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REGIONAL EFFLUENT DISPOSAL STUDY FOR THE CITY OF REHOBOTH BEACH, DELAWARE

SUPPLEMENTAL DILUTION MODELING

Prepared By

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Project No. 0918-013

INTRODUCTION

This document describes the additional modeling efforts used to conclude the preliminary study of the proposed ocean outfall for the City of Rehoboth Beach, Delaware. Lawler, Matusky & Skelly Engineers, LLP (LMS) performed the following tasks:

1. *Optimize Diffuser Design* – LMS conducted a sensitivity analysis to estimate the effect of diffuser spacing and length on the initial dilution achieved in the preliminary diffuser design

2. *Extend Rehoboth Beach Outfall* – Based on the preliminary diffuser design developed previously, the impacts of extending the outfall from 6,000 feet offshore to 9,000 feet and 12,000 feet offshore, considering only Rehoboth Beach discharge flows

3. *Relocation of Regional Solution* – LMS modeled an additional outfall location north of Rehoboth Beach off Cape Henlopen State Park in Lewes at coordinates 075°03.82'W, 38°46.65'N, considering the discharge flows of the Regional scenario

See Figure 1 for the locations of these outfalls. Each scenario was modeled using the Cornell Mixing Zone Expert System (CORMIX) under ambient conditions for the coastal waters off Delaware. The diffuser sensitivity analysis (Task 1 above) was based on the ambient conditions in LMS (2003). The ambient conditions for the simulations under Tasks 2 and 3 were developed based on the ECOM3d (a variant of the Princeton Ocean Model) modeling results reported in Garvine (2003) using 8-hour peak flow rates.

PRELIMINARY DIFFUSER DESIGNS

The preliminary outfall diffuser designs were modeled using CORMIX-GI version 4.1GT using the 'virtual' diffuser approach described in Distante et. al, (1994) and summarized in LMS (2003). Table 1 lists the physical dimensions of the two diffuser designs. Figure 2 shows the diffuser schematics.

Table 1. Preliminary Diffuser Designs

Item		Regional	Rehoboth-only
Outfall	Material	HDPE*	HDPE*
	Diameter (in)	36	24
	8-hr Peak Flow (MGD)	20.0	6.67
Diffuser	Type	Y	Y
	Length (ft)	184	120
	Diameter (in)	24	18
Riser	Number	24	16
	Length (ft)	1	1.5
	Diameter (in)	6	4
Nozzle	Number	48	32
	Length (ft)	1	1
	Diameter (in)	4	3

*High density polyethylene

The simulations performed under Task 1 were based on the Rehoboth-only scenario, with the number of ports and the port spacing modified to evaluate the importance of diffuser design in overall dilution performance. Table 2 summarizes the variations on the Rehoboth-only diffuser design shown in Table 1.

Table 2. Diffuser Optimization Variations Simulated with CORMIX

Set	Number of Ports	Diffuser Length (ft)	Port Spacing (ft)
Fixed Diffuser Length	12	120	11
	14	120	9.25
	16*	120*	8*
	18	120	7
Fixed Port Spacing	14	104	8
	16*	120*	8*
	18	136	8
	20	152	8

*Original run from preliminary diffuser design study (LMS 2003)

AMBIENT CONDITIONS

The ambient conditions used for the six sensitivity runs under Task 1 were identical to the Rehoboth-only scenario described in LMS' April 2003 report.

Modifications to previously developed ambient conditions were made to simulations performed under Tasks 2 and 3. Based on Garvine's September 2003 report, which contained model results and observations from 1993, average depth, discharge depth, current speed, and surface and bottom density were changed. The most significant of these modifications was to the current velocities, which were provided as the vector components of the tidal and subtidal velocities over depth. Previously, current velocity data was based on measurements reported in Garvine (1991). However, the results of the ECOM3d model suggest that, although spatially close, velocity fields in the vicinity of the observation mooring are substantially different than in the vicinity of the proposed outfall, most likely due to influences of the freshwater flow from the Delaware estuary. As a consequence, the current velocities used in the present investigation are significantly higher in magnitude and substantially different in direction. Thus, for comparison purposes, the 6,000 foot Rehoboth scenario was rerun with the new ambient conditions.

The dilution modeling is focused on the summer season when bathing use at the beaches is at its highest. The velocity data with the largest onshore component was selected from the monthly average data for May through September (i.e. "summer" months), which was determined to be August for all scenarios. The tidal velocities shown represent averages over half the tidal sinusoid (i.e., $u_{avg} = u_{max} * 2/\pi$) and are depth-averaged (see Table 1 of Garvine 2003 for M2 amplitude or maximum tidal velocity). The negative of the alongshore (i.e., north) and negative of the offshore (i.e., west) tides are the selected tidal components. Subtidal velocities were calculated by simple depth averaging (see Table 2 of Gavine 2003).

Table 3 summarizes the current velocities used, and Figure 3 shows the vectors spatially. These velocities are an order of magnitude greater than velocities used in the first phase modeling.

Table 3. Current Velocities Based on Garvine (2003)

	Alongshore (cm/s)				Offshore (cm/s)				Vector Sum	
	Tidal Amplitude		Subtidal	Total	Tidal Amplitude		Subtidal	Total		
Scenario	Peak	Avg.	Avg.	Avg.	Peak	Avg.	Avg.	Avg.	Mag. (cm/s)	Dir. (deg. True)
Relocated Regional	-56.4	-37.5	-1.3	-38.8	-15.1	-9.9	-0.8	-10.7	**40.2**	**338**
Rehoboth (6,000 ft)	-44.1	-28.8	-4.4	-33.2	-1.8	-1.3	-1.3	-2.6	**33.3**	**349**
Rehoboth (9,000 ft)	-48.0	-32.6	-3.0	-35.6	-3.0	-2.1	-0.2	-2.3	**35.7**	**349**
Rehoboth (12,000 ft)	-49.6	-33.7	-0.7	-34.4	4.0	2.7	1.3	4.0	**34.6**	**0**

NOTES: Negative offshore velocities are onshore. Direction is clockwise degrees from true north. Shoreline direction is approximately 353 degrees true north.

Table 4 summarizes the temperature, salinity, and calculated densities used in the model for all simulations except for Task 1. The values used were based on the average observations from Mooring A during summer 1993 (see Table 5 in Garvine 2003), extrapolated to surface and bottom as required in the CORMIX input user interface.

Table 4. Temperature, Salinity, and Density Based on Garvine (2003) Mooring A, Summer 2003

Location	Temperature (°C)	Salinity (ppt)	Density (kg/m^3)
Near Surface	15.9	28.8	1021.0
Near Bottom	11.1	31.0	1023.6

MODELING RESULTS

Modeling results are shown in Figures 4 and 5 and in Tables 5 through 7. Figure 4 shows the shoreline dilutions for the fixed diffuser length and fixed port spacing diffuser optimization runs (Task 1). The minimum shoreline dilutions for these simulations are summarized in Table 5. As shown, dilution varies substantially with the length of the diffuser but does not vary by changing the port spacing on a given length of diffuser. The port spacing (8 ft/port) and number of ports (16) developed in the first phase of dilution modeling based on general design principles were determined to be appropriate for Tasks 2 and 3 of this phase of the modeling.

Table 6 and Figure 5 show the results of extending the outfall 9,000 and 12,000 feet (Task 2), along with the 6,000-foot outfall run under the updated ambient conditions. The down-current distance to reach 100:1 dilution appears to be related to the magnitude of the velocity at the alternative diffuser locations.

Table 7 summarizes the model results for the relocated regional outfall, and Figure 5 shows the distance to reach the 100:1 dilution.

