicate that, most of the time, the diffuser does a better job of mixing the cool water effluent with the ambient sea water than does the single port. The performance of the diffuser will depend on its orientation on the sea floor. A north-south orientation of the diffuser is recommended. Both the diffuser and the single port outfall cause the formation of a cool water lens on the sea floor under all conditions investigated.

The temperature deficiency of the lens formed from the single port is about 1°C and the hyprochloride concentration is expected to be about 0.05 ppm on the sea floor.

Assuming a north-south diffuser orientation, it is predicted to provide good to excellent dilution 98.4 percent of the time. The combination of a 90+ percentile current speed and a north or south current direction, which is expected to occur 1.6 percent of the time, prevents the diffuser from working properly. When the diffuser is working properly, the temperature deficiency of the lens formed from the diffuser is roughly 0.06 to 0.63°C in all conditions except the fast north-south currents. These temperatures correspond to hyprochloride concentrations of 0.003 to 0.032 ppm. During the 1.6 percent of the time when the diffuser performs poorly, the predicted temperature deficiency 100 m downcurrent is about 6°C. The corresponding hyrochloride concentration is 0.3 ppm. The poor performance associated with fast parallel currents occurs because the plumes issuing from individual diffuser ports are entraining effluent from upstream ports rather than ambient sea water. While the physical dilution of each port plume remains the same, the effective dilution is reduced to almost nothing. At the slower currents, the plumes can reach near the surface and the resulting mixing provides adequate dilution. When the current speed is fast, the individual plumes are bent over and immediately interact with their neighbors.

When operating properly, the diffuser provides its improved dilution by distributing the cool water effluent over a much larger range of depths in the water column. At a distance of 200 m, the diffuser plume occupies up to 15 m (88%) of the water column. This fact, together with the tendency of discharged water to meander around in the vicinity of the outfall suggests that water with a slight temperature deficiency, will unavoidably be taken into the intake cage if the 96 m diffuser configuration is employed. Vertical positioning of the intake cage will not effect this and there is a risk that positioning the cage at the surface will cause trapping of the cool water plume within the water column in stratified conditions.

In contrast, the single port outfall generates a thinner cool water lens with a temperature deficiency of about 1°C and a hyprochloride concentration on the sea floor of about 0.05 ppm. Because of the thinner and denser cool water lens, vertical separation of the cool water lens from the intake cage is possible, provided a sufficient horizontal distance between the intake cage and the outfall is maintained. CORMIX predictions are approximate, but the they indicate that the maximum thickness of the cool water lens 300 m away from the point of discharge will be about 2 m (**Figure 12** elevation frame). If a single port outfall is selected, the intake cage should be placed at mid-depth to ensure vertical separation.

The single port configuration provides a maximum $\Delta T = 1.1$°C at a 100 m distance from the discharge, under all conditions investigated. The diffuser provides a maximum $\Delta T = 0.63$°C at 100 m from the discharge for 98.4 percent of the time. The maximum ΔT for the remaining 1.6 percent of the time is about 6°C. For comparison, the World Bank has a requirement that power plant thermal discharges have a $\Delta T < 3$°C at distances greater than 100 m from the discharge. It is unclear if this requirement is applicable to water discharges that are cooler than the surrounding ambient. Dilution provided by the single port configuration could be improved somewhat by reducing the port diameter to increase the exit velocity. As presently configured the exit velocity is 1.0 m/s for the base case flow. Reducing the port diameter to 1.54 m would increase the exit velocity to 3.0 m/s. This would lead to the plume occupying the full water column near the single port, but the plume would restratify and be restricted to the bottom 15 to 30% of the water column at a lateral distance of, say, 200 m. The faster exit speed would help reduce marine fouling. The price would be a higher hydraulic head requirement.

The cool water plume is expected to always be located at the sea floor for the range of conditions investigated. This, however, cannot be guaranteed by computer modeling. As indicated above, CORMIX predictions are not exact. If CORMIX has underestimated the amount of dilution that will occur, then the cool water plume densities have been overestimated. This implies that trapping of the plume within the water column instead of on the sea floor is a possibility (because actual plume densities could be less than predicted).

Calculation of the distribution of visitation probabilities based on the near bottom current measurements from LATEX site 20 shows that cool water lens will revisit locations around the outfall. There is no way to guarantee horizontal separation of cool water lenses from the intake cage. It does, however, appear to be possible to guarantee vertical separation if a single port outfall is used. If a diffuser is used, the cool water lens will occupy a vertical section of the water column used by the intake cage, however the temperature deficiency in this event will be small (usually 0.1°C or less, but sometimes 0.5°C).

The temperature deficiencies reported here are significantly smaller than the range of natural temperature variation recorded at LATEX site 20. The near bottom ambient temperature range was 12.3 to 30.2°C with a mean value of 22.5°C. The near surface ambient temperature range was 10.9 to 32.0°C with a mean value of 23.3°C. The temperature ranges for the bottom and surface meters was 17.9 and 21.1°C. These statistics were reported in Shell's "Preliminary Oceanographic Criteria" document.

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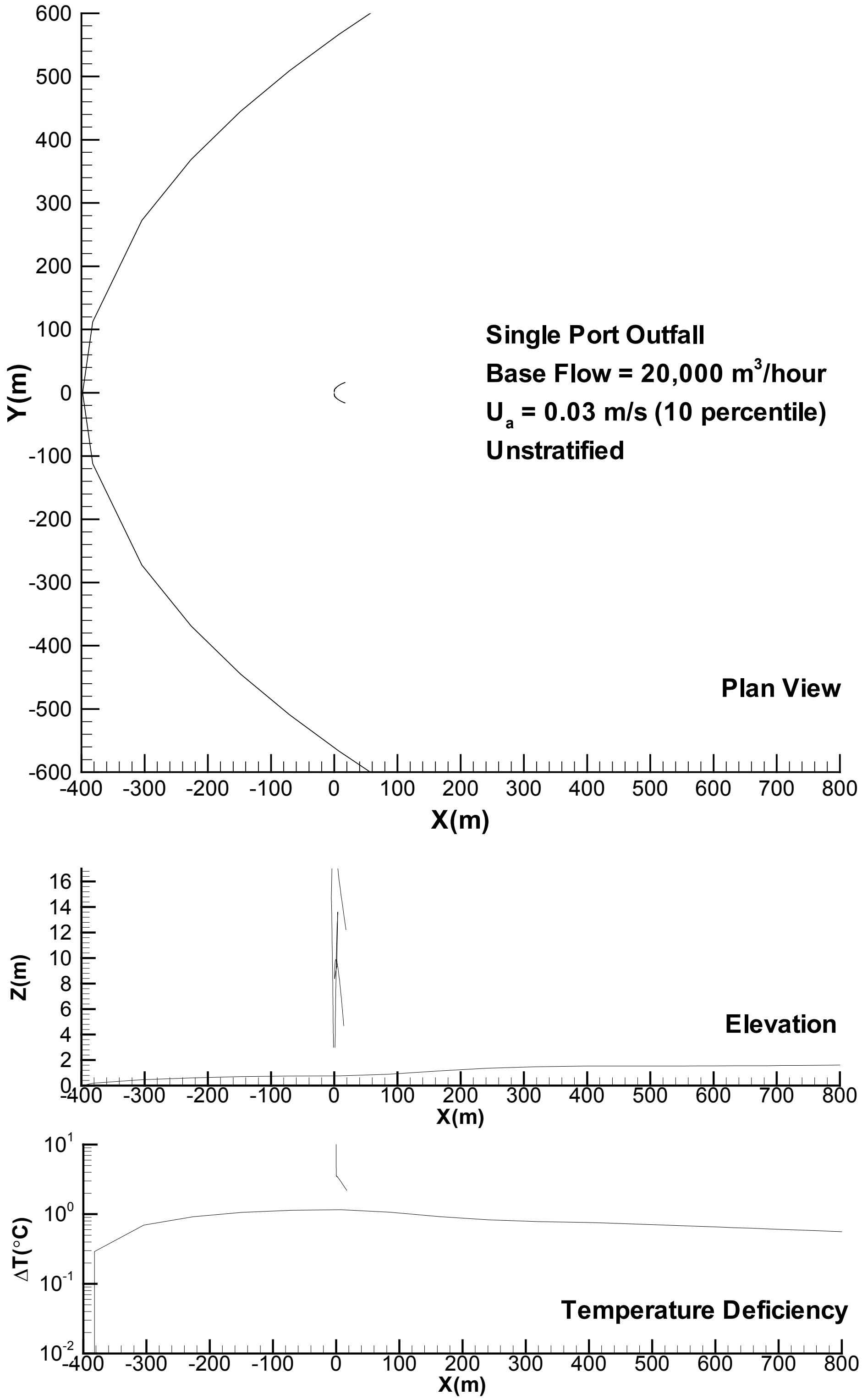

Figure 7. Cool water plume from single port outfall, 20,000 m3/hr, current speed = 0.03 m/s (10 percentile), unstratified water column. Top frame shows plan view of horizontal plume boundaries. Middle frame shows elevation (side view) of plume. Bottom frame shows maximum temperature deficiency as a function of downstream distance.

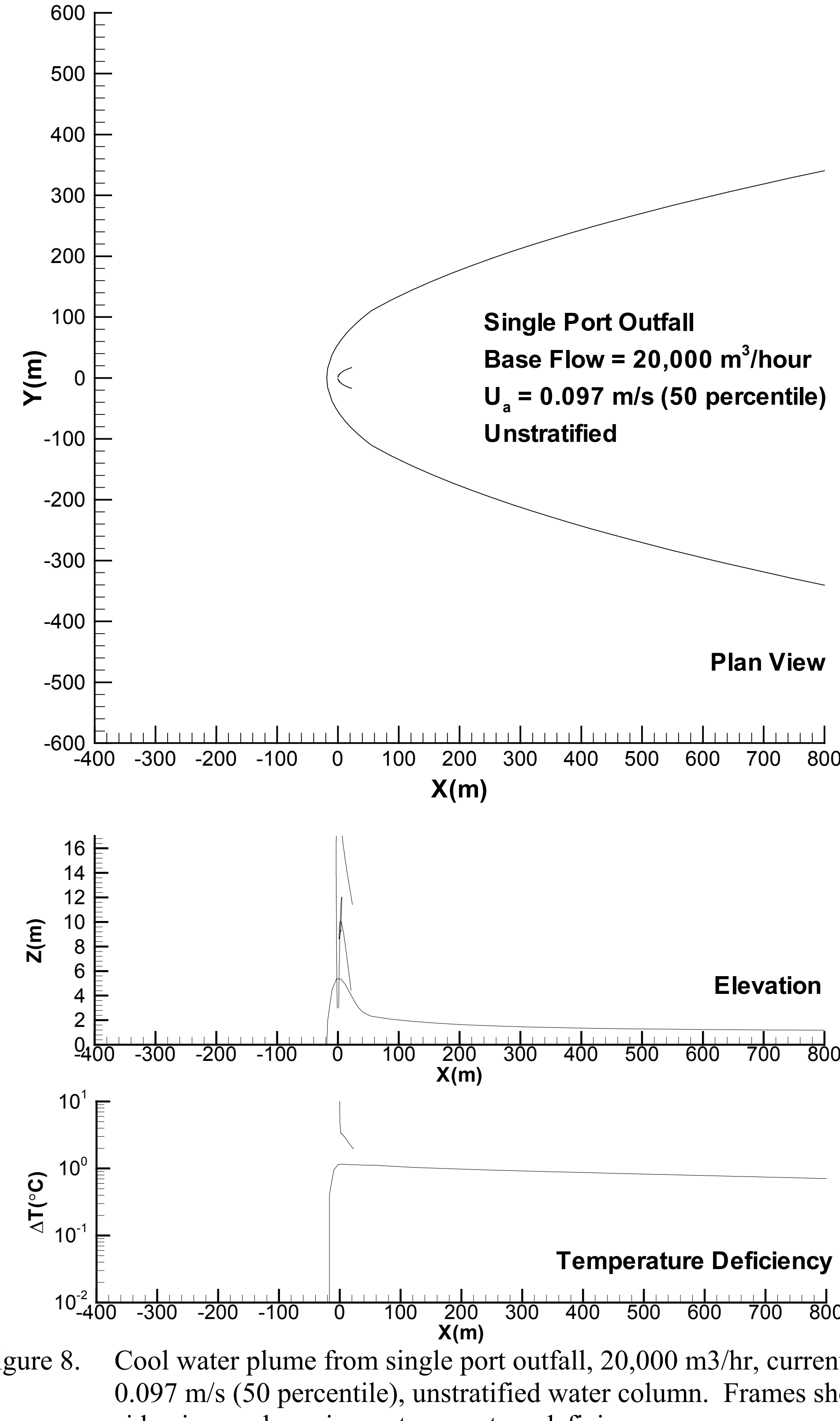

Figure 8. Cool water plume from single port outfall, 20,000 m3/hr, current speed = 0.097 m/s (50 percentile), unstratified water column. Frames show top view, side view and maximum temperature deficiency.

