CORMIX
THERMAL MIXING ZONE ANALYSIS AND DILUTION STUDY

Chesapeake Bay at Calvert Cliffs Nuclear Power Plant, Maryland

Calvert Cliffs Nuclear Power Plant - Photographer:John Swarey

Alion Science and Technology
and
Blue Hill Hydraulics Incorporated

May 2007

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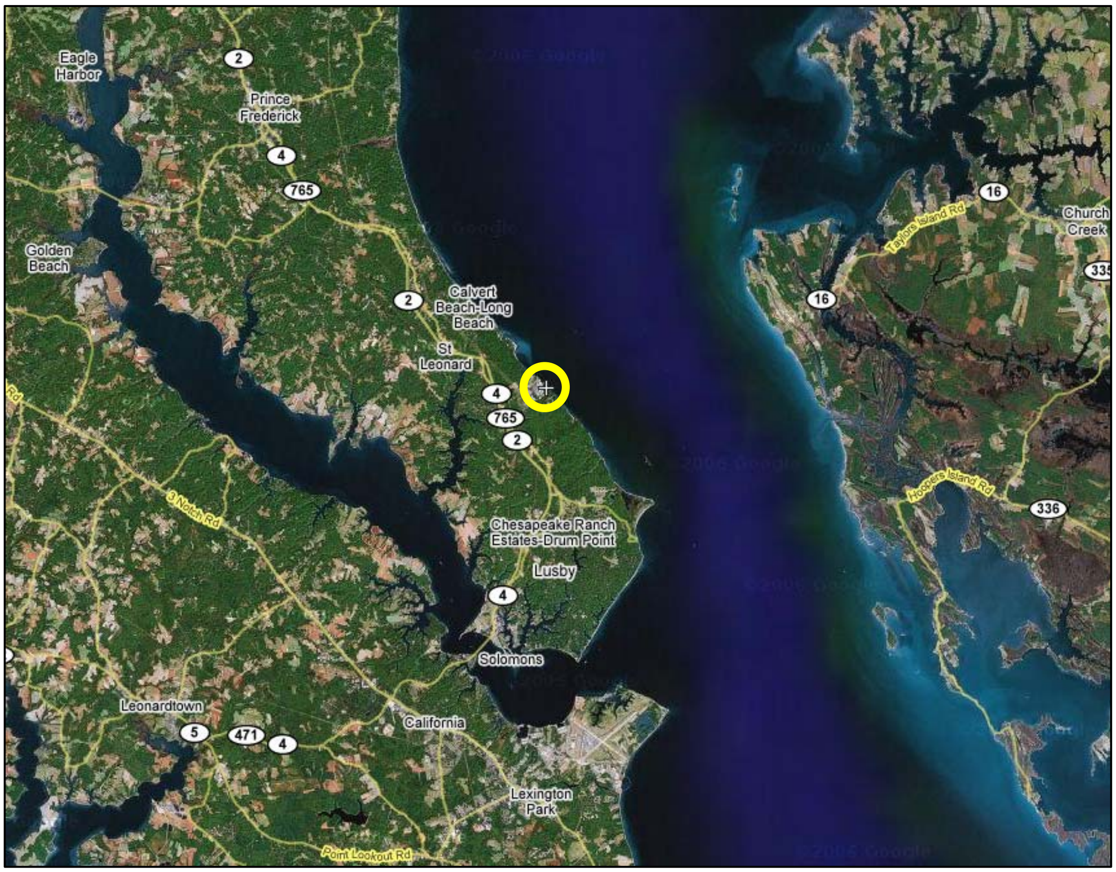
1. **Objective**

The primary objectives of this study were to: (1) calculate the size of the thermal plume produced by the proposed Calvert Cliffs Unit 3 discharge using the Cornell Mixing Expert System (CORMIX), and (2) to calculate liquid effluent dilution factors.

The analyses were based on average flow conditions in the Chesapeake Bay at the Calvert Cliffs project site, and information describing the configuration, placement, and operation of the proposed Unit 3 diffuser (Figure 1 shows project location).



Map Credit: Wikimapia

Figure 1: Calvert Cliffs Nuclear Power Plant and Vicinity
(aerial photograph with roadmap overlay, the yellow circle identifies the CCNPP)

The thermal plume and mixing analysis described herein considers the behavior of the Unit 3 diffuser operating in isolation. As is shown graphically in Figure 3, the estimated size of the Unit 3 thermal plume is quite small relative to the thermal plume created by Units 1 and 2. Because of the separation distance between the two discharge locations, and the fact that the discharge flow rate from Unit 3 is comparatively small, mixing of the Unit 3 effluent should not be affected by existing flows.

2. Background

CORMIX is an expert system designed for the analysis of mixing problems in natural water bodies (Jirka *et al.*, 1997).

To study this mixing problem, the program required input describing the size of the estuary in the vicinity of the project, flow speeds in the estuary; discharge flow rate and temperature rise; and discharge geometry. Based on these data, the CORMIX results were compared to state regulatory requirements for thermal mixing. The CORMIX results were also used in the development of a depth-averaged, hydrodynamic, flow model.

The ***FLOW-3D***® software system was used to construct a depth-averaged flow model of the estuary near the project (Flow Science, 2007). Model results near the discharge were compared to the CORMIX answers, and calibration parameters were adjusted so that the ***FLOW-3D***® results matched closely with the CORMIX results in the near-field. The resulting flow model was used to calculate time-averaged effluent dilution factors at shoreline locations where CORMIX could not be applied (*e.g.*, at locations beyond one tidal excursion length or at the adjacent shoreline).

3. Methodology

A three-step approach was used to calculate thermal mixing and effluent dilution for the proposed Calvert Cliffs Unit 3 diffuser. In Step One, required input data was assembled. In Step Two, the CORMIX analysis was carried out and questions regarding the size of the thermal mixing zone were answered. In Step Three, the hydrodynamic flow model was used to calculate effluent dilution factors in the far-field.

Step One: Input Data Preparation
Required data for the analyses were derived from USGS field data, NOAA navigational charts, and reports and design drawings provided by the power station. For reference, a listing of these data is provided in the following section.

Step Two: Thermal Mixing Study (CORMIX)
The extent of the proposed Unit 3 thermal plume was calculated for average flow conditions and the results were compared to state regulations.

Step Three: Calculation of Dilution Factors (*FLOW-3D*®)
Dilution factors for *far-field* shoreline locations were calculated from the results of the tidal flow model.

4. Input Data

Input for these studies can be divided into two categories: (1) Receiving Water Baseline Data, and (2) Outfall Baseline Data. So that this analysis can be repeated in the future – the data, and source, used to derive the input are provided in Tables 1 and 2 (Appendix One contains a portion of a CORMIX input file for reference).

Receiving Water Baseline Data

Table 1: Receiving Water Baseline Data for CCNPP Unit 3 Discharge System

Input Quantity/Data	Parameter Value	Reference
Bathymetry Surrounding Project Site	NOAA Navigational Chart	Chart Number 12264 - Chesapeake Bay, Patuxent River and Vicinity
Minimum Water Surface Elevation at Discharge Location	10 ft = MSL – 0.6 ft = MLW = 3.05 m	Calvert Cliffs Unit 3 Construction and Operation Station License Application (2007), Environment Report Section 3.4.
Tidal Excursion	Mean Range = 1 ft = .305 m Spring Range = 1.1 ft = .335 m	NOAA Tides and Currents Website – http://tidesandcurrents.noaa.gov/tides07/tab2ec2c.html#50
Maximum Ebb and Flow Tidal Velocities	1 ft/s = .305 m/s	Schreiner, S.P., *et al.* (1999), "Validation of the CORMIX Model Using Thermal Data from Four Maryland Power Plants," Versar, Inc., Columbia, MD.
Receiving Water Temperature(s)	Average annual Temperature 57.5 degrees F (14.2 degrees C)	Baltimore Gas and Electric Company (1970), "Environmental Report, Calvert Cliffs NPP."
Average Windspeed[1]	3.28 ft/s = 1.00 m/s	Baltimore Gas and Electric Company (1970), "Environmental Report, Calvert Cliffs NPP."
Salinity	13.0 ‰	Baltimore Gas and Electric Company (BG&E) and ANSP (1979), "Non-radiological Environmental Monitoring Report. Calvert Cliffs Nuclear Power Plant January-December 1978."
Receiving Water Density (57.5 degrees F, 13.0 ‰)	63.004 lb/ft^3 = 1009.22 kg/m^3	Fofonoff, P. and R. C. Millard Jr (1983), "Algorithms for Computation of Fundamental Properties of Seawater," Unesco Tech. Papers in Marine Sciences 44, 53 pp.