Table 5. Results of Diffuser Optimization Simulations

Set	Number of Ports	Time to Shoreline Intersection (hr)	Minimum Dilution At Shoreline**
Fixed Diffuser Length (120 ft)	12	13.5	69
	14	13.4	69
	16*	13.5	69
	18	13.5	70
Fixed Port Spacing (8 ft/port)	14	13.7	65
	16*	13.5	69
	18	13.2	74
	20	13.0	79

*Original run from preliminary diffuser design study (LMS 2003)
**CORMIX Dilution is calculated as the ratio of the discharge concentration to the predicted concentration

Table 6. Results for Extending Outfall

Scenario	Downcurrent distance to 100:1 dilution (feet)	Time to 100:1 dilution (minutes)
6,000 ft offshore	415	5.4
9,000 ft offshore	432	5.4
12,000 ft offshore	420	5.3

Table 7. Results for Relocated Regional Outfall

Scenario	Downcurrent distance to 100:1 dilution (feet)	Time to 100:1 dilution (minutes)
Relocated Regional Diffuser	490	5.5

CONCLUSIONS/RECOMMENDATIONS

Based on the supplemental CORMIX dilution modeling, the following conclusions are made:

1. The results of the diffuser optimization simulations suggest that modifying the port spacing or the number of ports would not significantly improve dilution. In addition, the preliminary diffuser design was based on generally accepted principles that balance dilution and costs. Therefore, the preliminary diffuser design is adequate for the Rehoboth flow and ambient conditions.

2. Relocating the Rehoboth-only outfall from 6,000 to either 9,000 or 12,000 feet offshore would not improve the time and distance to the 100:1 dilution based on the modeling results. However, extending the outfall would provide an additional margin of safety, allowing more time for decay

and additional dilution beyond the 100:1 target. Extending the outfall would also increase head losses that must be overcome to achieve necessary velocities through the diffuser.

3. The preliminary diffuser design for the Regional discharge would provide adequate mixing at the relocated site. 100:1 dilution would be achieved within 500 feet of the diffuser.

4. The addition of the average tidal current component to the ambient velocities used for the supplemental dilution modeling are likely to be more realistic than using the subtidal currents alone. Subtidal currents are small in comparison to tidal currents in the region off the Delaware coast, and the timescale over which these predictions would be valid is limited due to the presence of tidal currents. Running currents can be expected to persist for the majority of the 12.4 hour tidal cycle, resulting in a comparably short period during which subtidal current velocities dominate. As the time of travel along the plume centerline to reach 100:1 dilution is only five minutes, the location of this dilution will vary along the principal axis of the tidal current, which is essentially parallel to shore. The model was performed for average tidal strength to show representative locations where the 100:1 dilution would occur.

5. Garvine noted that both the vertical and horizontal variability in the current field are high, even by the standards of the coastal ocean. Eddies or gyres (nearly closed current fields) of approximately 5 km surround the alternative diffuser locations for Rehoboth Beach and the Regional solution. These current fields, which are not simulated in the dilution model, will further disperse the plume and limit its contact with the shoreline.

REFERENCES

Beckers, C. V. Density, Version 1.1. *Density calculator program based on the Tumlirz equation adopted from The Sea, Vol. 1, M. N. Hill, ed.*

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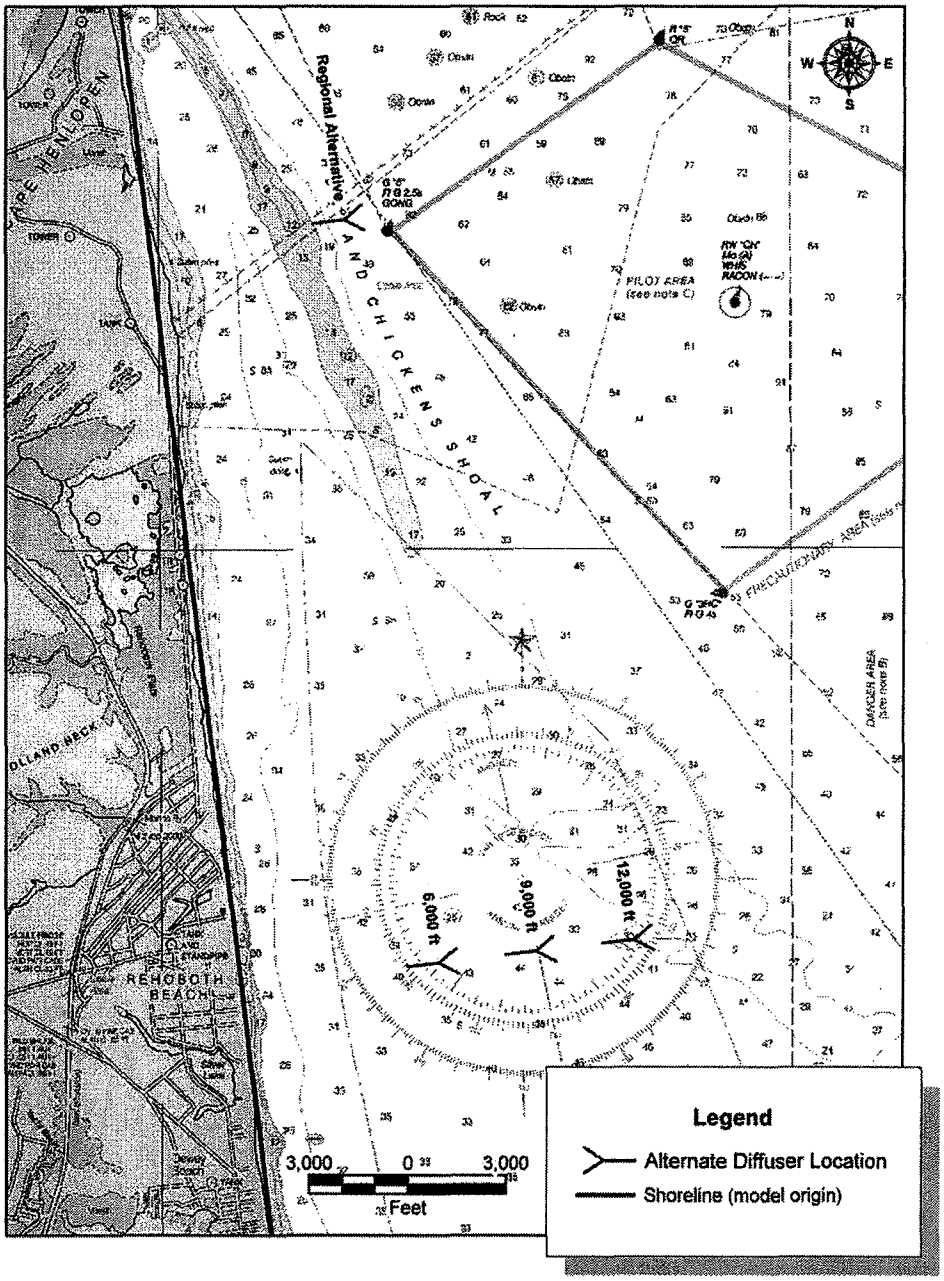