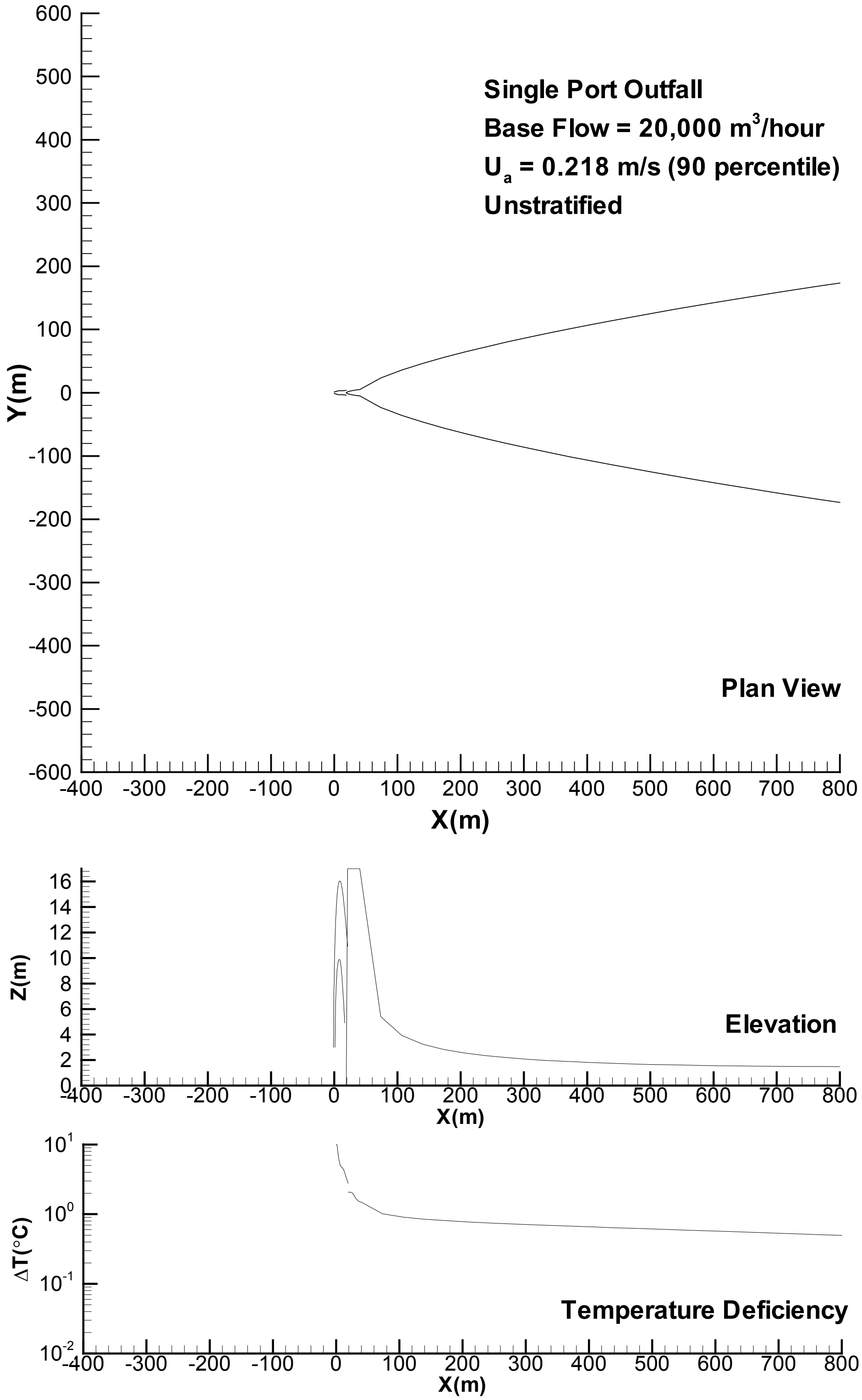

Figure 9. Cool water plume from single port outfall, 20,000 m3/hr, current speed = 0.218 m/s (90 percentile), unstratified water column. Frames show top view, side view and maximum temperature deficiency.

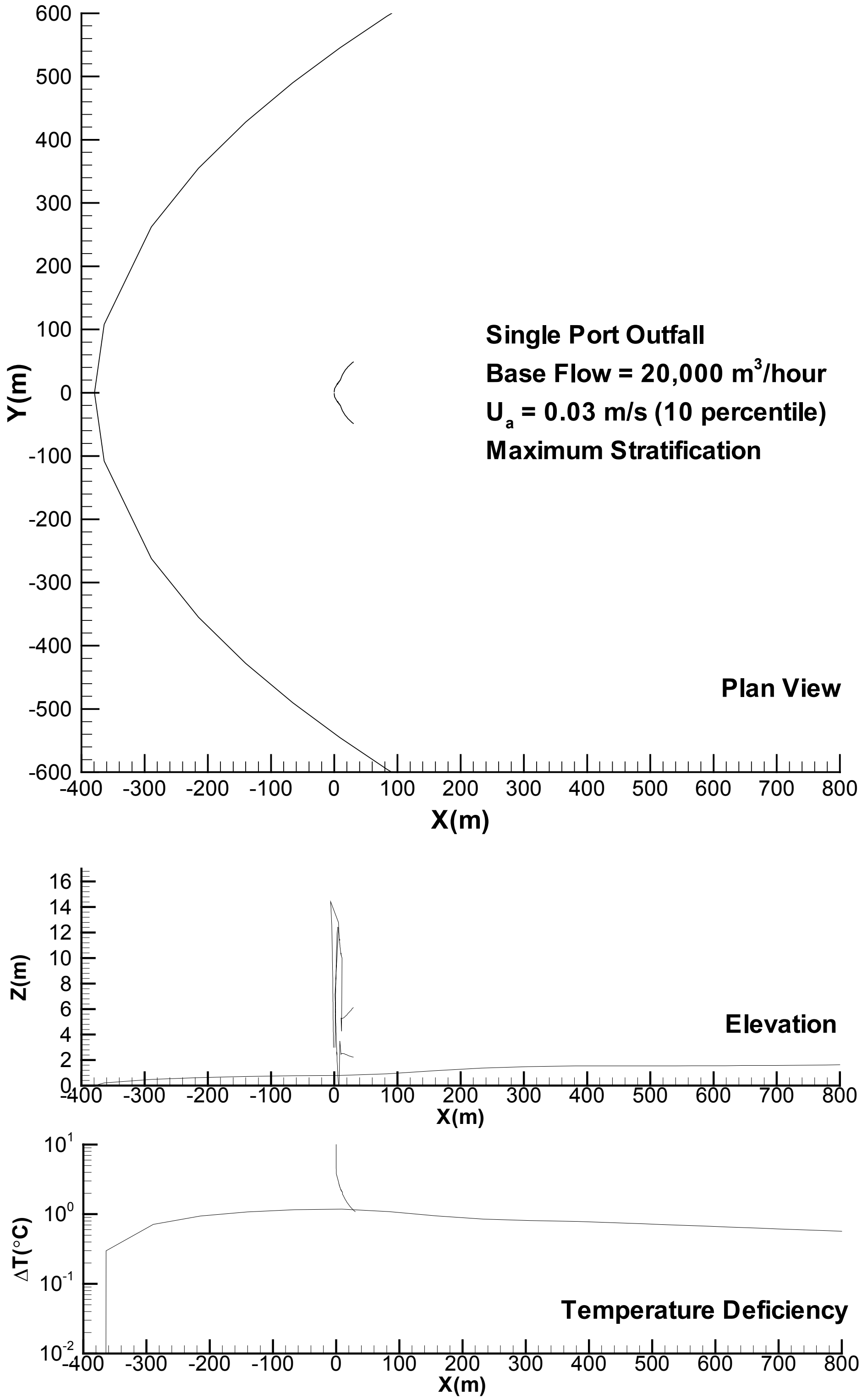

Figure 10. Cool water plume from single port outfall, 20,000 m3/hr, current speed = 0.0.03 m/s (10 percentile), water column has maximum stratification. Frames show top view, side view and maximum temperature deficiency.

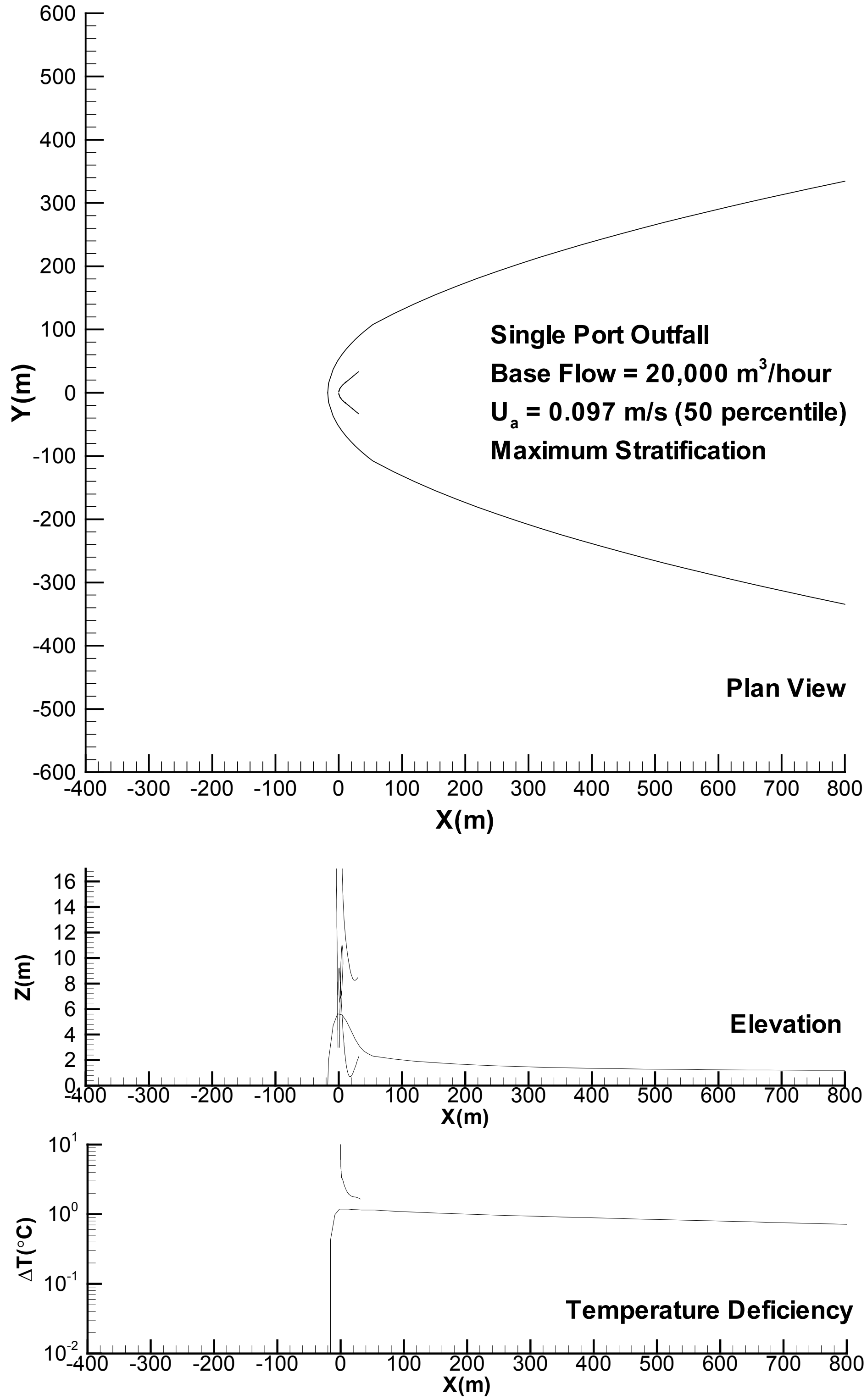

Figure 11. Cool water plume from single port outfall, 20,000 m3/hr, current speed = 0.0.097 m/s (50 percentile), water column has maximum stratification. Frames show top view, side view and maximum temperature deficiency.