[1] Within the framework of a CORMIX analysis, the wind works to promote mixing. However, the calculated trajectory of a plume does not change with varying windspeed (i.e., only mixing rates vary). A low average windspeed was used in this analysis to reduce the amount of mixing caused by the wind. In terms of the analysis results the specification of a low windspeed is conservative.

Outfall Baseline Data

Table 2: Outfall Baseline Data for CCNPP Unit 3 Discharge System

Input Quantity/Data	**Parameter Value**	**Reference**
Location	1,200 ft south of the Unit 3 intake structure	COLA ER Section 3.4 for CCNPP Unit 3
Discharge Water Temperature ΔT	12 degrees F = 6.667 degrees C	COLA ER Section 3.4 for CCNPP Unit 3
Discharge Water Density (69.5 degrees F, 13.0 ‰)	62.919 lb/ft^3 = 1007.87 kg/m^3	Fofonoff, P. and R. C. Millard Jr. (1983), “Algorithms for Computation of Fundamental Properties of Seawater,” Unesco Tech. Papers in Marine Sciences 44, 53 pp.
Discharge Flow Rate	17,633 gpm = 1.1125 m^3/s	AREVA RFI-07-153 (dated: 3/19/07)
Diffuser Type	Multiport	Calvert Cliffs Unit 3 Construction and Operation Station License Application (2007), Environment Report Section 3.4.
Number of Discharge Ports	3	Ibid.
Distance of Shore	550 ft = 167.6 m	COLA ER Section 3.4 for CCNPP Unit 3
Orientation	Parallel to Shoreline	Calvert Cliffs Unit 3 Construction and Operation Station License Application (2007), Environment Report Section 3.4.
Height of Discharge Ports above Bottom	3 ft = .91 m	Ibid.
Angle of Inclination	22.5 degrees	Ibid.
Nozzle Diameters	16 inches = .406 m	Ibid.
Active Diffuser Length	18.75 ft = 5.715 m	Ibid.

5. Thermal Mixing Zone Analysis

5.1 State of Maryland Thermal Discharge Water Quality Regulations

The State of Maryland has established thermal discharge water quality regulations that limit the spatial extent of thermal plumes (COMAR 26.08.03.03). Criteria applicable to tidal areas are as follows:

- The 24-hr average of the maximum radial dimension measured from the point of discharge to the boundary of the full capacity 2ºC (3.6ºF) above ambient isotherm (measured during the critical periods) may not exceed ½ of the average ebb tidal excursion,
- The 24 hr average full capacity 2ºC (3.6ºF) above ambient thermal barrier (measured during the critical periods) may not exceed 50 percent of the accessible cross section of the receiving water body. Both cross sections shall be taken in the same plane,
- The 24 hr average area of the bottom touched by waters heated 2ºC (3.6ºF) or more above ambient at full capacity (measured during the critical periods) may not exceed 5 percent of the bottom beneath the average ebb tidal excursion multiplied by the width of the receiving water body.

5.2 Results

To determine whether or not the proposed Unit 3 thermal plume would satisfy the State of Maryland thermal discharge water quality standards a series of five CORMIX calculations were carried out. Each of these calculations was completed for a different tidal condition as identified in Table 3, and in each case the length and width of the plume was noted (see Appendix Two for sample graphics).[2] When all of the calculations were finished, the size of the thermal plume envelope was estimated as shown in Figure 2 (following page).

Table 3: Thermal Mixing Zone Results

Plume No.	Description	Length	Width
1	Max. Ebb	207 ft / 63 m	59 ft / 18 m
2	Max. Flood	207 ft / 63 m	59 ft / 18 m
3	Slack	19 ft / 6 m	6 ft / 2 m
4	Mid. Tide (before slack)	105 ft / 32 m	43 ft / 13 m
5	Mid. Tide (after slack)	105 ft / 32 m	43 ft / 13 m
Overall	**Thermal Plume Envelope**	**414 ft / 126 m**	**69 ft / 21 m**

[2] The following definitions apply to the length and width of the thermal plume reported in Table 3: *length* is defined as the along shore distance from the point of discharge to the 2ºC isotherm, and *width* is conservatively defined as the CORMIX calculated plume top-width (2 x BH) measured in the cross-shore direction at the downstream extent of the 2ºC isotherm.