Figure 1. Alternate Diffuser Locations

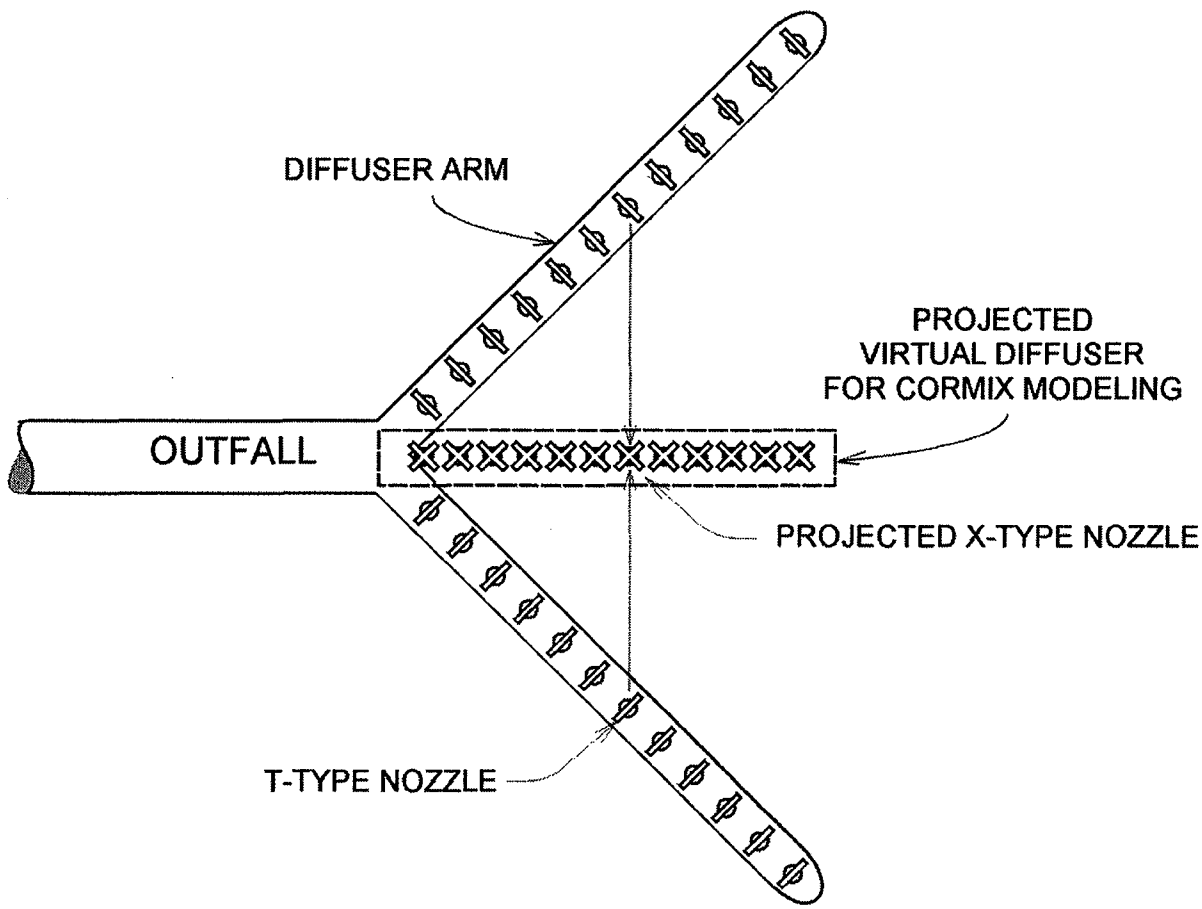


Figure 2. Y-Type Diffuser and Projected Virtual Diffuser for CORMIX Modeling

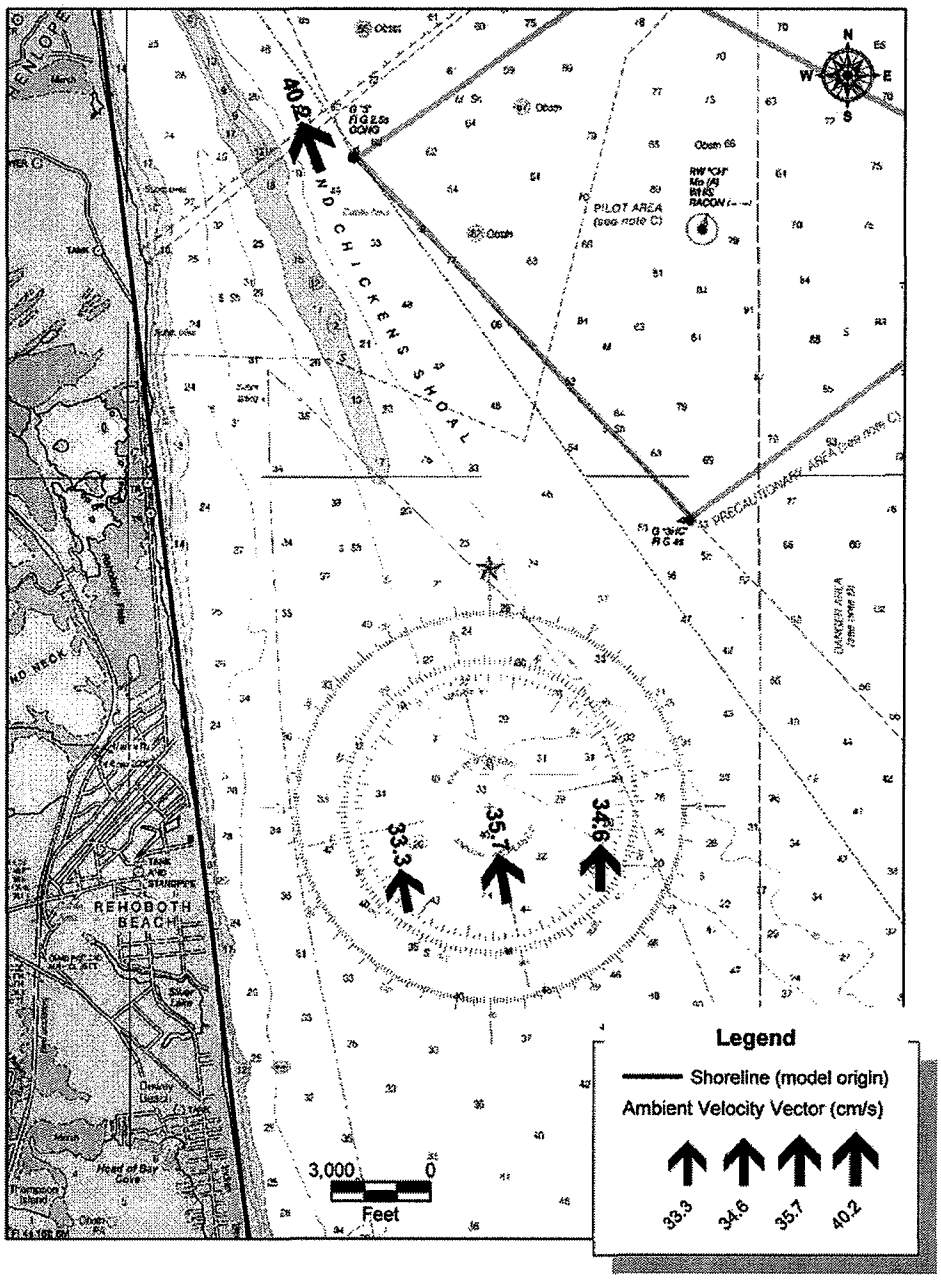
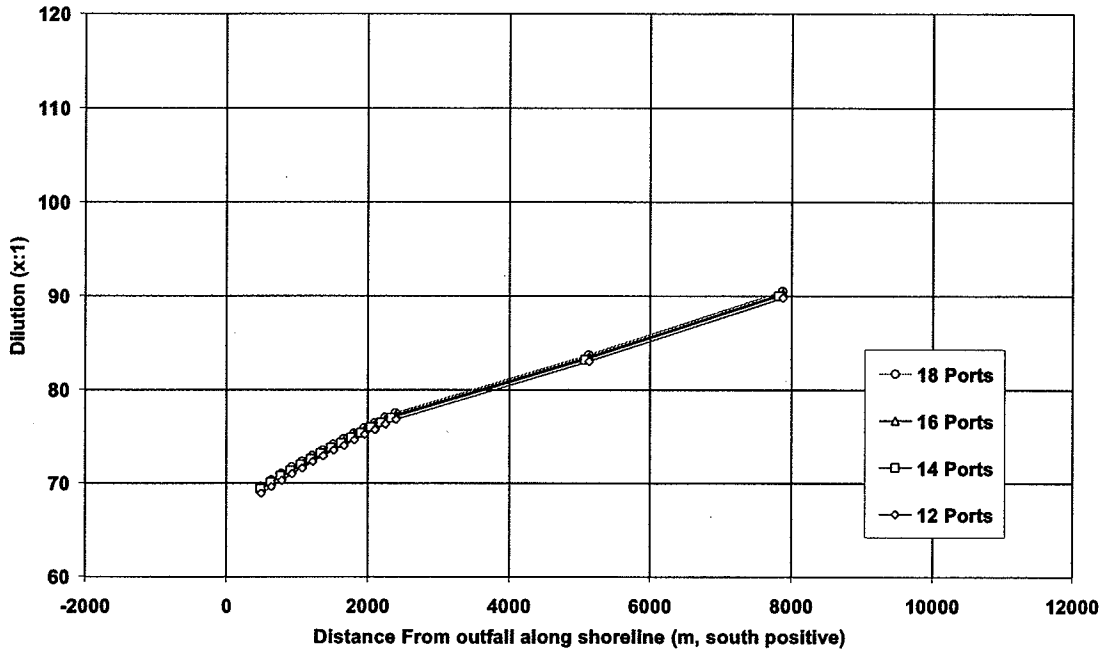