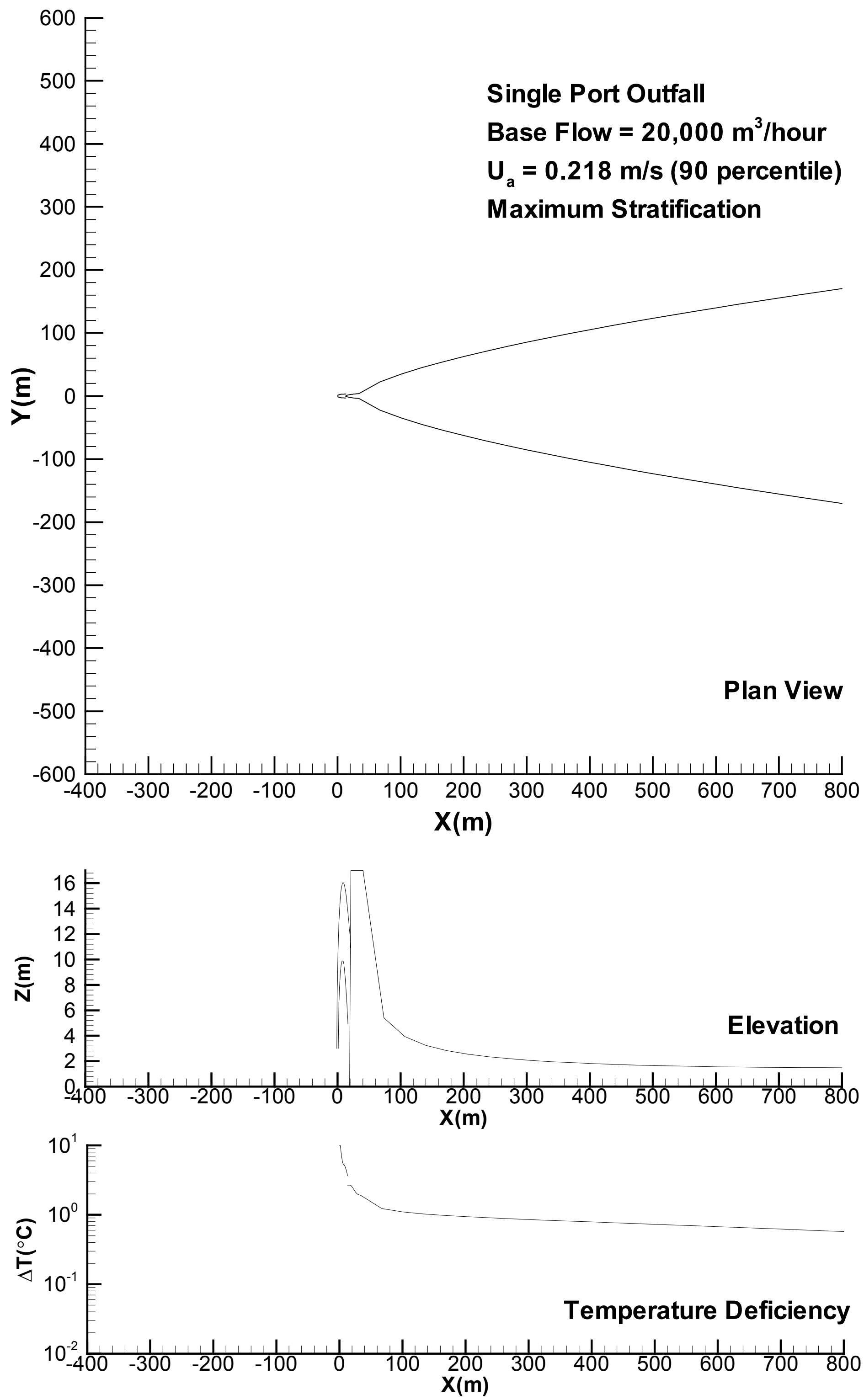

Figure 12. Cool water plume from single port outfall, 20,000 m3/hr, current speed = 0.0.097 m/s (50 percentile), water column has maximum stratification. Frames show top view, side view and maximum temperature deficiency.

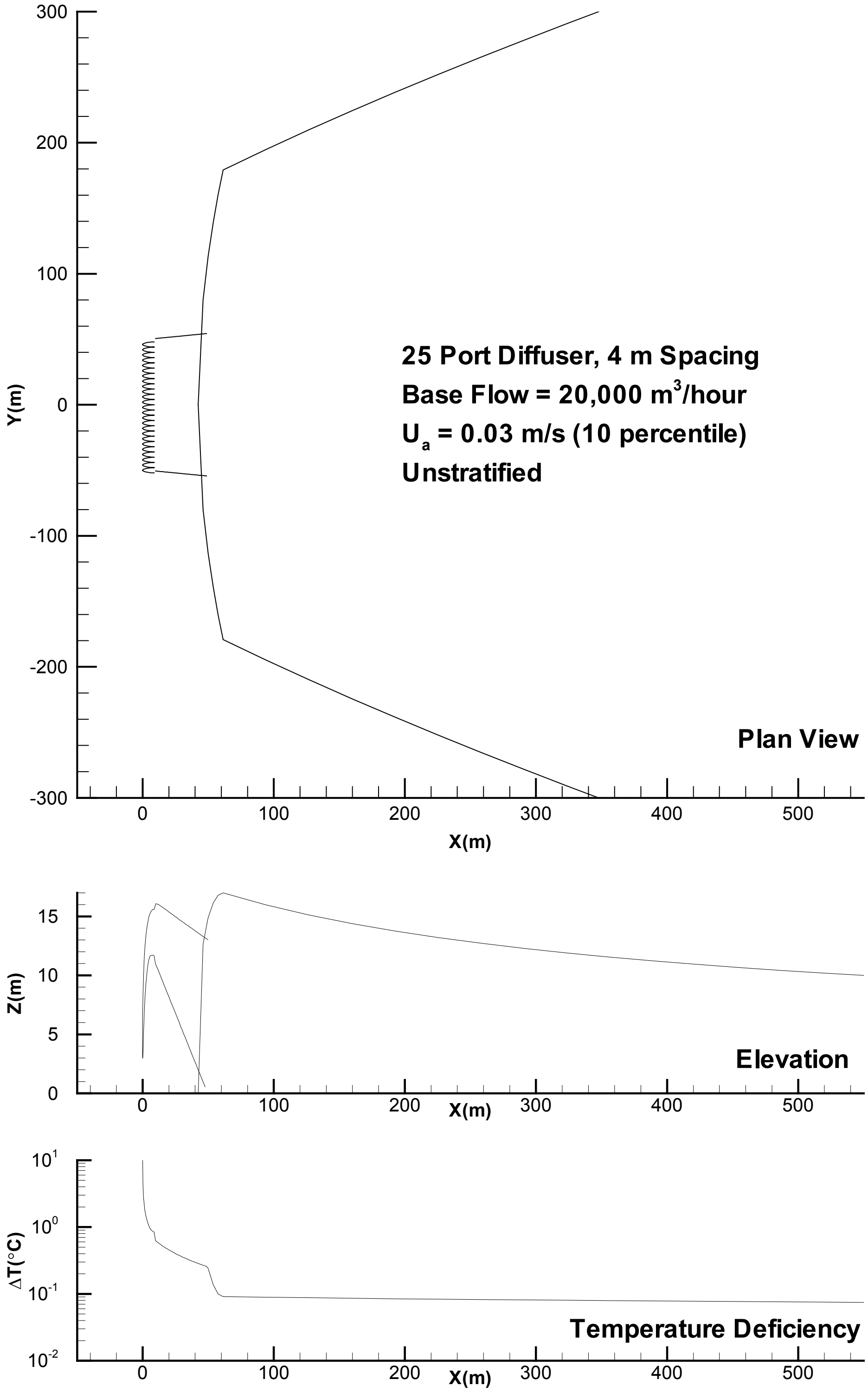

Figure 13. Cool water plume from 25 port, 96 m diffuser, 20,000 m3/hr, current speed = 0.03 m/s (10 percentile), unstratified water column. Frames show top view, side view and maximum temperature deficiency.