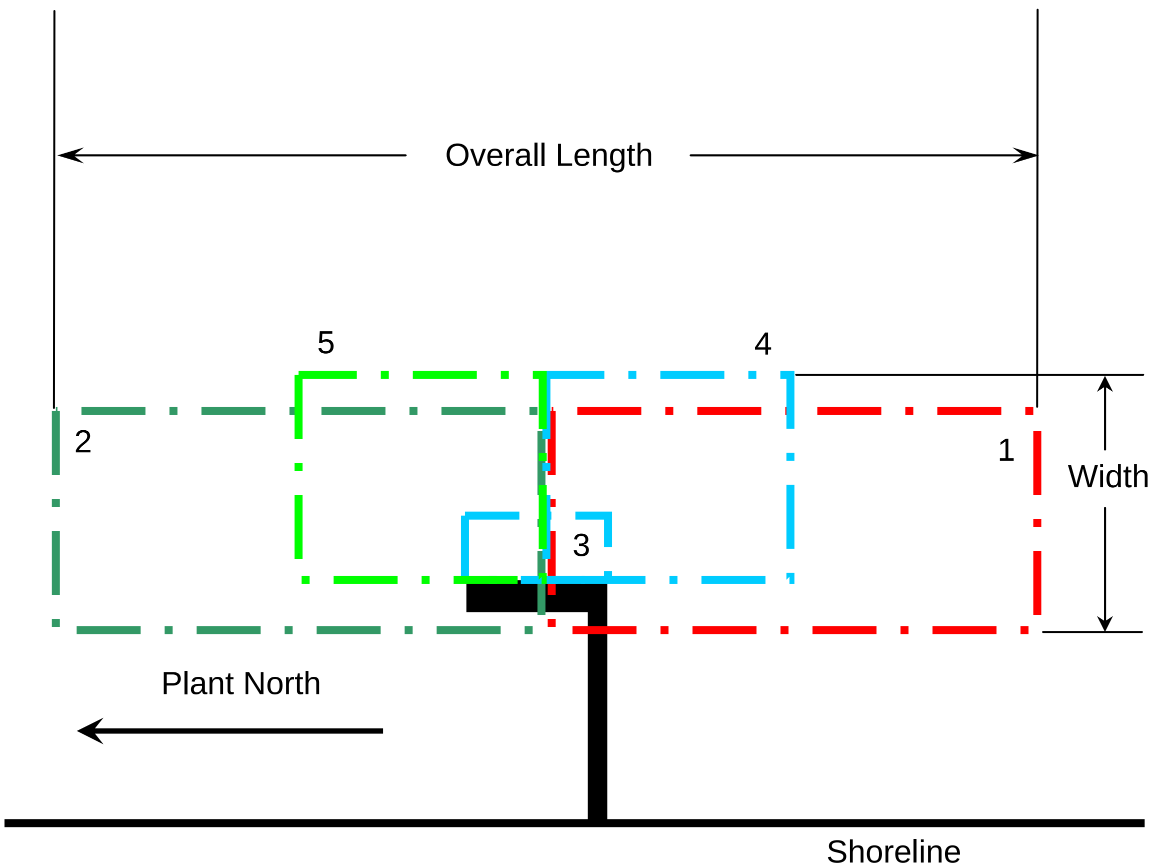
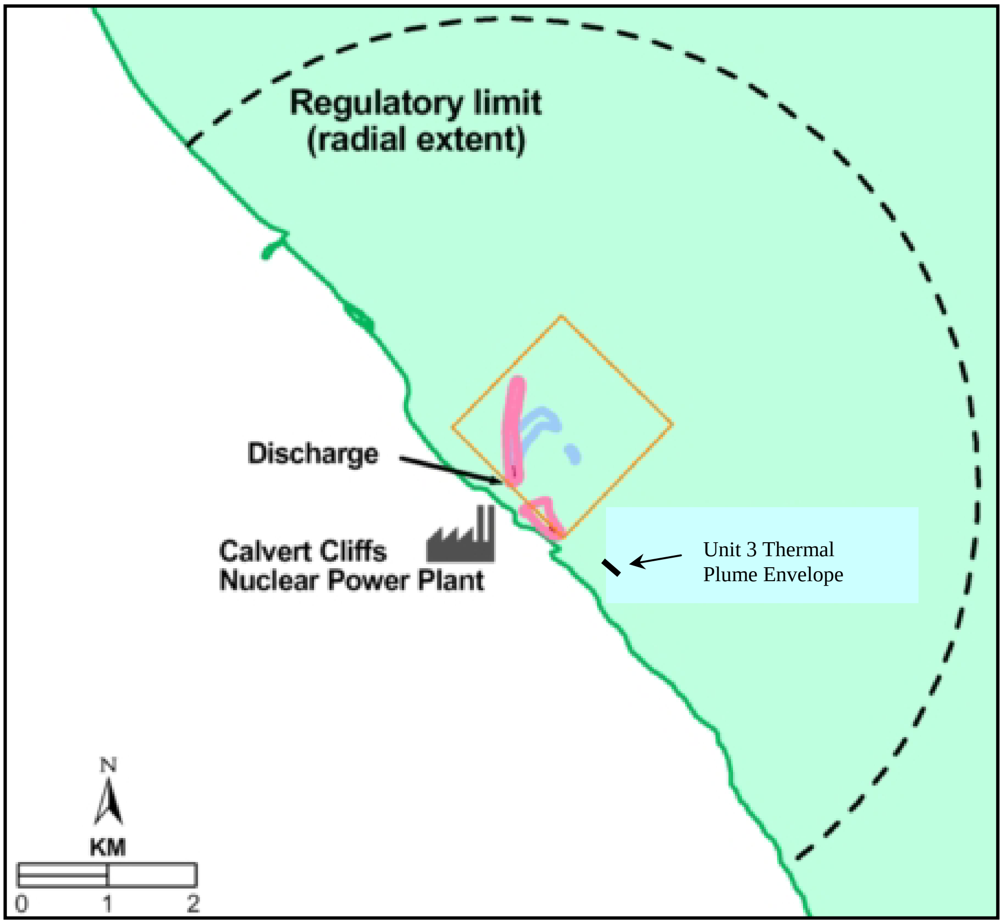


Figure 2: Thermal Plume Envelope - Definition Sketch
(plume numbers are identified in Table 3)

A sensitivity test (see Appendix 5) was completed to address concerns related to seasonal temperature changes (*i.e.*, different ΔTs) and their effect on the size of the thermal plume. The maximum ΔT analyzed was equal to 6.67 degrees C (12 degrees F). This is equal to the ΔT used for the thermal analysis of Units 1 and 2. The results of the sensitivity test indicate that the size of the thermal plume envelope (Figure 2) becomes smaller as ΔTs are reduced.[3]

[3] Note: the salinity of the influent water was assumed to be the same as the salinity of the discharge water, so changes in salinity were not considered in the sensitivity analysis (*i.e.*, discharge water density was assumed to be a function of temperature alone).

Figure 3 shows the size of the Unit 3 thermal plume envelope compared to the State of Maryland regulatory limit for radial extent.



Note: Scale is not exact.

Figure 3: Calvert Cliffs Nuclear Power Plant Thermal Plumes

(the thermal envelope for Units 1 and 2 is colored orange – areas of measured increased water temperatures are magenta and blue [flood and ebb tide measurements respectively], the thermal envelope for Unit 3 is black)

Table 4 provides a comparison of the State of Maryland regulatory limits to the calculated Unit 3 thermal plume size. In each case, the thermal plume satisfies the state requirement.[4]

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[4] As discussed in Appendix 5, the size of the thermal plume should be less and dilution should increase if ΔTs are reduced. Thus, the results presented here are bounding provided that the actual operating ΔT is equal to or less than 6.66 deg. C.

Table 4: Comparison of State of Maryland Regulatory Limits to Calculated Thermal Plume Size

Water Quality Standard	**Permissible Limit**	**Calculated**
The 24-hr average of the maximum radial dimension measured from the point of discharge to the boundary of the full capacity 3.6ºF (2ºC) above ambient isotherm (measured during the critical periods) may not exceed one-half of the average ebb tidal excursion.	4,101 ft / 1250 m	< 207 ft / 63 m
The 24-hr average full capacity 3.6ºF (2ºC) above ambient thermal barrier (measured during the critical periods) may not exceed 50 percent of the accessible cross section of the receiving water body. Both cross sections shall be taken in the same plane.	16,000 ft / 4,800 m	69 ft / 21 m
The 24-hr average area of the bottom touched by waters heated 3.6ºF (2ºC) or more above ambient at full capacity (measured during the critical periods) may not exceed 5 percent of the bottom beneath the average ebb tidal excursion multiplied by the width of the receiving water body.	1.3×10^7 ft^2 / 1.2×10^6 m^2	2.9×10^4 ft^2 / 2.7×10^3 m^2

Note: All of the calculations are based on the size of the thermal plume envelope as shown in Figure 3.

5.3 Conservative Assumptions

Two conservative assumptions were used in the thermal plume analysis.

First, the average depth of the receiving water was specified as 13ft/4.0m (See Appendix 1 – HA input parameter); however, the depth of the bay is greater than this in areas where mixing occurs. CORMIX requires that the receiving water be assumed to have a rectangular cross-section, and the average depth of the cross-section cannot be more than 30% greater than the depth at discharge. In this analysis, the depth at discharge was based on design drawing information and the average depth of the receiving water was specified to be 30% greater. As a result of this simplification, the amount of mixing calculated should be less than it would be if the depth of the receiving water was deeper.

Second, the comparisons of thermal plume size to state limits are based on the extent of the thermal plume envelope (see Figure 2) not the size of the instantaneous thermal plume. This adds a safety factor of about two to the analysis. However, in either case the size of the thermal plume is much less than the state's requirements since the limits are based on the bay width at the discharge location.

6. Dilution Study

6.1 Analysis Procedure

The CORMIX computer program was designed to study mixing in steady-flows. Recently, however, the program has been adapted for the study of mixing in tidally influenced waters (Nash, 1995). The revised program works well to estimate mixing in near-field regions; however, the approach is not suitable for calculating mixing in areas where the plume's transit time is much greater than 3.5 hours (*i.e.*, about ¼ of a tidal cycle) unless the transit time is so great that tidal effects can be ignored (note: this approach was used to calculate time-averaged dilution credits in tidal waters 50-miles downstream of the project; however, these estimates are recognized to be conservative – see discussion in Section 6.1.3).

The ***FLOW-3D***® computer program was used to construct a depth-averaged flow model of the estuary so that far-field dilution credits could be calculated in areas where CORMIX could not be applied.[5] CORMIX results (*i.e.*, near-field dilutions credits) were used to provide calibration data for the depth-averaged flow model, and subsequent simulation results were used to determine transit times and far-field dilution credits (see Section 6.1.2).