Figure 3. Ambient Velocity Vectors

(a)



(b)

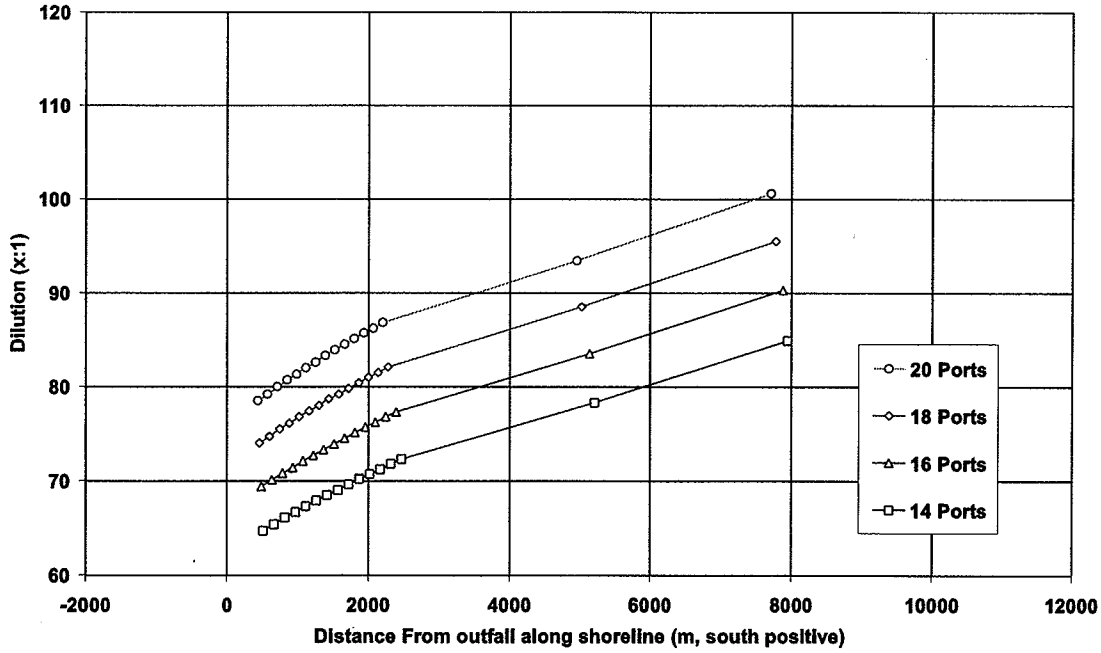


Figure 4. Diffuser Optimization Results: (a) Fixed Diffuser Length; (b) Fixed Port Spacing

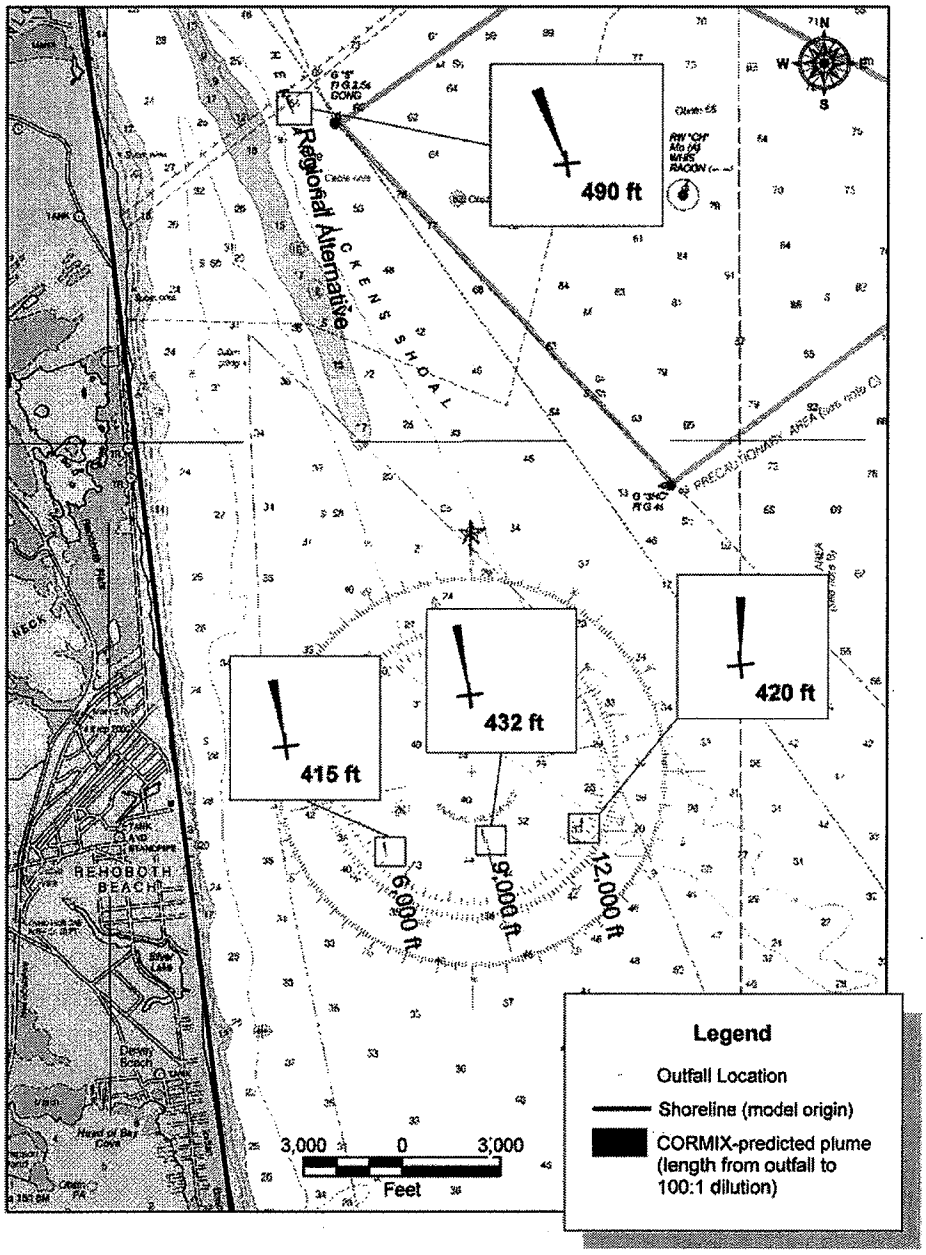


Figure 5. Distance to 100:1 Dilution

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3. *Evaluation of Regional Alternatives* – LMS evaluated two locations for discharging regional flows: the outfall location north of Rehoboth Beach off Cape Henlopen State Park in Lewes at coordinates 075°03.82'W, 38°46.65'N, and the location 6,000 feet offshore of Rehoboth Beach that is under consideration for the Rehoboth-only discharge alternative.

See Figure 1 for the locations of these outfalls. Each scenario was modeled using the Cornell Mixing Zone Expert System (CORMIX) under ambient conditions for the coastal waters off Delaware. The diffuser sensitivity analysis (Task 1 above) was based on the ambient conditions in LMS (2003). The ambient conditions for the simulations under Tasks 2 and 3 were developed based on the ECOM3d (a variant of the Princeton Ocean Model) modeling results reported in Garvine (2003) using 8-hour peak flow rates.