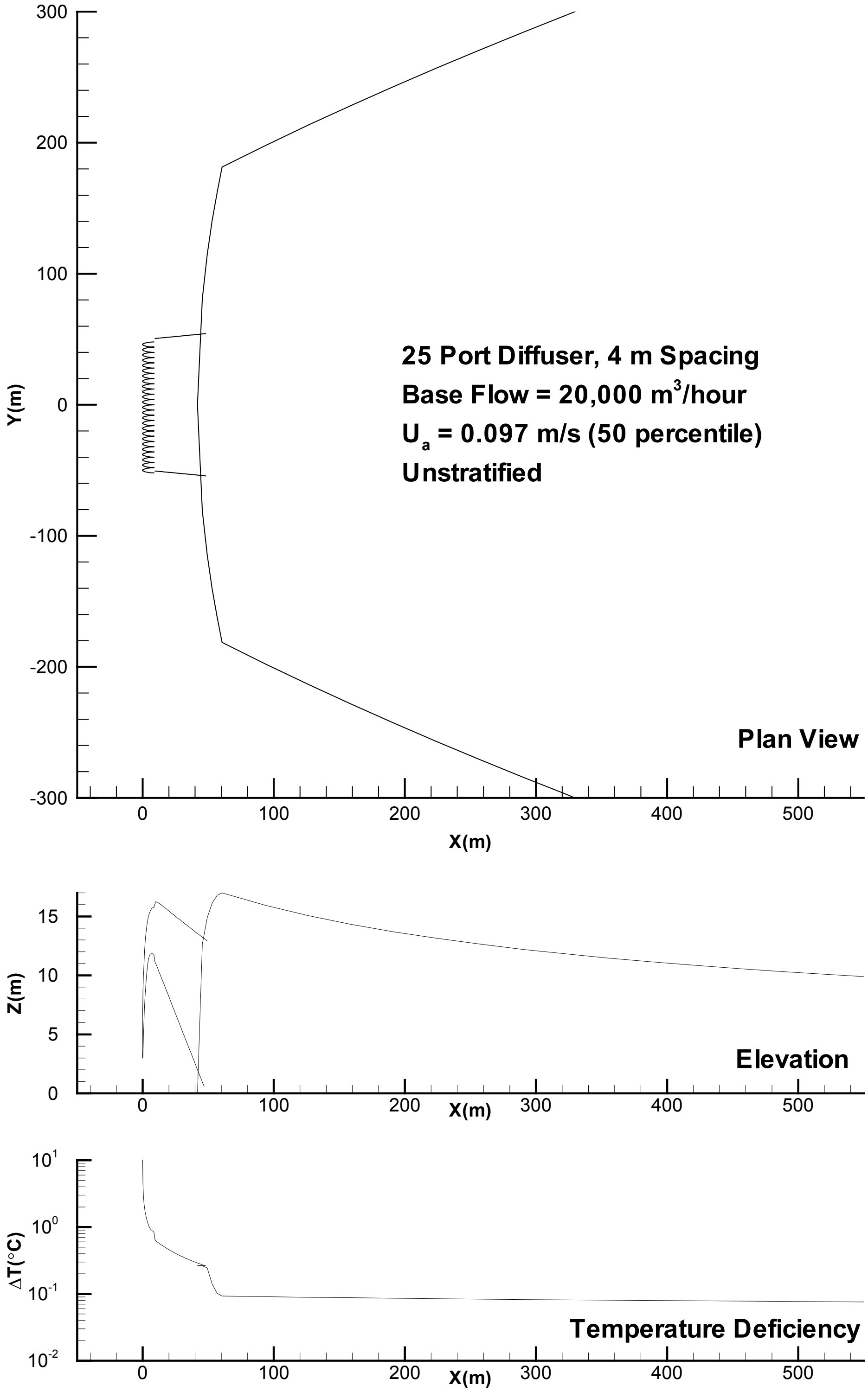

Figure 14. Cool water plume from 25 port, 96 m diffuser, 20,000 m3/hr, current speed = 0.097 m/s (50 percentile), unstratified water column. Frames show top view, side view and maximum temperature deficiency.

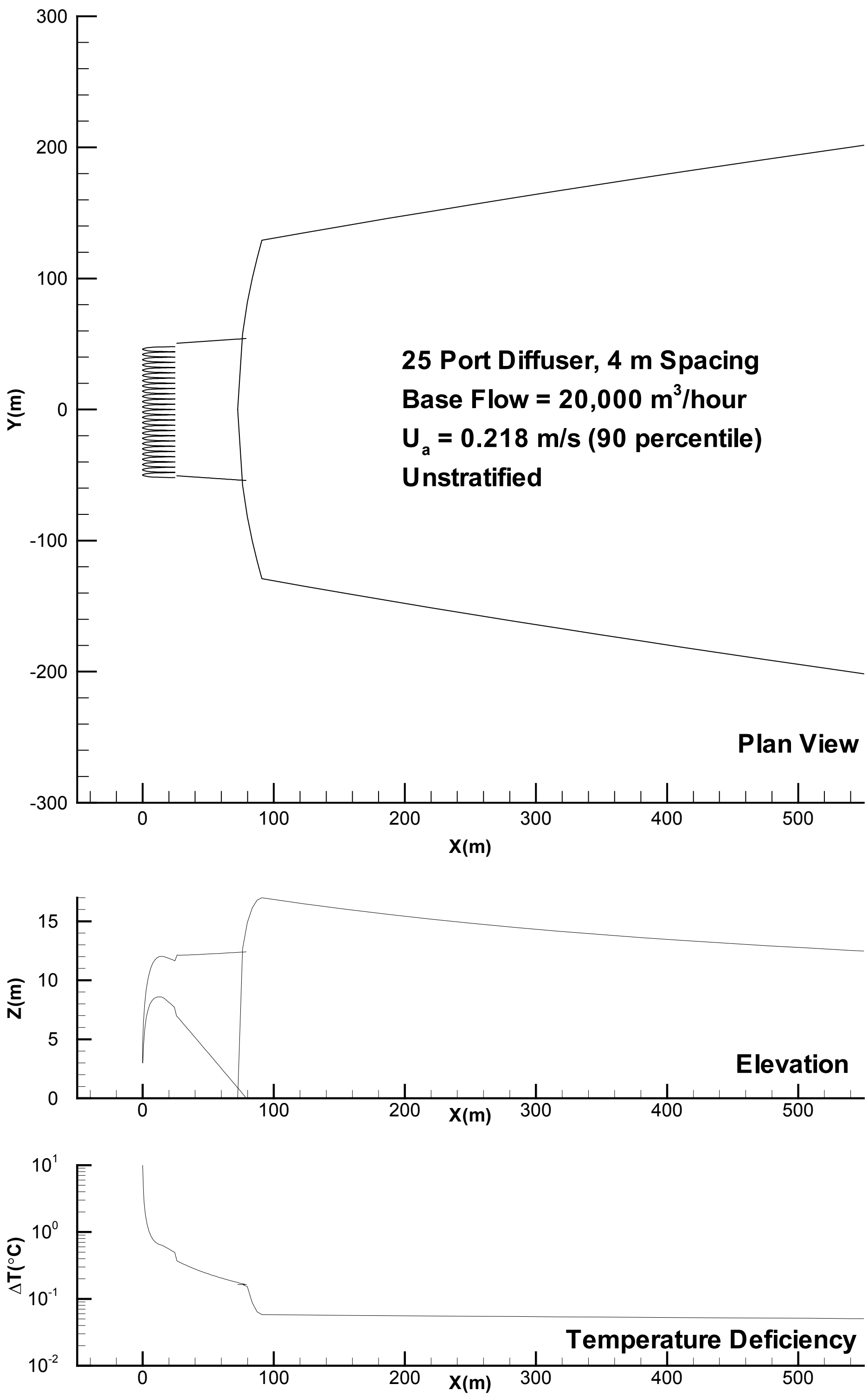

Figure 15. Cool water plume from 25 port, 96 m diffuser, 20,000 m3/hr, current speed = 0.218 m/s (90 percentile), unstratified water column. Frames show top view, side view and maximum temperature deficiency.

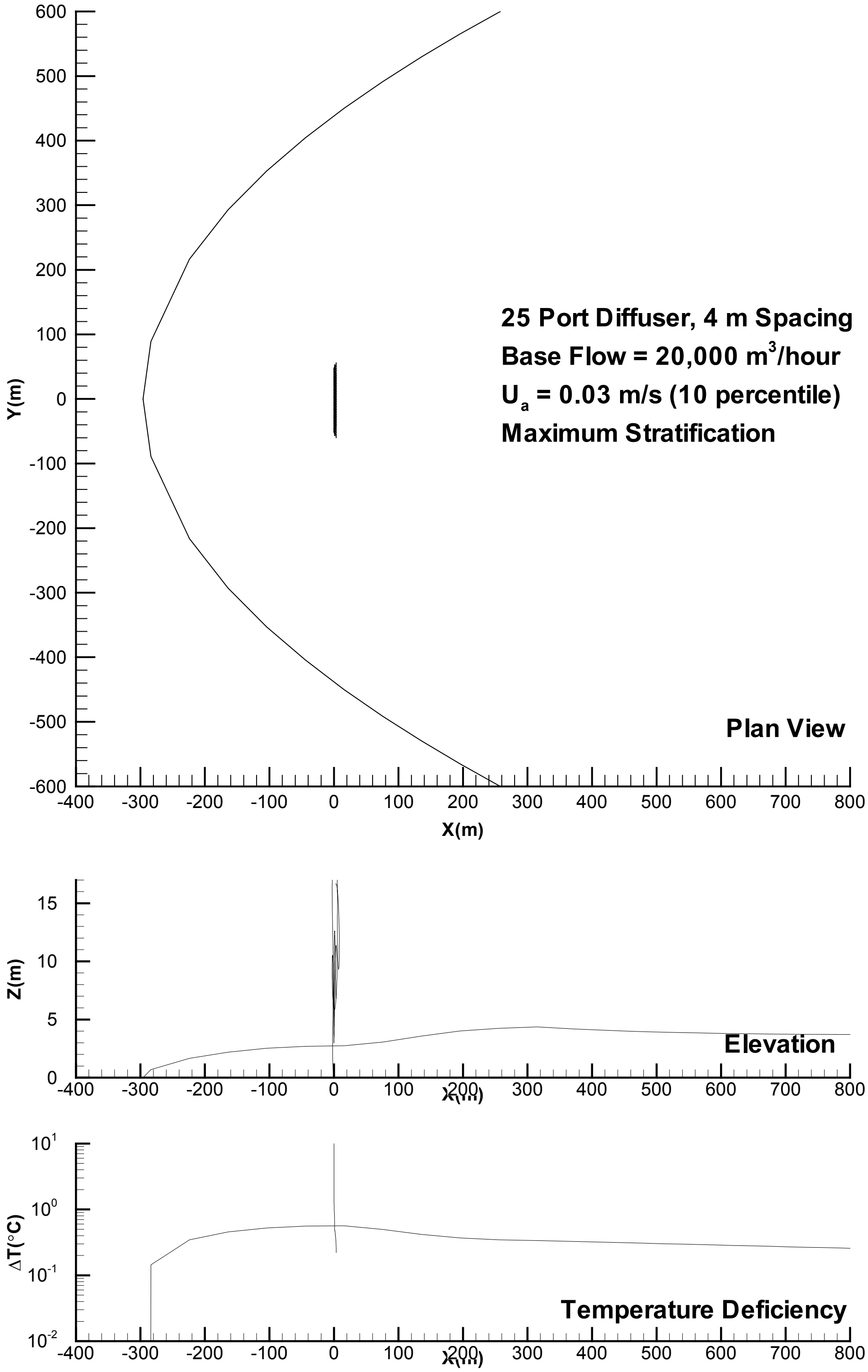

Figure 16. Cool water plume from 25 port, 96 m diffuser, 20,000 m3/hr, current speed = 0.03 m/s (10 percentile), water column has maximum stratification. Frames show top view, side view and maximum temperature deficiency.