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[5] ***FLOW-3D***® is a finite volume computer program that uses the transient, three-dimensional, Navier-Stokes equations as governing equations (a reduced depth-averaged set of equations can also be solved). The program has been commercially available since the mid-1980s and is currently being used to help resolve problems related to GSI-191.

6.1.1 Calculation of Near-Field Dilution Credits

Near-field Dilution credits were calculated with CORMIX following a procedure similar to the one used to complete the thermal mixing study. A series of five calculations, each associated with a different part of the tidal cycle (*e.g.*, flood, ebb, mid-tide after slack, mid-tide before slack, and slack), were completed. And, the size and extent of mixing zones associated with the 2 degree, 1 degree, and 0.5 degree C isotherms were noted.

As shown in Table 5, the size and extent of the *largest* area covered by a mixing zone during a tidal cycle was reported.

6.1.2 Calculation of Far-Field Dilution Credits

CORMIX could not be used to calculate dilution credits at shoreline locations listed in Table 6 because the transit times to these locations are much greater than about 3.5 hours.[6] Or, in the case of the *Nearest Shoreline* and the *Southern Property Boundary* the time-dependent effects of the tide could not be adequately addressed by the CORMIX tidal routines. Dilution credits, at far-field locations, were instead calculated from the results of a tidal flow model.

The bathymetry of the tidal flow model was the same as that used in the CORMIX calculations. That is, the Chesapeake Bay's cross section was assumed to be rectangular (4 meters deep and 9,600 meters wide) and prismatic. Receiving water data was also the same as that used for the calculation of near-field dilution credits and the thermal study. Only the discharge geometry and tidal velocities were different.

The discharge geometry (*i.e.*, the multi-port diffuser) was not built explicitly into the tidal flow model since the tidal model was depth-averaged (*i.e.*, the model had only one computational cell in the vertical direction) and the minimum size of the computational cells was larger than the size of the diffuser (note: this second simplification was used to limit the size of the tidal flow model).

Tidal velocities were based on those used to calculate near-field dilution credits and in the thermal study. However, in this case, a drift velocity based on monthly mean inflows to the bay defined at cross-section B of Figure 4(a) was incorporated into the tidal boundary conditions. The drift velocity accounts for the seaward movement of water in the bay and was calculated to be equal to 60,000 cfs divided by the cross-sectional area of the water body (*i.e.*, flows in the tidal model were biased in the seaward direction).[7]

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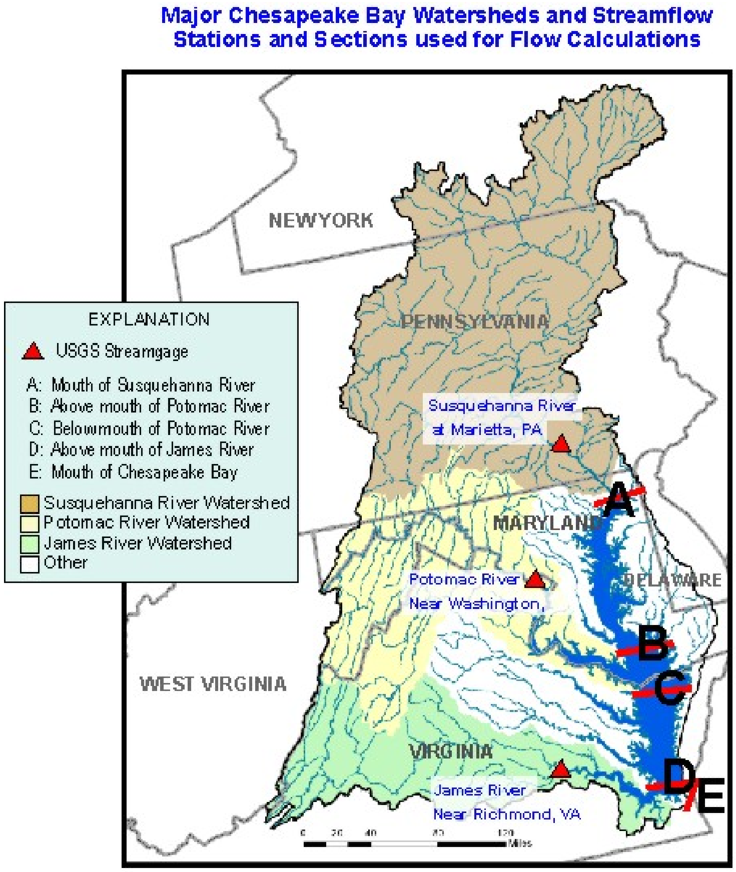
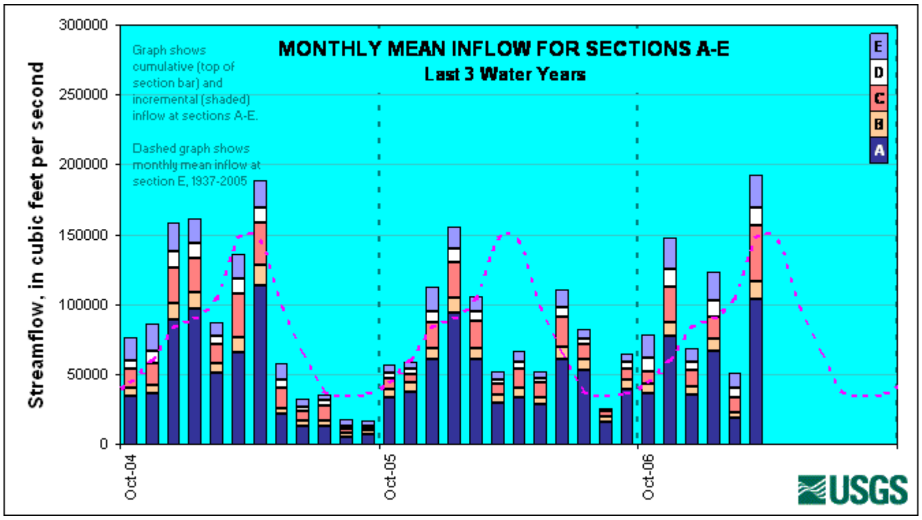
[6] A notable exception to this rule applies to the calculation of dilution credits for shoreline locations 50 miles away – CORMIX was used in this case – see Section 6.1.3 for a discussion.

[7] NOTE: In a previous CORMIX mixing zone study, performed by Versar, Inc. for the Maryland Power Plant Research Program, symmetric tidal velocities were used and the results of the analysis compared closely with measured data at Calvert Cliffs. For this reason, these same velocities were used as input to the CORMIX analyses reported herein



(a)



(b)

Figure 4: USGS Flow Data
(a) Stations and Sections, (b) Monthly Mean Inflows

Adjustments to mixing parameters were made so that a close agreement between output from the tidal model and results of the thermal study was achieved. The calibrated tidal model was then used to calculate dilution credits at locations were CORMIX could not be applied (see sample graphics in Appendix Three).

Time averaged dilution credits were calculated from time-series results output at each of the locations of interest appearing in Table 6 after model spin-up (*i.e.*, once the results of the tidal model were quasi-steady). In contrast to this, transit times, were calculated to be the minimum time required for any effluent to reach a location of interest.

6.1.3 Calculation of Dilution Credits at 50-Miles

CORMIX was used to calculate dilution credits at shoreline locations 50-miles away. These locations are well beyond the limit of a tidal excursion, and it is estimated that about three weeks time is required for effluent to be transported to these locations. Since the transit time is much greater than the period of a tidal cycle (550 hours versus 12.6 hours) the CORMIX analysis was based on the drift velocity used in the tidal model. This approach neglects mixing energy provided by the tide and provides a conservative estimate of dilution at the 50-mile limit.

Figure 5 shows "centerline dilution" versus "centerline trajectory distance" downstream of the discharge. The green vertical line identifies the location of the 2 degree C isotherm, and the blue vertical lines identify locations where different CORMIX solution modules were used. The last solution module, number 261, applies to a condition where the plume centerline is attached to the shoreline and only gradual spreading takes place in the downstream direction. Thus, in much of the far-field, the plume extends only a portion of the total distance across the bay and a maximum dilution of 365 is calculated along the shoreline for most of the reach in question.[8]

[8] To contrast this result, a dilution of 1527:1 is calculated for a condition where total mixing occurs in the reach length.