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Item		Regional	Rehoboth-only
Outfall	Material	HDPE*	HDPE*
	Diameter (in)	36	24
	8-hr Peak Flow (MGD)	20.0	6.67
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	Length (ft)	184	120
	Diameter (in)	24	18
Riser	Number	24	16
	Length (ft)	1	1.5
	Diameter (in)	6	4
Nozzle	Number	48	32
	Length (ft)	1	1
	Diameter (in)	4	3

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*Original run from preliminary diffuser design study (LMS 2003) as summarized in Table 1.

AMBIENT CONDITIONS

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The dilution modeling is focused on the summer season when bathing use at the beaches is at its highest. The velocity data with the largest onshore component was selected from the monthly average data for May through September (i.e. "summer" months), which was determined to be August for all scenarios. The tidal velocities shown represent averages over half the tidal sinusoid (i.e., $u_{avg} = u_{max} * 2/\pi$) and are depth-averaged (see Table 1 of Garvine 2003 for M2 amplitude or maximum tidal velocity). The negative of the alongshore (i.e., north) and negative of the offshore (i.e., west) tides are the selected tidal

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Scenario	Peak	Avg.	Avg.	Avg.	Peak	Avg.	Avg.	Avg.	Mag. (cm/s)	Dir. (deg. True)
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Rehoboth (6,000 ft)*	-44.1	-28.8	-4.4	-33.2	-1.8	-1.3	-1.3	-2.6	**33.3**	**349**
Rehoboth (9,000 ft)	-48.0	-32.6	-3.0	-35.6	-3.0	-2.1	-0.2	-2.3	**35.7**	**349**
Rehoboth (12,000 ft)	-49.6	-33.7	-0.7	-34.4	4.0	2.7	1.3	4.0	**34.6**	**0**

NOTES: Negative offshore velocities are onshore. Direction is clockwise degrees from true north. Shoreline direction is approximately 353 degrees true north.
*This ambient scenario was used for both the regional and Rehoboth-only flow cases.

Table 4 summarizes the temperature, salinity, and calculated densities used in the model for all simulations except for Task 1. The values used were based on the average observations from Mooring 'A' during summer 1993 (see Table 5 in Garvine 2003), extrapolated to surface and bottom as required in the CORMIX input user interface.

Table 4. Temperature, Salinity, and Density Based on Garvine (2003) Mooring A, Summer 2003

Location	Temperature (°C)	Salinity (ppt)	Density (kg/m^3)
Near Surface	15.9	28.8	1021.0
Near Bottom	11.1	31.0	1023.6

MODELING RESULTS

Modeling results are shown in Figures 4 through 6 and in Tables 5 through 7. Figure 4 shows the shoreline dilutions for the fixed diffuser length and fixed port spacing diffuser optimization runs (Task 1). The minimum shoreline dilutions for these simulations are summarized in Table 5. As shown, dilution varies substantially with the length of the diffuser but does not vary by changing the port spacing on a given length of diffuser. The port spacing (8 ft/port) and number of ports (16) developed in the first phase of dilution modeling based on general design principles were determined to be appropriate for Tasks 2 and 3 of this phase of the modeling.

Figure 5 and Table 6 show the results of extending the outfall 9,000 and 12,000 feet (Task 2), along with the 6,000-foot outfall run under the updated ambient conditions. The down-current distance to reach 100:1 dilution appears to be related to the magnitude of the velocity at the alternative diffuser locations.

Figure 6 and Table 7 summarize the model results for the two regional flow scenarios simulated. The northern outfall location is deeper and experiences higher velocities than the southern alternative, which explains the relatively large difference between the two scenarios.

Table 5. Results of Diffuser Optimization Simulations

Set	Number of Ports	Time to Shoreline Intersection (hr)	Minimum Dilution At Shoreline**
Fixed Diffuser Length (120 ft)	12	13.5	69
	14	13.4	69
	16*	13.5	69
	18	13.5	70
Fixed Port Spacing (8 ft/port)	14	13.7	65
	16*	13.5	69
	18	13.2	74
	20	13.0	79

*Original run from preliminary diffuser design study (LMS 2003)
**CORMIX Dilution is calculated as the ratio of the discharge concentration to the predicted concentration

Table 6. Results for Extending Outfall of Rehoboth-Only Alternative

Scenario	Downcurrent distance to 100:1 dilution (feet)	Time to 100:1 dilution (minutes)
6,000 ft offshore	415	5.4
9,000 ft offshore	432	5.4
12,000 ft offshore	420	5.3

Table 7. Results for Evaluation of Regional Alternatives

Scenario	Downcurrent distance to 100:1 dilution (feet)	Time to 100:1 dilution (minutes)
Relocated Regional Diffuser	490	5.5
6,000 ft Offshore Rehoboth Diffuser with Regional Flow	789	10.8

CONCLUSIONS/RECOMMENDATIONS

Based on the supplemental CORMIX dilution modeling, the following conclusions are made:

1. The results of the diffuser optimization simulations suggest that modifying the port spacing or the number of ports would not significantly improve dilution. In addition, the preliminary diffuser design was based on generally accepted principles that balance dilution and costs.

Therefore, the preliminary diffuser design is adequate for the Rehoboth flow and ambient conditions.

2. Relocating the Rehoboth-only outfall from 6,000 to either 9,000 or 12,000 feet offshore would not improve the time and distance to the 100:1 dilution based on the modeling results. However, extending the outfall would provide an additional margin of safety, allowing more time for decay and additional dilution beyond the 100:1 target. Extending the outfall would also increase head losses that must be overcome to achieve necessary velocities through the diffuser.

3. The preliminary diffuser design for the Regional discharge would provide adequate mixing at the relocated site. The 100:1 dilution would be achieved within 500 feet of the diffuser. Relocating the Regional discharge diffuser to the Rehoboth-only location 6,000 feet offshore would result in a greater travel time and distance to the 100:1 dilution than any other alternative, although the time difference (approximately 5 minutes) is small in comparison to the characteristic timescale for the region (i.e., 12.4 hour tidal cycle).

4. The addition of the average tidal current component to the ambient velocities used for the supplemental dilution modeling is likely to be more realistic than using the subtidal currents alone. Subtidal currents are small in comparison to tidal currents in the region off the Delaware coast, and the timescale over which these predictions would be valid is limited due to the presence of tidal currents. Running currents can be expected to persist for the majority of the 12.4 hour tidal cycle, resulting in a comparably short period during which subtidal current velocities dominate. As the time of travel along the plume centerline to reach 100:1 dilution is on the order of five minutes, the location of this dilution will vary along the principal axis of the tidal current, which is essentially parallel to shore. The model was performed for average tidal strength to show representative locations where the 100:1 dilution would occur.

5. Garvine noted that both the vertical and horizontal variability in the current field are high, even by the standards of the coastal ocean. Eddies or gyres (nearly closed current fields) of approximately 5 km surround the alternative diffuser locations for Rehoboth Beach and the Regional solution. These current fields, which are not simulated in the dilution model, will further disperse the plume and limit its contact with the shoreline.