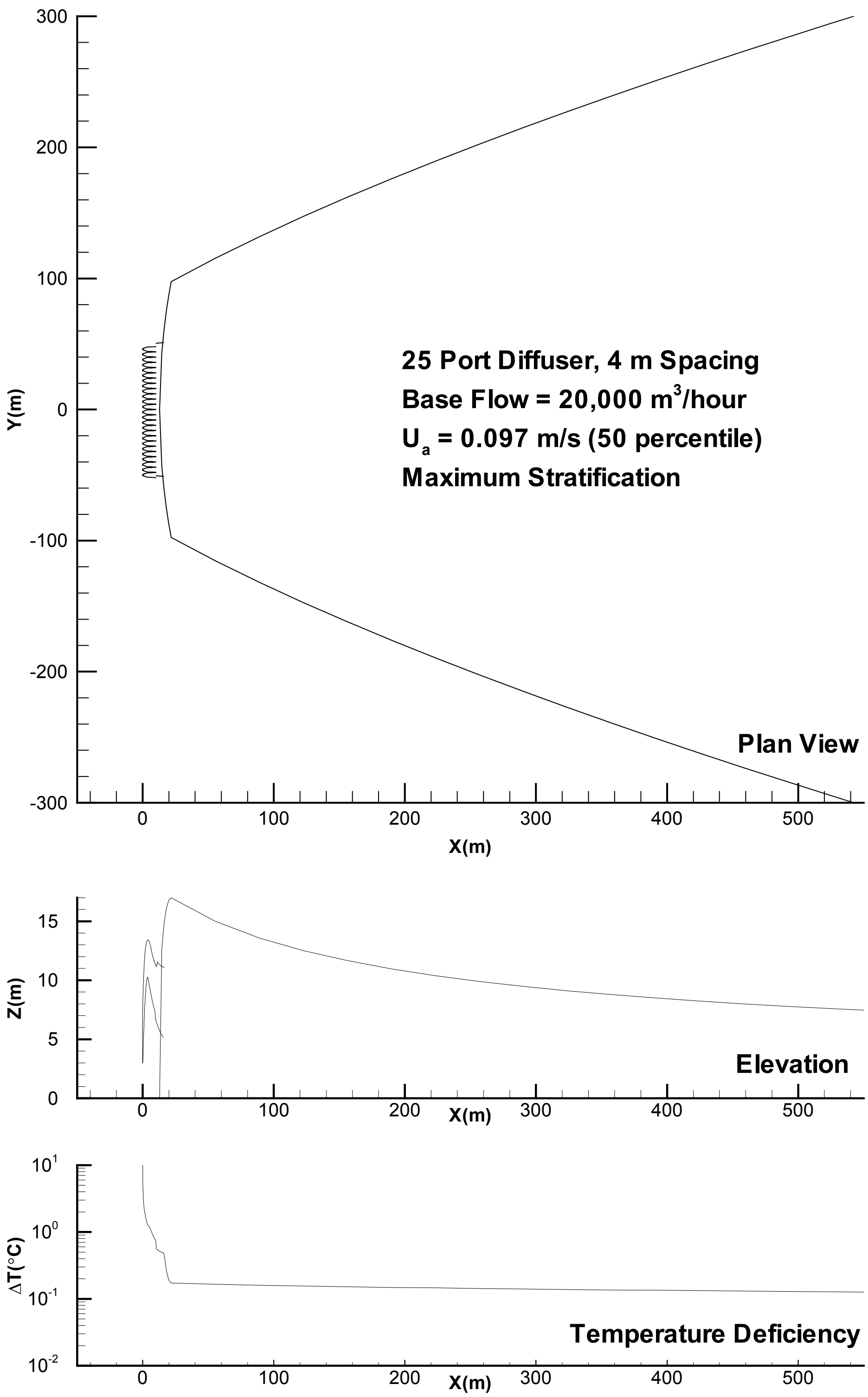

Figure 17. Cool water plume from 25 port, 96 m diffuser, 20,000 m3/hr, current speed = 0.097 m/s (50 percentile), water column has maximum stratification. Frames show top view, side view and maximum temperature deficiency.

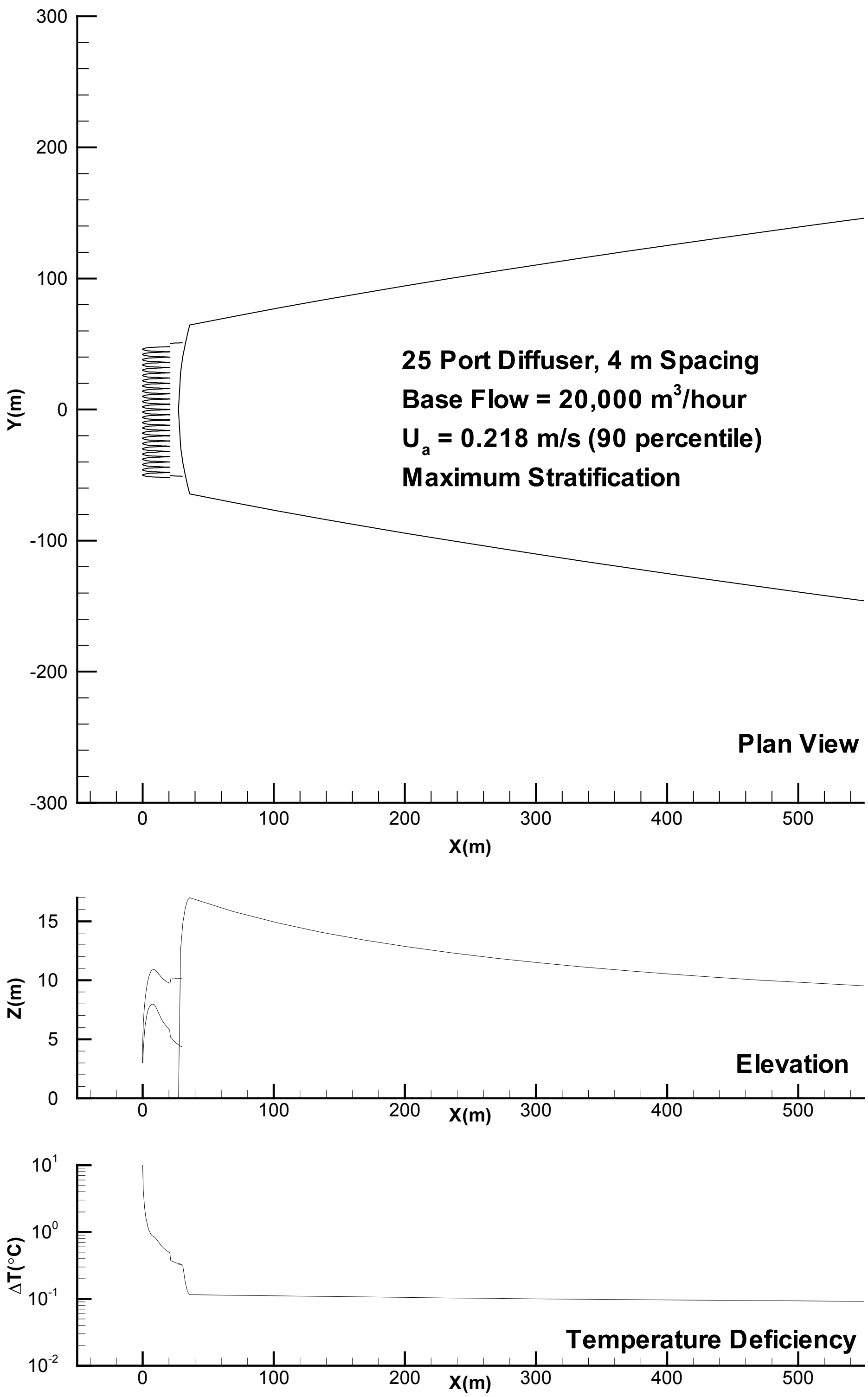

Figure 18. Cool water plume from 25 port, 96 m diffuser, 20,000 m3/hr, current speed = 0.218 m/s (90 percentile), water column has maximum stratification. Frames show top view, side view and maximum temperature deficiency.

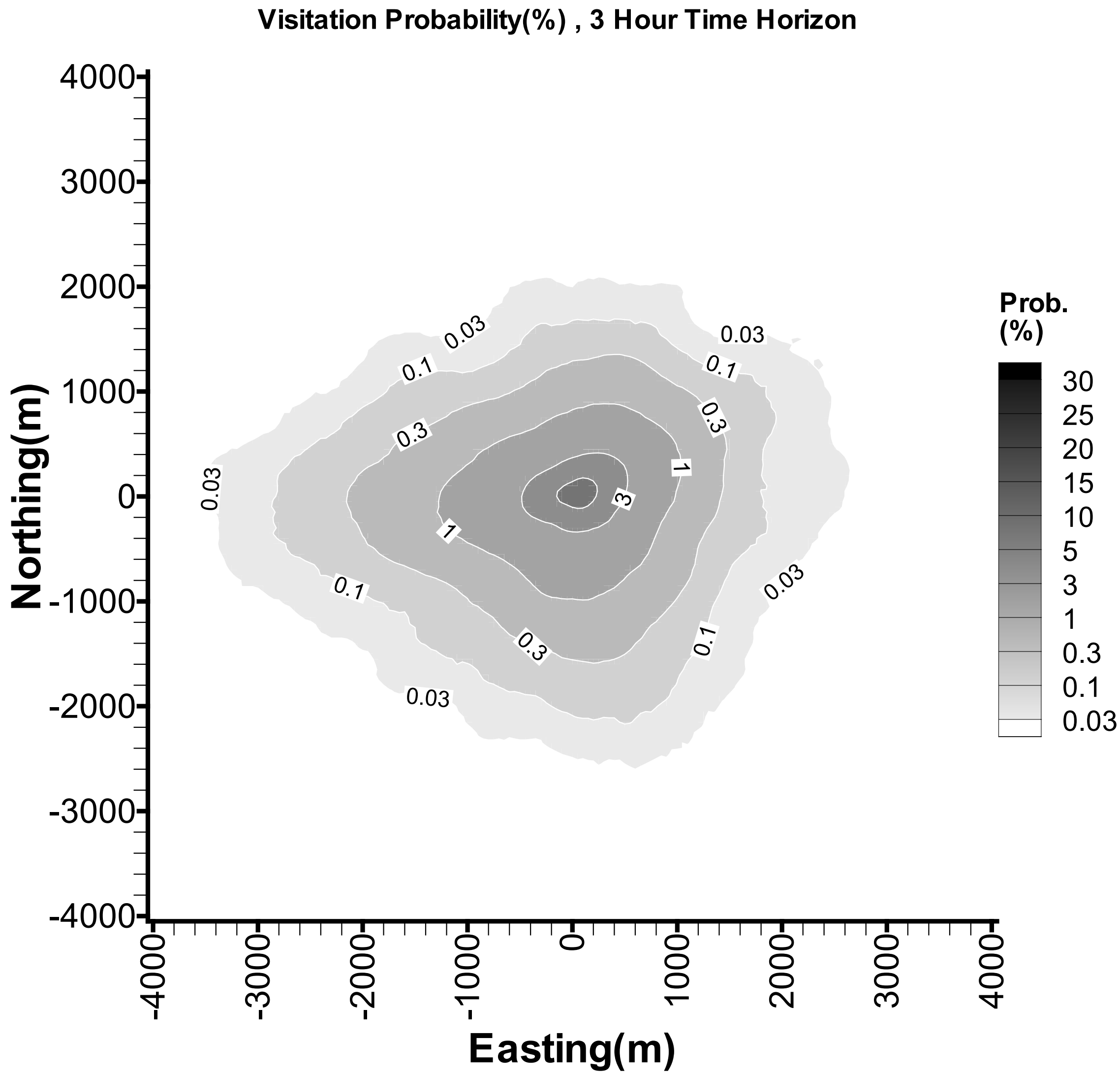

Figure 19. Visitation probability distribution around the outfall (coordinates (0,0) for 3 hour travel time limit. Contours show percent of the time water packets leaving outfall will visit during a year's operation. Coordinates are measured from the center of the outfall (0,0).