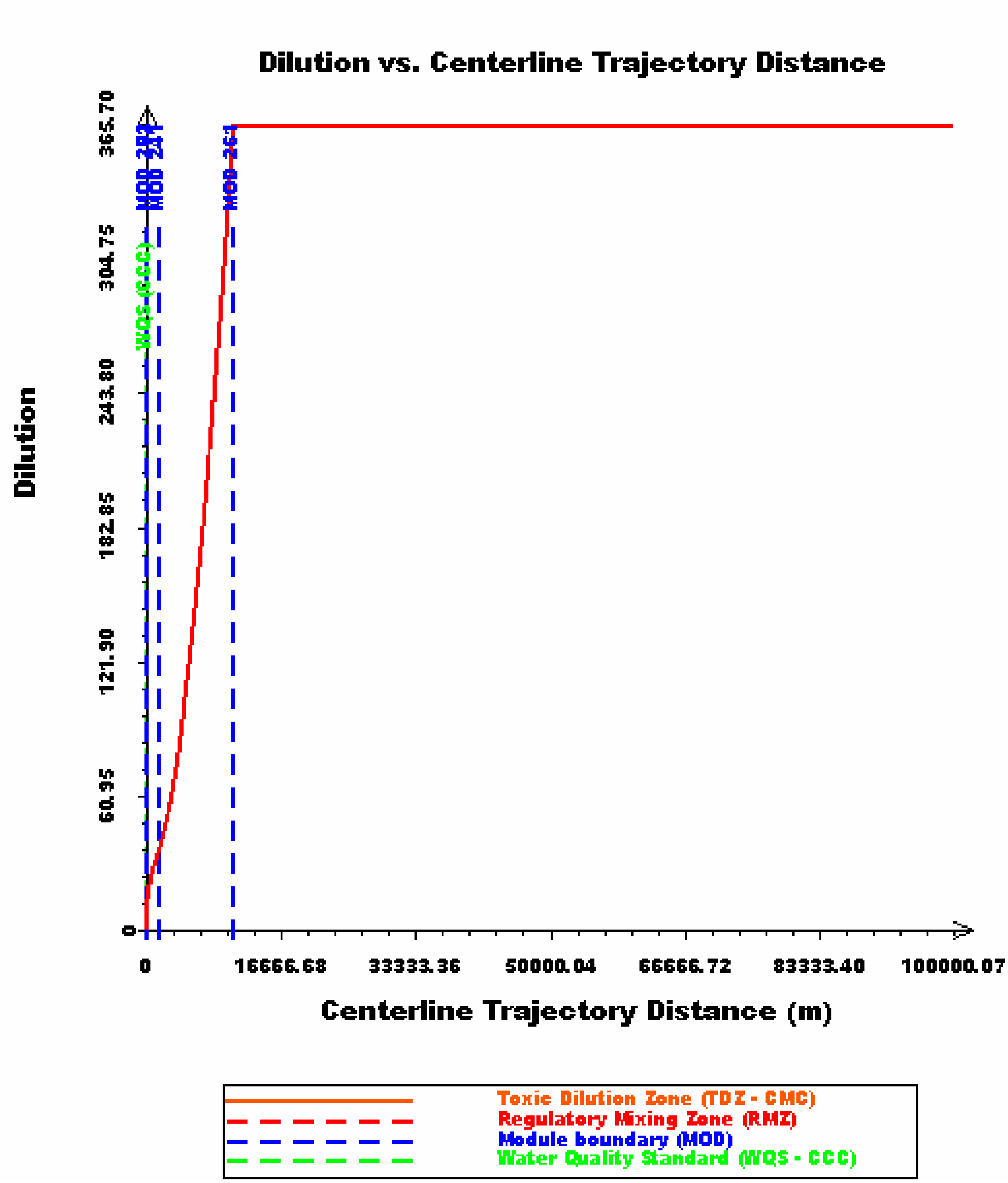


Figure 5: Centerline Dilution versus Distance
(standard CORMIX output reported in SI units - 50 miles equals 80,500 meters)

6.2 Results

Near-field and Far-field dilution credits are provided in Tables 5 and 6.

Shoreline dilution with respect to shoreline position is given in Figure 6. In this figure, shoreline position shown on the horizontal axis is referenced relative to the location of the discharge (*i.e.*, shoreline positions in the seaward direction are positive and shoreline positions in the upland direction are negative).

Table 5: Near-Field Dilution Credits

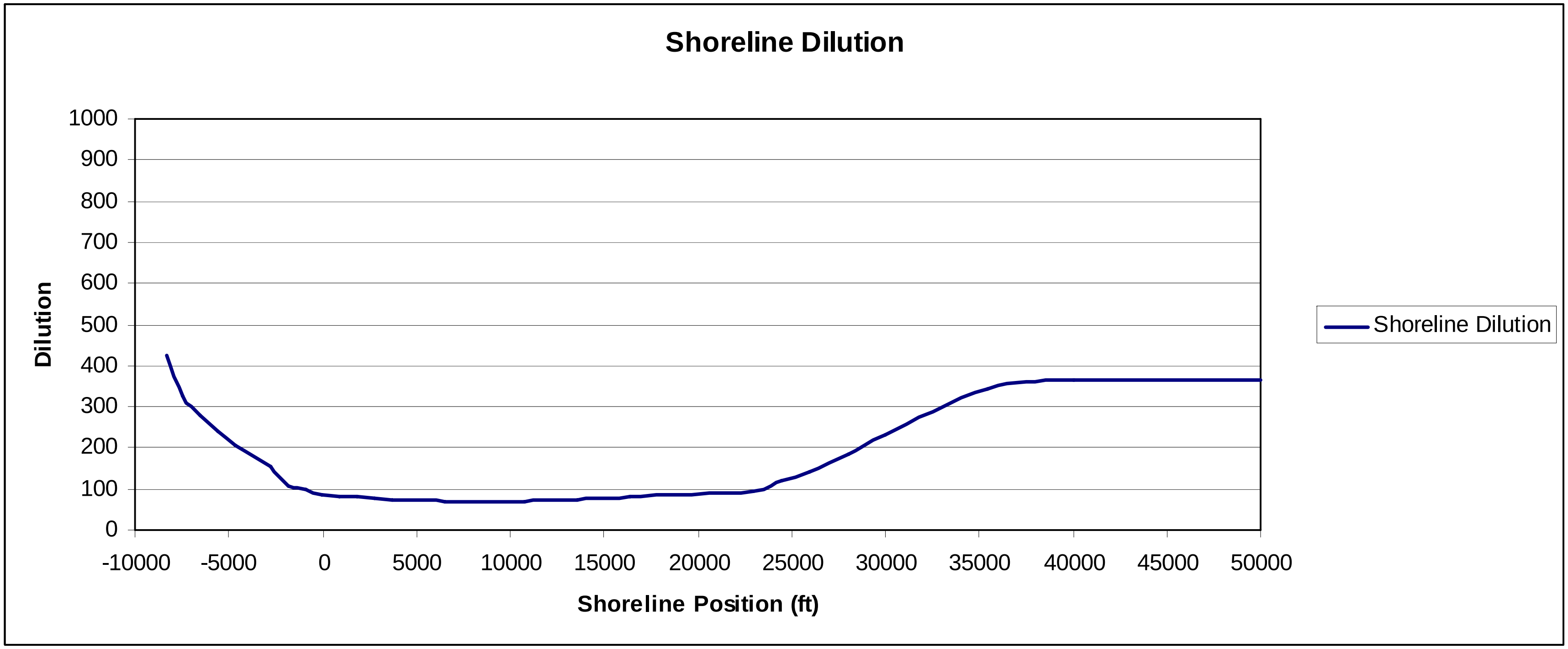
Definition of Mixing Zone	Minimum Dilution at Mixing Zone Perimeter	Area of Mixing Zone[9] (acres)	Length of Mixing Zone vs. CCNPP Shoreline Boundaries[10]	Width of Mixing Zone vs. Bay Width[11]
ΔT = 2 degree C Isotherm	3.4	0.13	3%	0.1%
ΔT = 1 degree C Isotherm	6.6	2.8	8%	0.4%
ΔT = 0.5 degree C Isotherm[12]	13.3	9.0	13%	0.9%

[9] The “Area of Mixing Zone” is the largest area covered by the mixing zone during a tidal cycle.
[10] The “Length of Mixing Zone” is the greatest along-shore distance covered by the mixing zone during a tidal cycle.
[11] The “Width of Mixing Zone” is the greatest cross-shore distance covered by the mixing zone during a tidal cycle.
[12] For this scenario the 0.5 degree C Isotherm is located at the limit of applicability for CORMIX. As a result, the length and width measures of the plume for the mid-tide analyses were extrapolated from the CORMIX output data.