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Beckers, C. V. Density, Version 1.1. *Density calculator program based on the Tumlirz equation adopted from The Sea, Vol. 1, M. N. Hill, ed.*

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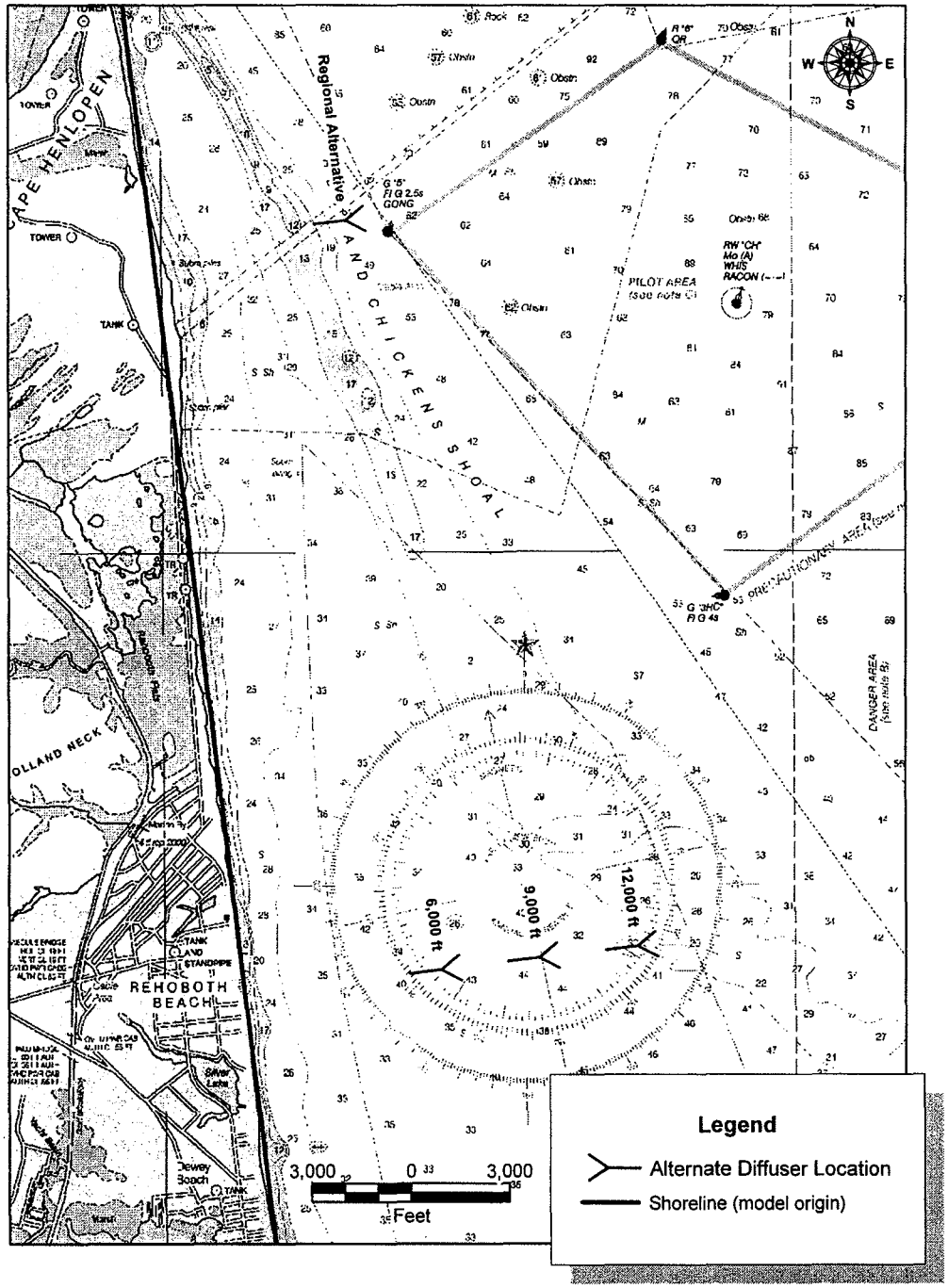