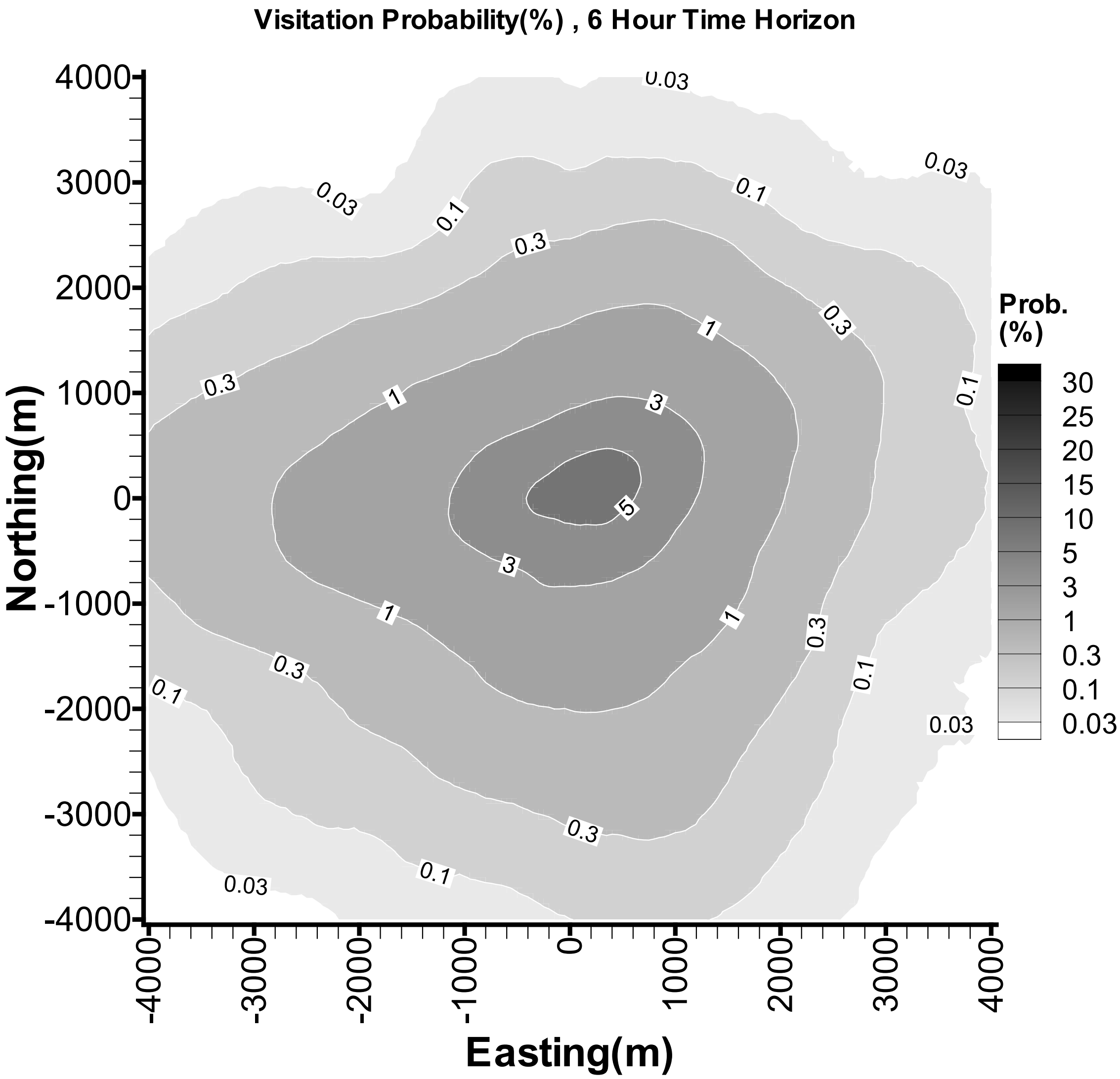

Figure 20. Visitation probability distribution around the outfall (coordinates (0,0) for 6 hour travel time limit. Contours show percent of the time water packets leaving outfall will visit during a year's operation. Coordinates are measured from the center of the outfall (0,0).

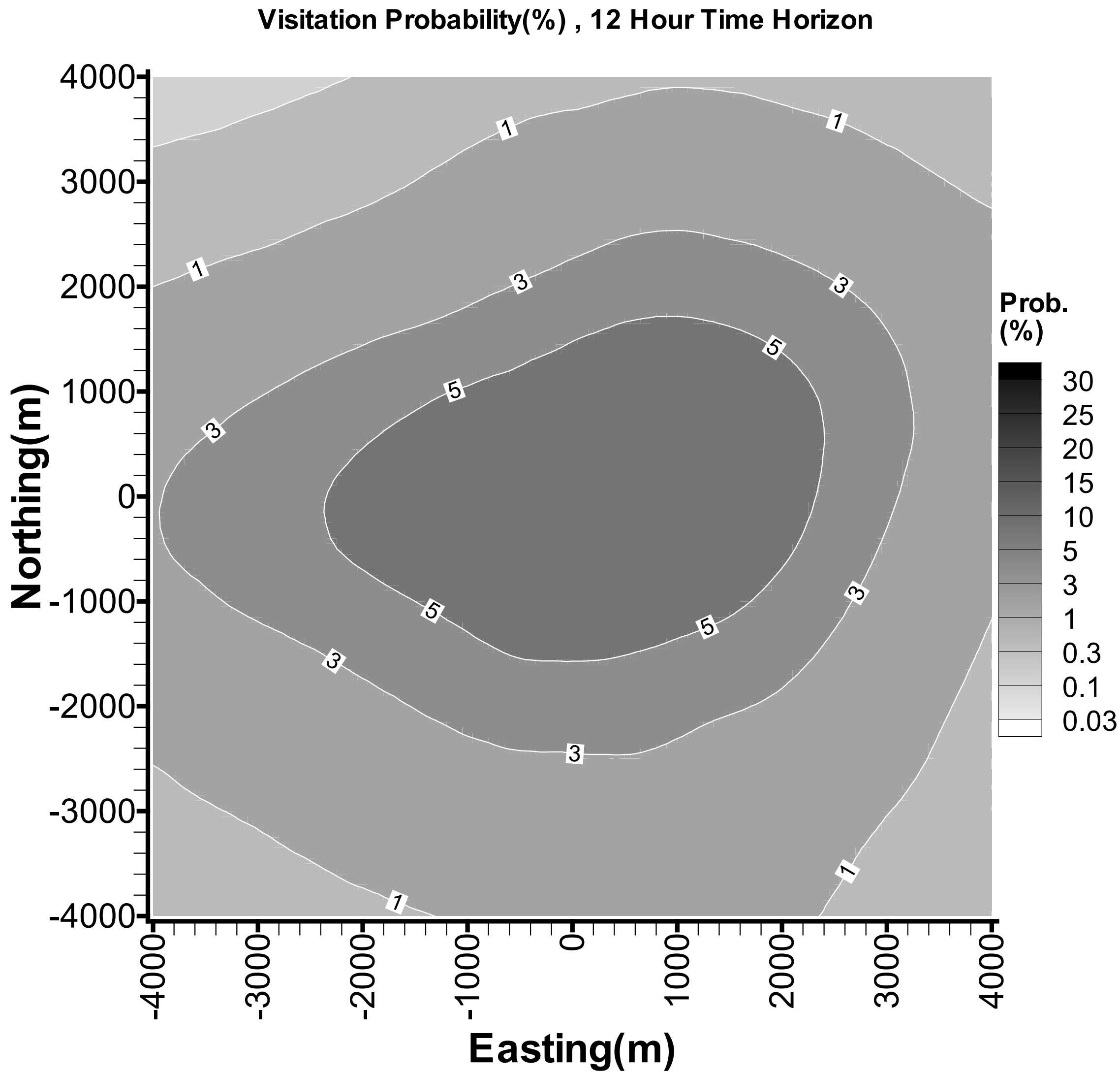

Figure 21. Visitation probability distribution around the outfall (coordinates (0,0) for 12 hour travel time limit. Contours show percent of the time water packets leaving outfall will visit during a year's operation. Coordinates are measured from the center of the outfall (0,0).

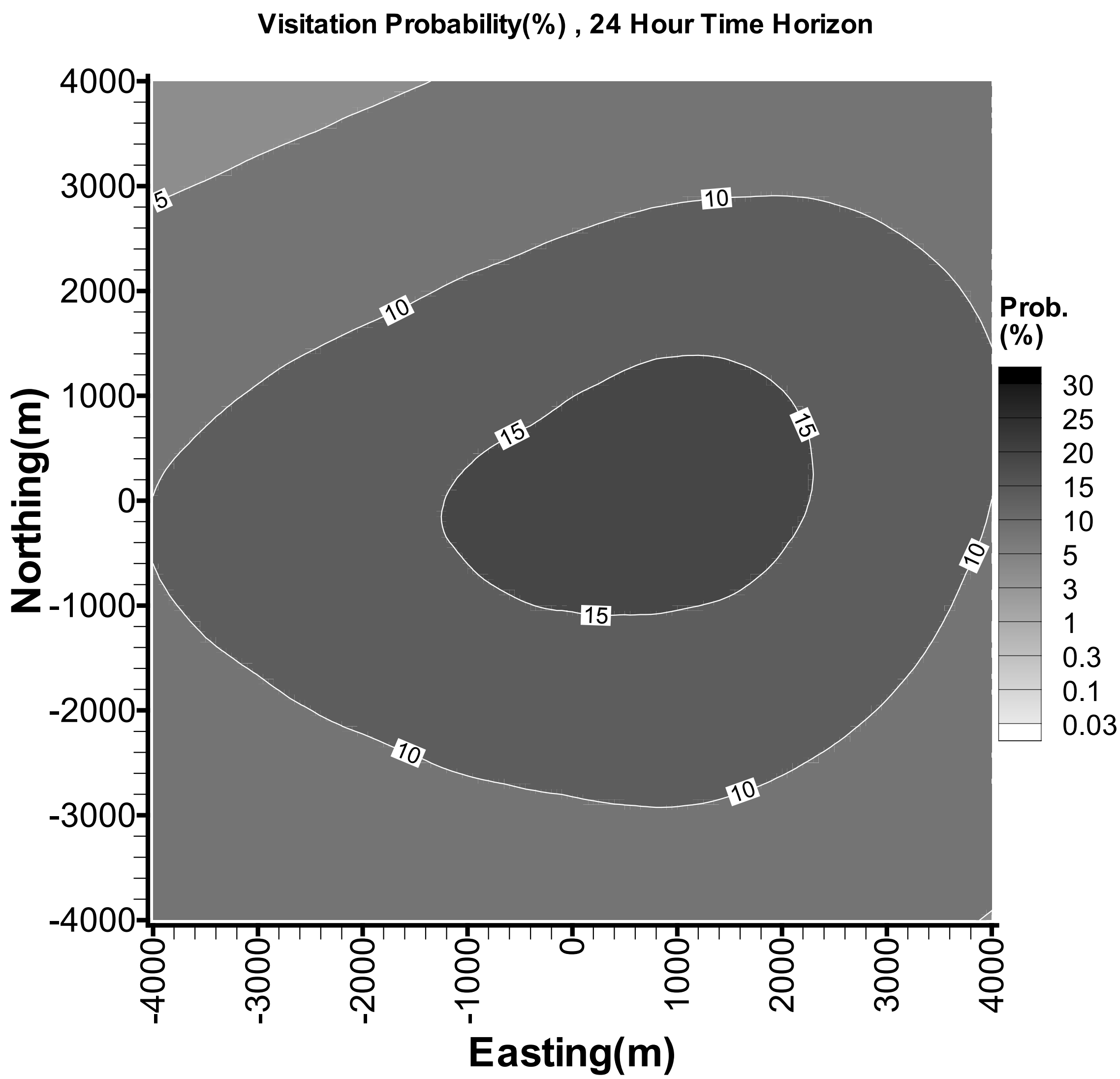

Figure 22. Visitation probability distribution around the outfall (coordinates (0,0) for 24 hour travel time limit. Contours show percent of the time water packets leaving outfall will visit during a year's operation. Coordinates are measured from the center of the outfall (0,0).