Table 6: Far-Field Dilution Credits[13]

Location	Transit Time (hr)	Time Averaged Dilution Credit
Calvert Beach[14]	N/A	N/A
Long Beach[5]	N/A	N/A
Northern Property Boundary[15]	3.5 *(conservative)*	377 *(conservative)*
Nearest Shoreline[16]	0.8	93
Southern Property Boundary	1.4	74
Minimum Shoreline Dilution[17]	4.0	69
Cove Point Beach	77	93
Tidal Waters 50-Miles Downstream[18,19]	550 (est.)	365
Shoreline of Chesapeake Bay Opposite of CCNPP[20]	N/A	N/A

[13] The time-average flow of water past the discharge location is based on upstream freshwater inflows equal to 60,000 cfs (USGS).
[14] Calvert Beach and Long Beach are located beyond the upstream limit of the tidal excursion.
[15] The Northern Property Boundary is located near the upstream limit of the tidal excursion.
[16] The transit time for this estimate is difficult to calculate since flows are perpendicular to nearest shoreline – transit time is based on wind-driven surface current of 0.2 ft/s (about 1/10th of typical wind speed).
[17] Approximately 8,900 ft south of discharge point.
[18] The calculated time-averaged dilution credit assumes that the plume is not laterally well-mixed 50-miles downstream of the discharge point and is, therefore, conservative.
[19] The calculated time-averaged dilution credit does not account for freshwater inflows downstream (*i.e.*, seaward) of the discharge location.
[20] The plume does not contact the shoreline of the Chesapeake Bay opposite of CCNPP according to this analysis.



Shoreline Location (ft)	Descriptor	Dilution
-8,000	Northern Property Boundary	377
-1,200	Cooling Water Intake	101
0	Nearest Shoreline Location	93
5,000	Southern Property Boundary	74
8,900	Minimum Dilution	69
23,000	Cove Point Beach	93
> 40,000	Far-Field to 50 Miles	365

Figure 6: Shoreline Dilution

6.3 Conservative Assumptions

Four conservative assumptions were used in the calculation of time averaged dilution credits and transit times.

First, the drift velocity used in the analyses is based on inflows from upstream locations only. However, as shown in Figure 4, additional water enters the bay at downstream locations in the vicinity of the project. The addition of this water should increase the dilution of the effluent and should increase its drift velocity.

Second, the bay cross-section used for these calculations under estimates the size of the bay in the area of interest. As a result, the dilution of the effluent should be under estimated as well.

Third, the effect of winds to increase mixing was not explicitly included in the tidal model (instead, winds were assumed to be light in the CORMIX analysis, and they did not affect the ***FLOW-3D***® study, use of both assumptions is conservative).

Fourth, the approach used to calculate dilution credits at 50-miles does not include the effect of tides which could increase mixing in the area of interest.

7. References

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Appendix One: CORMIX Input derived from Baseline Data (excerpt)

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2222222222222222222222222222222222222222222222222222222222222222222222222
                       CORMIX MIXING ZONE EXPERT SYSTEM
         Subsystem CORMIX2:  Multiport Diffuser Discharges
                         CORMIX Version 5.0GT
                      HYDRO2 Version 5.0.0.0 March 2007
-------------------------------------------------------------------------
-------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:   Calvert Cliffs
 Design case:       Discharge System for CCNPP Unit 3 - Ebb Tide
 FILE NAME:         C:\...RMIX 5.0\MyFiles\CCNPP Unit 3 Discharge
(ebb).prd
 Time stamp:        Tue Apr  3 13:01:37 2007

ENVIRONMENT PARAMETERS (metric units)
 Unbounded section
 HA     =        4.00 HD     =        3.05
 Tidal Simulation at TIME =        3.150 h
 PERIOD=     12.60 h UAmax =        0.305 dUa/dt=      0.097 (m/s)/h
 UA     =        0.305 F      =        0.020 USTAR =0.1517E-01
 UW     =        1.000 UWSTAR=0.1071E-02
 Uniform density environment
 STRCND=  U          RHOAM = 1009.2200