Figure 1. Alternate Diffuser Locations

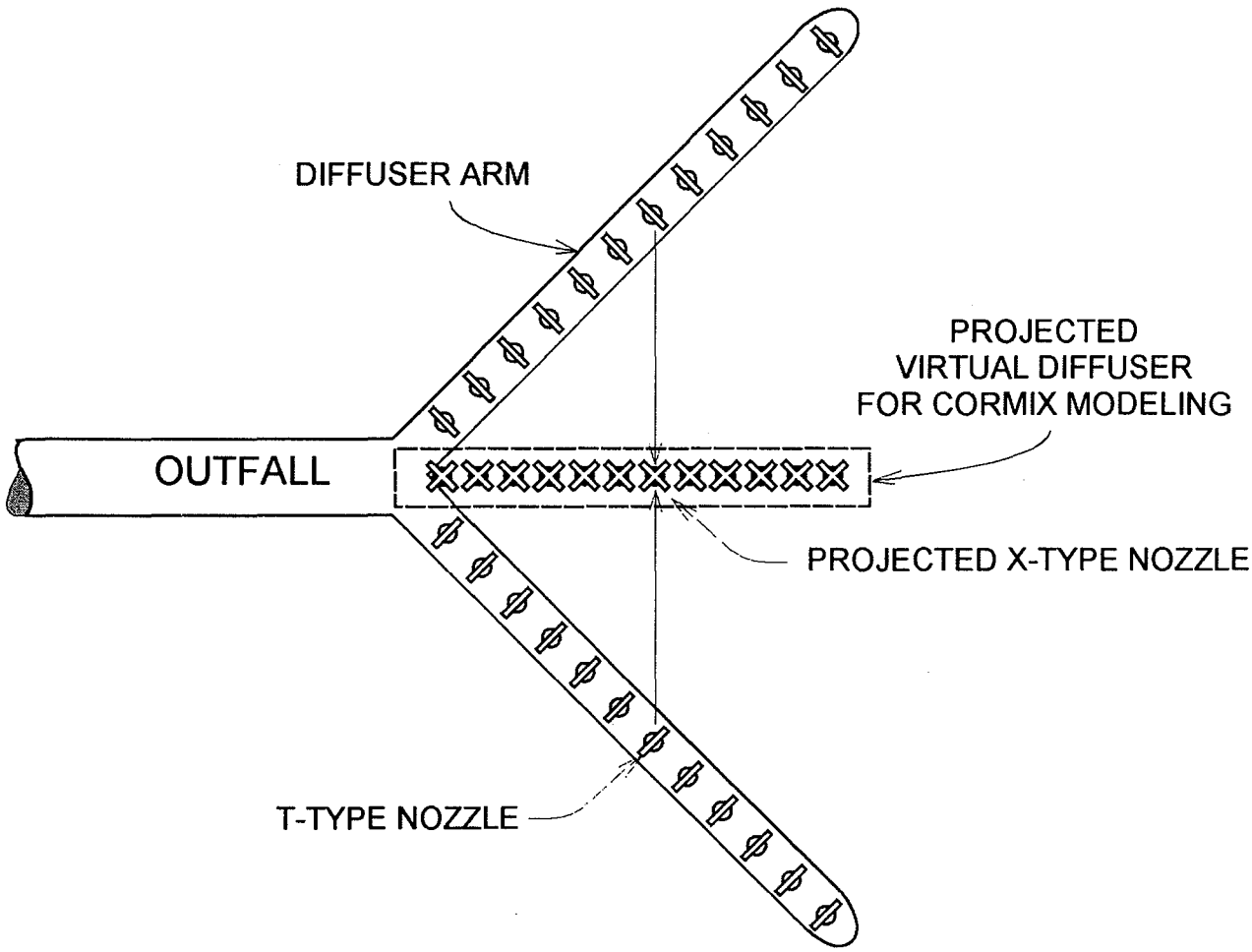


Figure 2. Y-Type Diffuser and Projected Virtual Diffuser for CORMIX Modeling

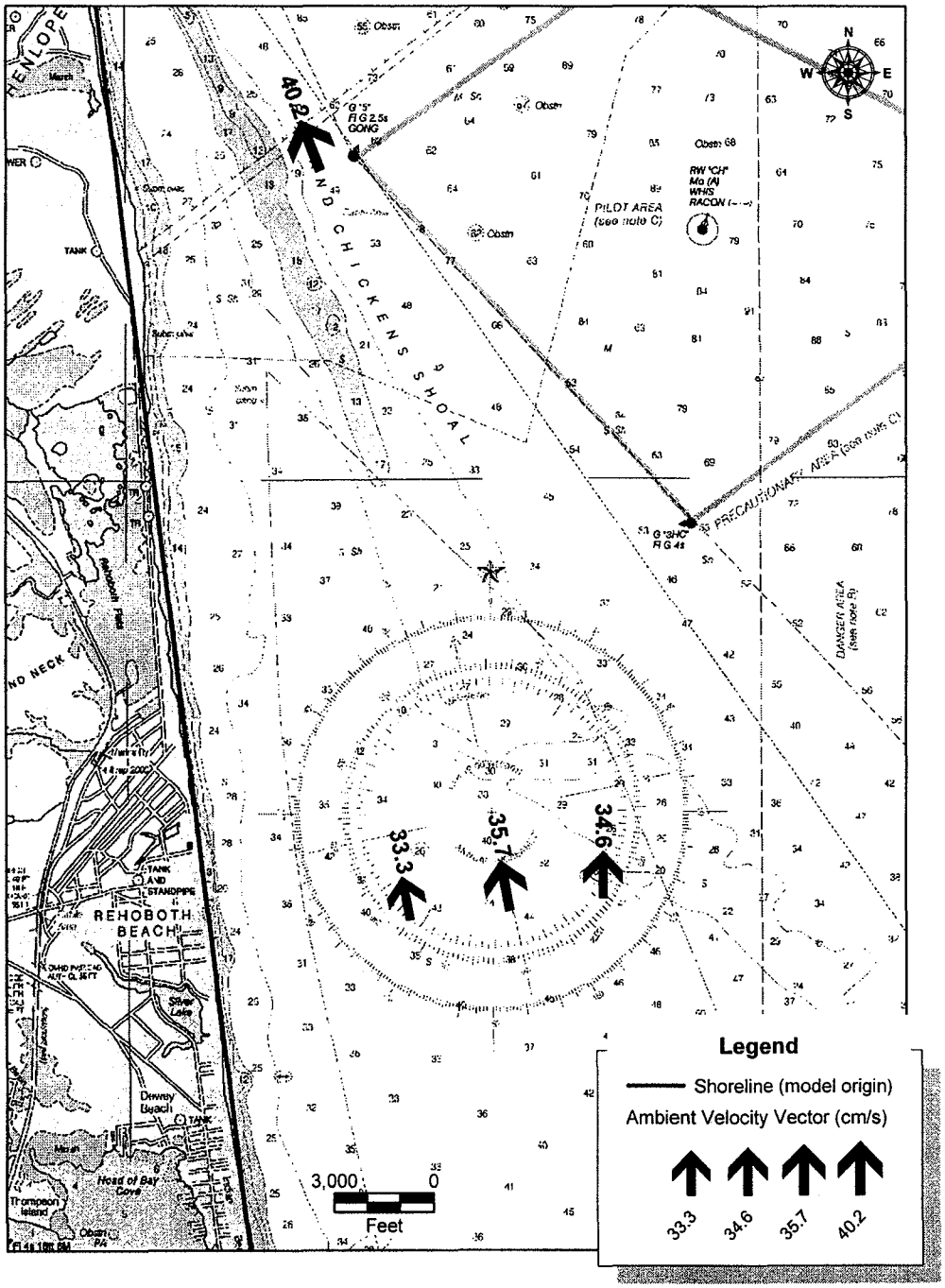
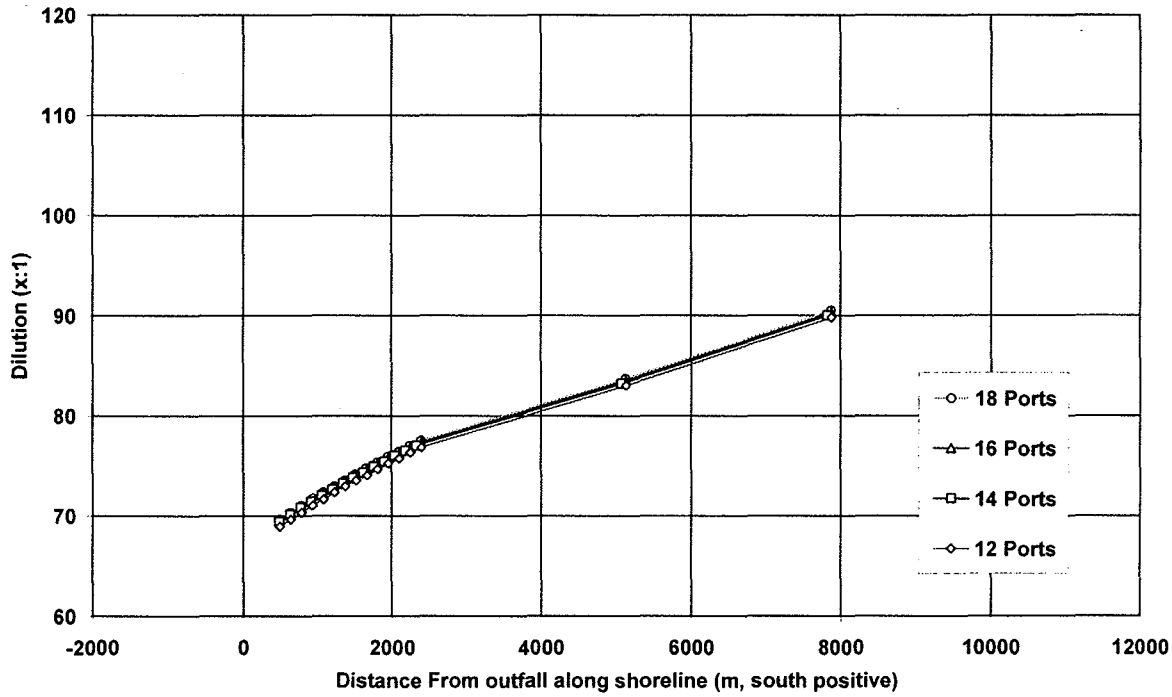


Figure 3. Ambient Velocity Vectors

(a)



(b)

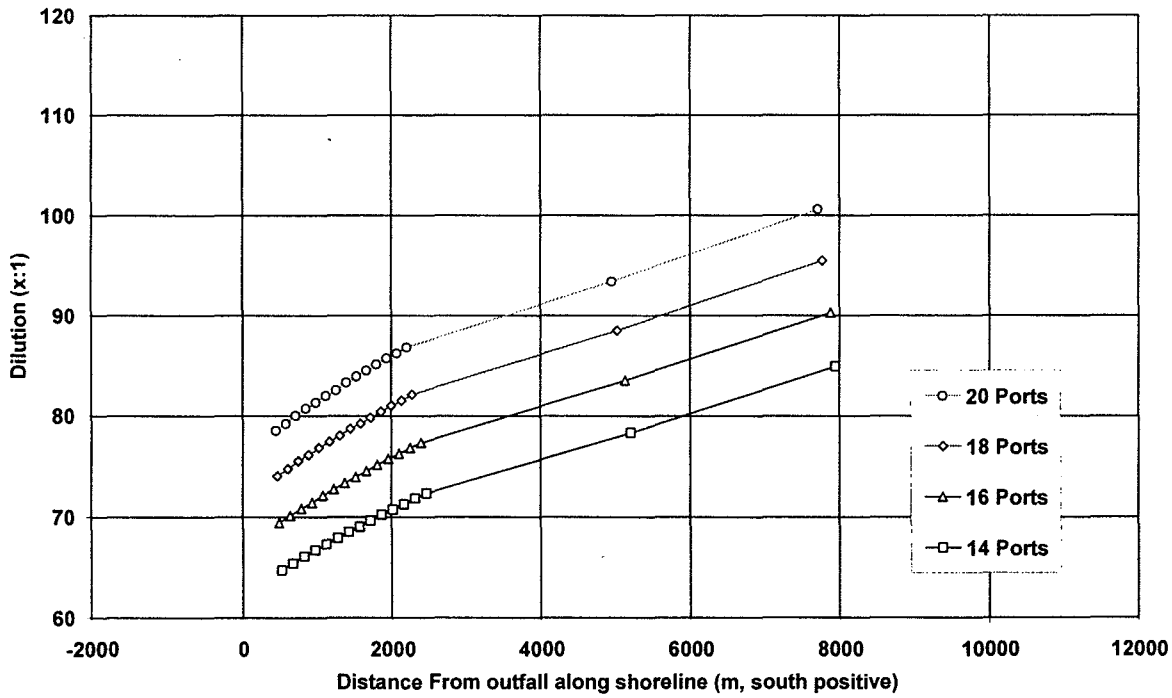


Figure 4. Diffuser Optimization Results: (a) Fixed Diffuser Length; (b) Fixed Port Spacing