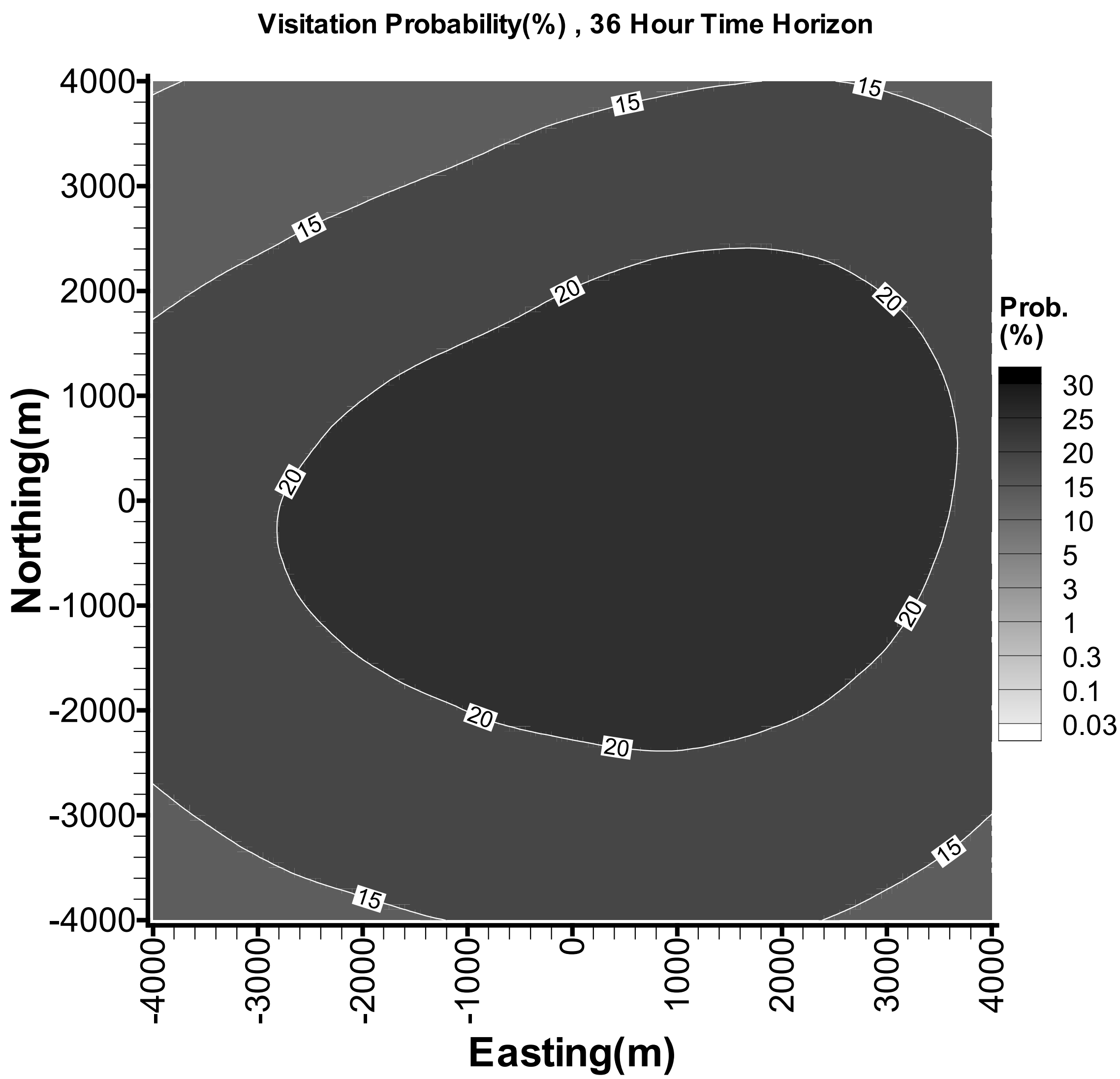

Figure 23. Visitation probability distribution around the outfall (coordinates (0,0) for 36 hour travel time limit. Contours show percent of the time water packets leaving outfall will visit during a year's operation. Coordinates are measured from the center of the outfall (0,0).

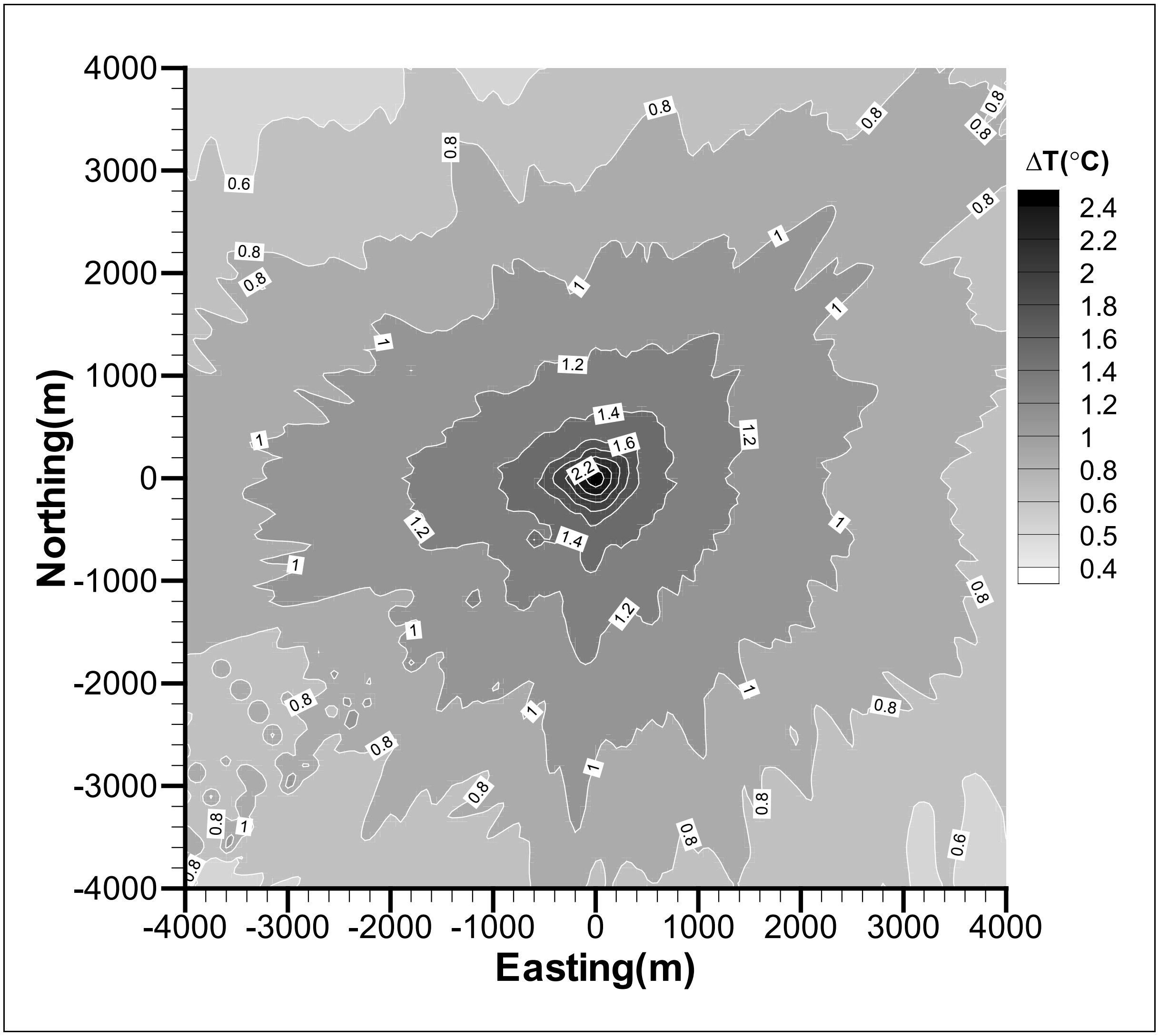

Figure 24. Predicted distribution of the maximum temperature deficiencies expected from single port outfall during a year's operation of the Gulf Landing LNG facility. The distribution is restricted to a thin layer on the sea floor, except at the point of discharge. Coordinates are measured from the center of the outfall (0,0).

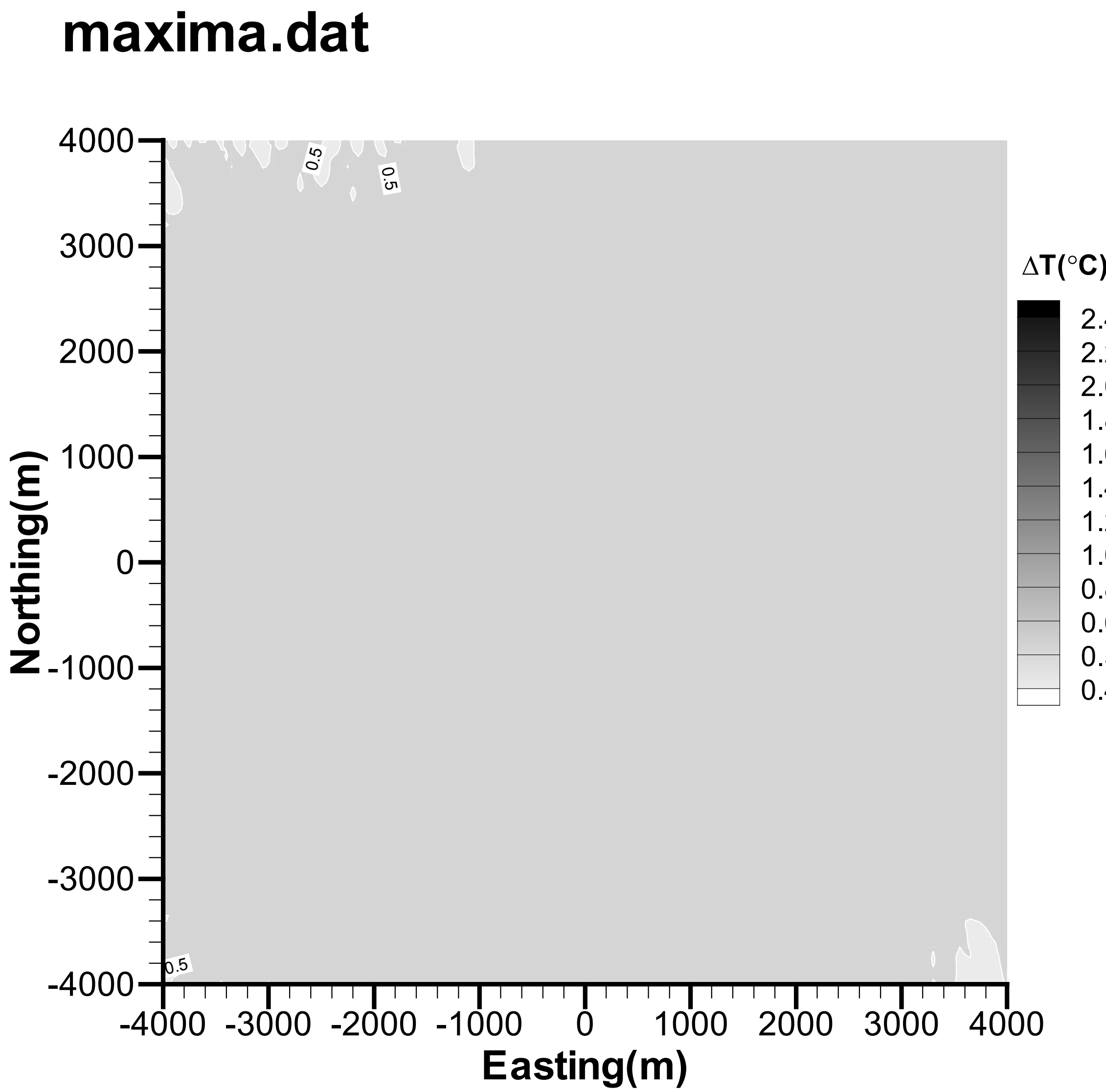

Figure 25. Predicted distribution of the maximum temperature deficiencies expected from 25 port diffuser (96 m) during a year's operation of the Gulf Landing LNG facility. The distribution occupies a large fraction of the water column (100% near the diffuser). Most of the figure represents temperature deficiencies of 0.5 to 0.6°C. Coordinates are measured from the center of the outfall (0,0).