DIFFUSER DISCHARGE PARAMETERS (metric units)
 Diffuser type:     DITYPE= unidirectional_parallel
 BANK   =  RIGHT     DISTB =     167.60  YB1    =     167.60  YB2    =
167.60
 LD     =        5.70  NOPEN =     3         SPAC   =        2.85
 D0     =        0.406 A0     =        0.130 H0     =        0.91  SUB0   =
2.14
 Nozzle/port arrangement:   unidirectional_without_fanning
 GAMMA =     180.00  THETA =      22.50  SIGMA =      90.00  BETA   =
90.00
 U0     =       2.859 Q0     =        1.112        =0.1112E+01
 RHO0   = 1007.8700  DRHO0 =0.1350E+01  GP0    =0.1312E-01
 C0     =0.6667E+01  CUNITS=  deg.C
 IPOLL =  3          KS     =0.7165E-05  KD     =0.0000E+00
```

Estimated from NOAA Navigation Data – Chart No. 12264 (and maximum CORMIX permissible value based on HD)

Notes: (1) Input derived from baseline date is highlighted.
(2) Refer to CORMIX User's Manual for variable definitions.

Appendix Two: CORMIX Sample Graphics – Max. Ebb/Flood Results

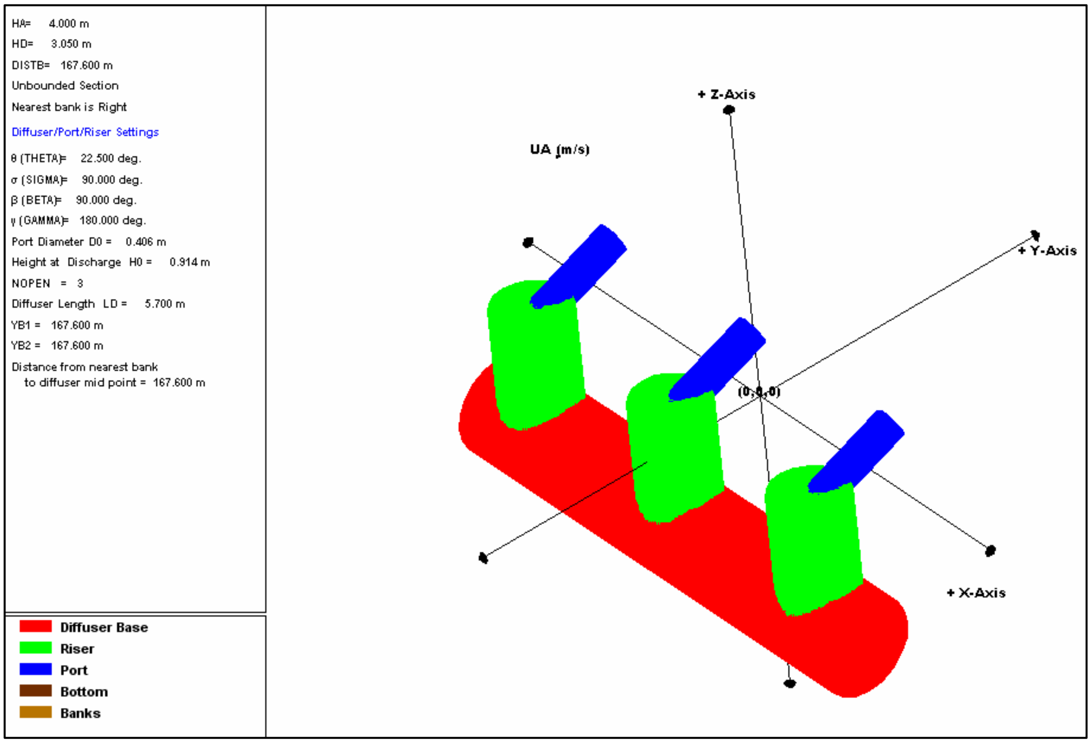

Figure 2-1: Schematic Diagram of Modeled Diffuser

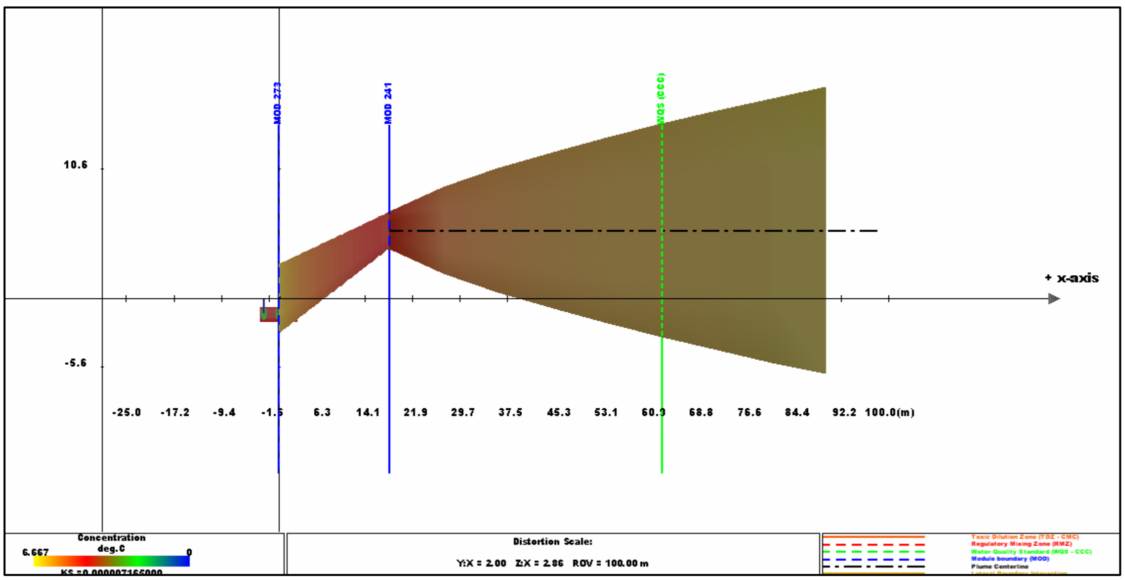

Figure 2-2: Plan View - Ebb Tide Plume
(water quality standard met 63.0 m [207.0 ft] downstream of diffuser)

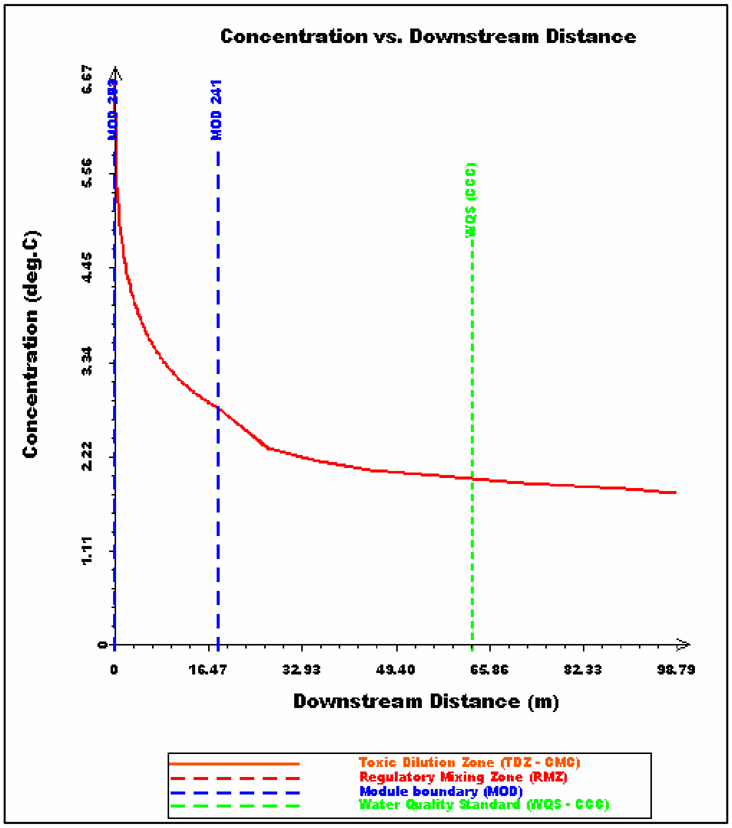

Figure 2-3: Downstream Distance where Water Quality Standard is Achieved (green line, 54.0 m [177.0 ft])

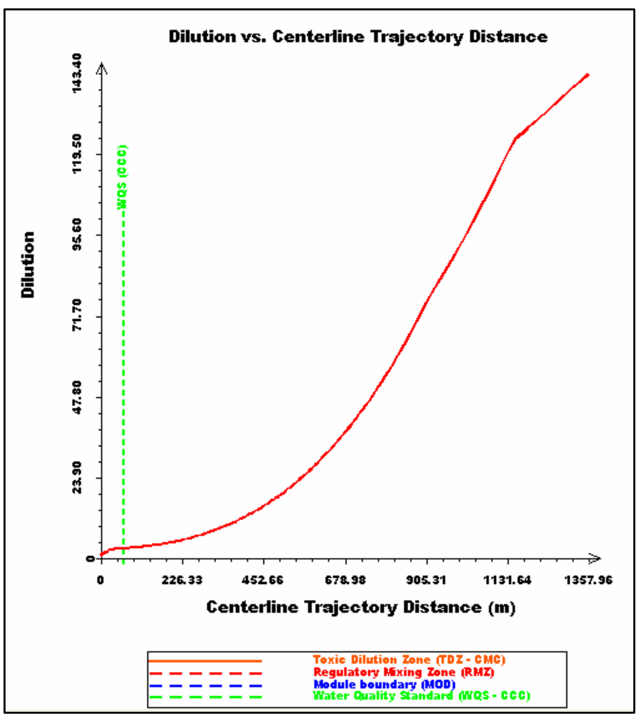