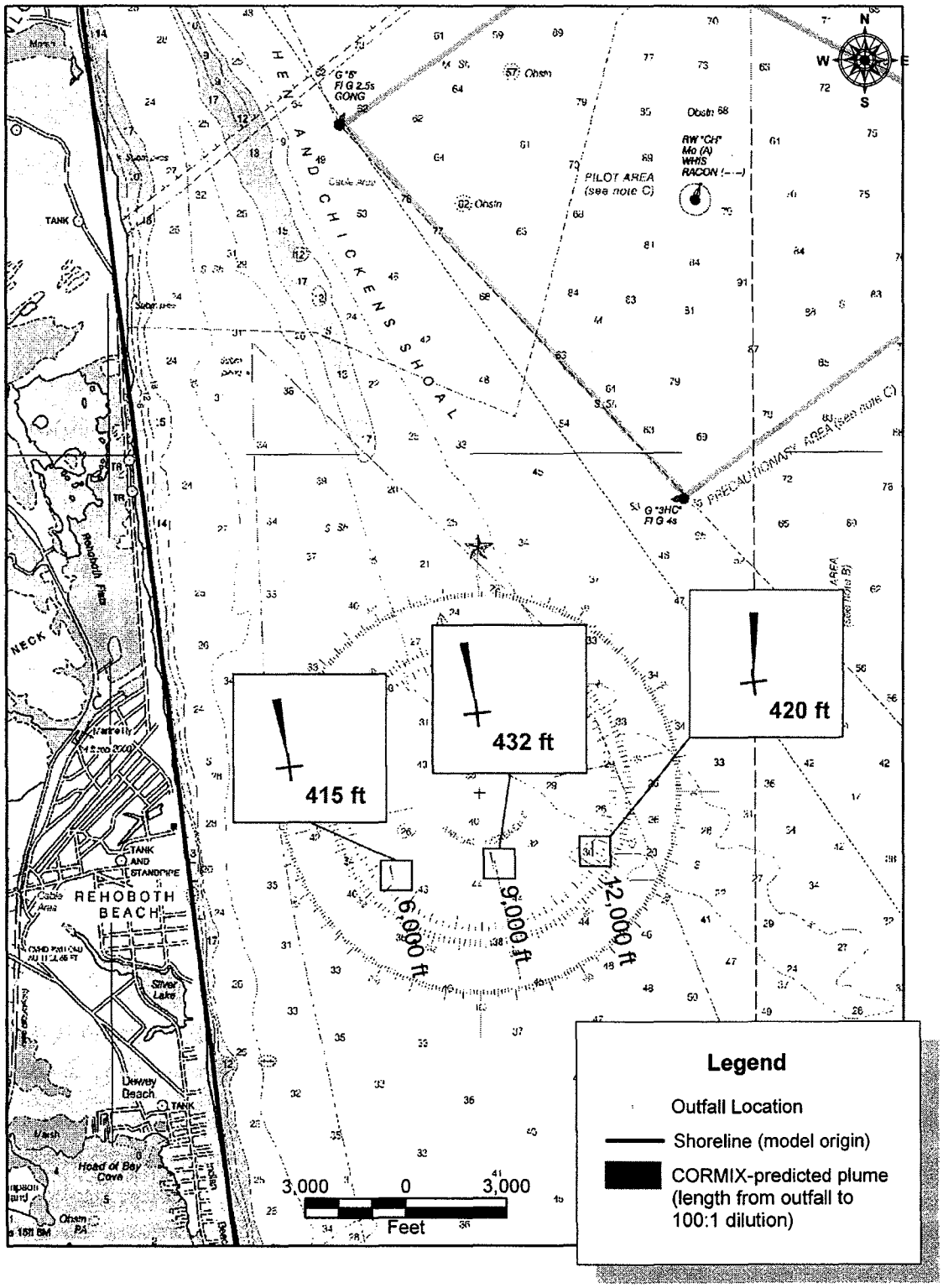


Figure 5. Distance to 100:1 Dilution (Rehoboth-Only Scenario)

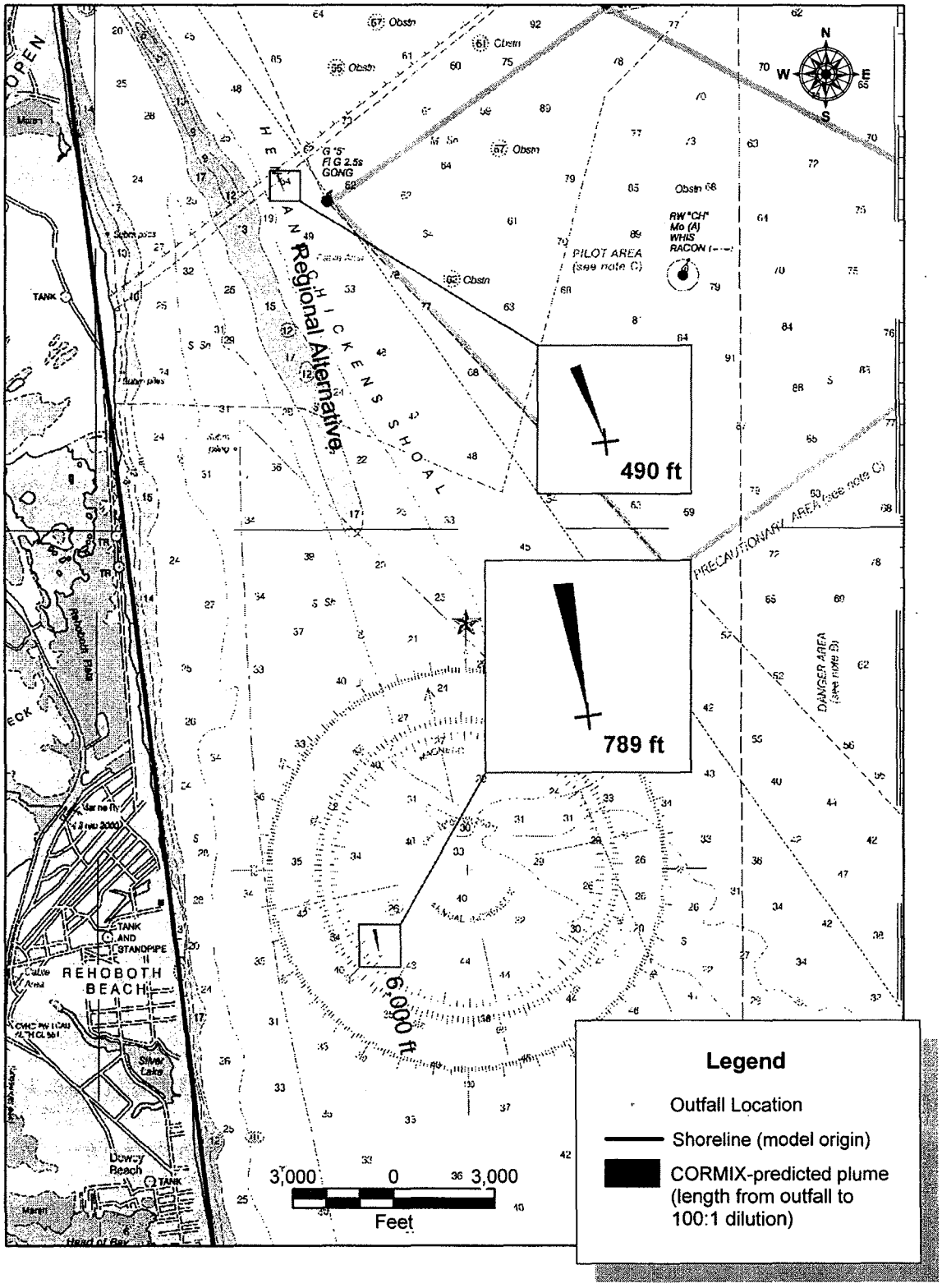


Figure 6. Distance to 100:1 Dilution (Regional Scenario)