Appendix A
Overview of Offshore Operators Committee Model

A.1 Introduction

The discharge model developed by Brandsma and Sauer (1983) under sponsorship of the Offshore Operators' Committee (OOC) simulates the unsteady, three dimensional behavior of offshore effluent plumes discharged from a single port outfall. The model has been continuously improved since its original release. The effluent may be drilling mud or cuttings or produced water. The model predicts effluent concentration distributions in the water column and the initial deposition distribution of particulates on the sea floor. The model has been validated in laboratory (Policastro, 1983; Brandsma et al., 1992) and field experiments (O'Reilly et al., 1989; Smith et al., 1994). A complete re-validation, using 681 model runs, has been completed recently (Brandsma and Smith, in preparation). The model has been used by government and industry to estimate the likely behavior and fate of drilling mud and cuttings discharged in the marine environment. The capability to simulate produced water discharges was added several years ago and the model has been increasingly used for this purpose. A mathematical description of the model can be found in Brandsma et al. (1992) and in Brandsma and Smith(1999).

The OOC model simulates the behavior of an effluent plume from the time it leaves the discharge port to some arbitrary later time and distance. A simulation proceeds in three phases: the initial dilution phase where the effluent actively entrains ambient fluid and moves vertically to a level of neutral buoyancy (or impinges on the sea surface or sea floor); a collapse phase where the effluent plume spreads at this level; and a dispersive phase where particles move in response to local currents and their own characteristic vertical velocity (downward for solids, upward for oil droplets). The combined initial dilution and collapse phases are often referred to collectively as the "dynamic plume". The dynamic plume is calculated first. Then a complex mass bookkeeping process analyzes the dynamic plume to form the initial conditions for the passive dispersion phase. A LaGrangian (particle following) technique is used in the dispersive calculation. The mass bookkeeping process creates many (usually, several thousand) independent, three-dimensional Gaussian distributed clouds from the dynamic plume. These clouds move through the water column according to the local ambient currents and grow according to the 4/3rds power law. For most discharges, material exists in the dynamic plume and passive dispersion calculations simultaneously.

The three calculation phases are implemented as separate modules in the program. The initial dilution is calculated with an integral plume model that treats the plume from the time it leaves the discharge pipe until is contacts a horizontal surface or reaches its level of neutral buoyancy. This is the phase where the effluent is swiftly diluted by the entrainment of ambient water. The entrainment is driven by the vector difference of the velocities of the effluent plume and momentum and buoyancy at the mouth of the discharge pipe. As the effluent plume entrains ambient sea water, its diameter grows and the concentrations of constituents in the plume decrease rapidly. The density of the plume will approach that of sea water. When there is a density gradient, the effluent and ambient densities may become equal. The point where this happens is termed the level of neutral buoyancy or the trap depth. In the absence of a density gradient there is no trap depth, and the plume will reach the surface if it is positively buoyant, or the seabed if negatively buoyant. The determination of when the plume impinges on the surface or seabed is a geometric one. The model deems the surface or sea floor to have been reached when the distance from the plume centerline to the surface or sea floor becomes less than 78% of the plume radius. The 78% allows for some deformation of the plume at impingement.

Some of the effluent separates from the main part of the plume because of two mechanisms. Particulates having some vertical velocity (because their density differs from that of sea water) migrate up or down from the main plume. Ambient turbulence and turbulence created by the presence of the discharge pipe has been observed to cause separation of a part of the effluent from the main plume, at least when the densimetric Froude number of the discharge is less than 1. There is a question, not yet resolved, whether or not turbulent separation applies for discharges having Froude numbers significantly more than 1. The densimetric Froude number is the ratio of plume momentum to buoyancy. Small Froude numbers are the result of large differences of effluent density from ambient density and low discharge rates. Large Froude numbers arise from small density differences and high discharge rates.

After initial dilution, the effluent plume will spread out (collapse) at its trap depth or at the surface or seabed if one of these was reached. Collapse occurs only if there is a density gradient or if the plume density when it reaches the surface or seabed is significantly different from that of the surrounding ambient fluid. The collapse phase is terminated when the plume's spreading rate caused by density differences becomes less than the spreading rate associated with ambient turbulent dispersion.

The dynamic and dispersive phases are coupled by a mass bookkeeping process that converts the mass flux within the dynamic plume to discrete clouds in the dispersive phase. The initial dynamics calculations are saved at intervals forming a history of the dynamic plume. Each interval is a potential source of clouds for the dispersive phase. Depending on the characteristics of the particulates and of the effluent plume, some of the particulates will separate from the plume because of their differing density. A small fraction of the particulates and some of the effluent fluid may separate from the main body of the plume because of turbulence near the discharge pipe. In either case, the flux of these constituents from one interval to the next may change. The flux change of each constituent as it passes through the interval determines the number and mass content of clouds created from that interval. Any mass flux remaining at the end of the dynamic plume also acts as a source of clouds. Visualize the dynamic plume as a leaky pipe composed of connected intervals, fixed in space, with a leak in each connection. The mass inflow to each interval and the leakage rate of that interval determines the flow passed on to the next interval. Each leak in the pipe is a source of clouds to be passively dispersed. Clouds from any one interval always have the same initial position in space, but different creation times. Sizes of the created clouds are based on the plume dimensions at the point they are created, together with the ambient current speed and the time interval between clouds. Once a cloud is created, it is free to be advected and dispersed by local ambient currents and turbulence. The mass distribution of each cloud is assumed to be Gaussian in three dimensions, a mathematically convenient form.

The final computational phase is passive dispersion, applied separately to each constituent of the effluent. The only remaining dynamic property is the vertical velocity associated with each of its particulate constituents (e.g., solids or oil droplets). Here, the effluent constituents are advected by ambient currents, dispersed by ambient turbulence, and migrate vertically according to their vertical velocity. Horizontal dispersion of clouds is calculated using the 4/3 power law for oceanic dispersion (Fischer et al., 1979). This law says that the horizontal dispersion coefficient is proportional to the horizontal length scale of the dispersing substance, raised to the 4/3 power. The dispersive phase calculations are organized around a simulation grid consisting of a rectangular region with its principal axes parallel to the cardinal directions of the compass (north-south, east-west). The simulation grid is subdivided into contiguous, square cells. Clouds are advected until they are fully deposited on the sea floor (if they are settling solids) or carried outside the boundary of the simulation grid. A single cloud of solid particles typically deposits its contents in a band paralleling the current direction.

The concentrations of suspended particulates or of tracer or of the fluid portion of the effluent in the water column at any point are calculated by summing the contributions from individual clouds using the mathematical description for Gaussian clouds. In practice, only the clouds near enough to the point to make a significant contribution are used in the calculation. The OOC model organizes points into concentration profiles that lie on vertical lines extending from the water surface to the sea floor. Concentration profiles can be placed anywhere in the simulation grid.

OOC model outputs are provided in plain text (ASCII) data files. so that results are portable between machines. These files can be read by post-processing programs to prepare tabular or graphical data products.

OOC model output has been used to produce:

- suspended solids and tracer concentration distributions through arbitrary cross-sections of the water column,

- graphs of maximum concentration versus distance downcurrent,
- volume visualizations of iso-concentration surfaces,
- animations of effluent plumes in tidal currents,
- contour plots of solids deposited on the sea floor,
- graphs of deposition amounts versus sea floor area,
- graphs of maximum deposition as a function of distance,
- tables of specific contaminant concentrations as a function of distance.

Appendix B
CORMIX Model Overview

The Cornell Mixing Zone Expert System (CORMIX) is a software system (Doneker and Jirka, 1990; Jirka et al., 1996) for the analysis, prediction and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. It was developed under several cooperative funding agreements between Cornell University and the U.S. Environmental Protection Agency

The CORMIX system uses a rule-based expert system approach to data input and processing. The CORMIX system leads the user through a dialog, giving guidance as needed, while the user specifies the problem to be analyzed. CORMIX consists of three subsystems:
CORMIX1: analysis of submerged single port discharges
CORMIX2: analysis of submerged multi-port discharges (diffusers)
CORMIX3: analysis of buoyant surface discharges (from a canal)
The basic CORMIX methodology relies on the assumption of steady ambient conditions. However, recent versions also contain special routines for application to highly unsteady environments, such as tidal reversal conditions, in which transient recirculation and pollutant build-up effects can occur.

The system's major emphasis is on the initial mixing zone, but it also predicts for larger distances. The system is intended for use in complying with water quality regulatory constraints. CORMIX is presently used by the U.S. EPA for setting allowable effluent concentrations, including Gulf of Mexico produced water discharges.

CORMIX divides the problem domain into a series of subregions. Any single dilution problem will involve the linkage of several of these subregions to form a complete solution for the problem. The choice of sub-regions is by a decision tree whose branches depend on critical values of several non-dimensional parameters. A non-dimensional parameter is a grouping of dimensional values (e.g., discharge rate, current speed, water depth, etc) where the grouping is such that the grouping is dimensionless. Dimensionless groupings commonly used in plume modeling include the Reynolds number, the densimetric Froude number and the stratification parameter. CORMIX uses many others. In many cases the critical values apply to asymptotic solutions the problems handled by the various subregions. In general the equations solved in each sub-region are simplified.

Indeed, CORMIX simplifies its task by restricting inputs to ideal cases: constant water depth, constant current speed and direction, continuous discharges, etc. CORMIX allows inputs for the following:
- Bounded channels: rivers, estuaries
- Unbounded channels: ocean, lakes
- Uniform current
- Three types to ambient density profiles
- Effluent is fluid only (no particles)
- Buoyant (positive, negative or neutral)

CORMIX relies on the existence of a mixing zone. A mixing zone is defined as a area or volume where numeric water quality criteria can be exceeded as long as acutely toxic conditions are prevented. A mixing zone can be thought of as a limited area or volume where the initial dilution of a discharge occurs. Water quality criteria apply at the boundary of the mixing zone, not within the mixing zone itself (course notes, EPA Mixing Model Workshop, 1998).

CORMIX uses a flow classification system to guide its calculations. Dimensional parameters related to the problem are input by the user (e.g.: ambient current speed, discharge flow rate or exit velocity, orifice diameter, water depth, ambient density, discharge density, etc). From these, a series of length scales are calculated. Typical length scales are: jet-to-plume transition, jet/crossflow transition, plume/crossflow transition, jet/stratification transition, plume/stratification. The non-dimensional ratios of these length scales are used to classify the mixing problem into one of 35 flow classes (for CORMIX1, single port outfalls). The flow class is the basis for choosing appropriate computational modules for the problem at hand. Recent versions of the CORMIX system replaced some flow classes and modules with CORJET, an integral buoyant jet model (Jirka and Fong, 1981).

References for Appendix B

Doneker, R.L. and Jirka, G. H. 1990. Expert System for Hydrodynamic Mixing Zone Analysis of Conventional and Toxic Submerged Single Port Discharges (CORMIX). Report EPA/600/3-90/012. Environmental Research Laboratory. U.S. Environmental Protection Agency. Athens, Georgia. (NTIS accession number is PB90-187196).

Jirka, G.H., Doneker, R.L., and Hinton, S.W. 1996. Users manual for CORMIX: a hydrodynamic mixing zone model and decision support system for pollutant discharges into surface waters. Report under cooperative agreement CX824847-01-0. Office of Science and Technology. U.S. Environmental Protection Agency. Washington, D.C.

Jirka, G.H. and Fong, H.L.M. 1981. Vortex dynamics and bifurcation of buoyant jets in crossflow. J. Engineering Mechanics. ASCE. Vol 107. pp479-499.