Figure 2-4: Dilution along Centerline Trajectory of Plume

Appendix Three: *FLOW-3D*® Sample Graphics – Max. Ebb Results

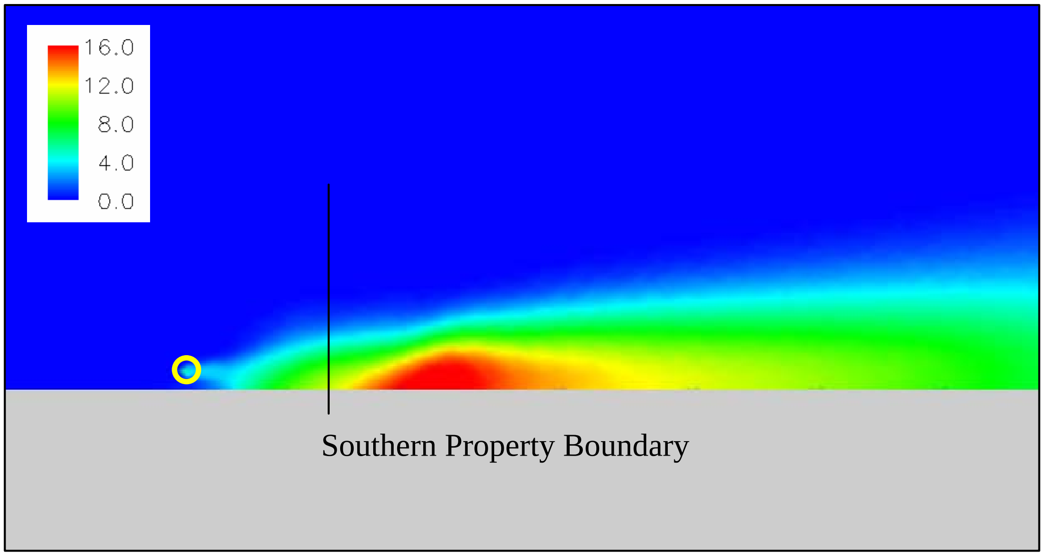

Figure 3-1: Max. Ebb Concentration Distribution
(discharge location is circled)

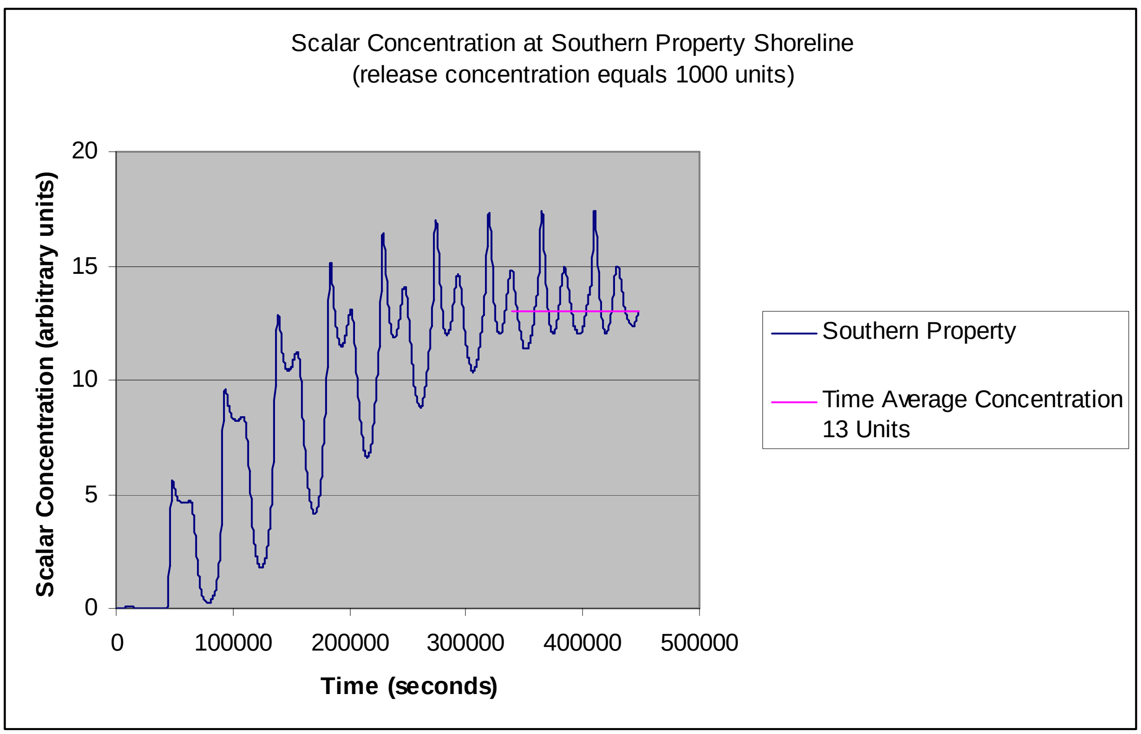

Figure 3-2: Scalar Concentration at Southern Property Boundary

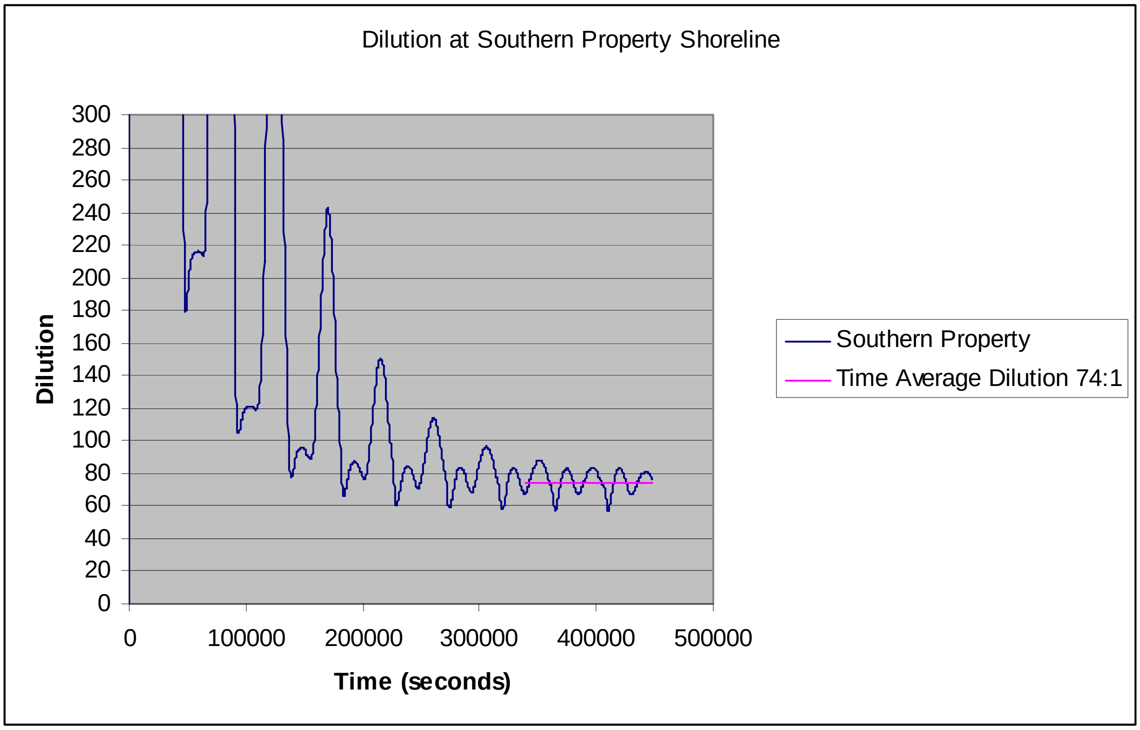

Figure 3-3: Calculated Dilution at Southern Property Boundary

Appendix Four: CORMIX Input Records – Prediction File Excerpts

1. Flood and Ebb Conditions

2222222222222222222222222222222222222222222222222222222222222222222222222222
CORMIX MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX2: Multiport Diffuser Discharges
CORMIX Version 5.0GT
HYDRO2 Version 5.0.0.0 March 2007

CASE DESCRIPTION
Site name/label: Calvert Cliffs
Design case: Discharge System for CCNPP Unit 3 - Ebb/FloodTide
FILE NAME: C:\...hn\Desktop\CCNPP Unit 3 Discharge (ebb flood).prd
Time stamp: Wed May 16 14:32:42 2007
ENVIRONMENT PARAMETERS (metric units)
Unbounded section
HA = 4.00 HD = 3.05
Tidal Simulation at TIME = 3.150 h
PERIOD= 12.60 h UAmax = 0.305 dUa/dt= 0.097 (m/s)/h
UA = 0.305 F = 0.020 USTAR =0.1517E-01
UW = 1.000 UWSTAR=0.1071E-02
Uniform density environment
STRCND= U RHOAM = 1009.2200
DIFFUSER DISCHARGE PARAMETERS (metric units)
Diffuser type: DITYPE= unidirectional_parallel
BANK = RIGHT DISTB = 167.60 YB1 = 167.60 YB2 = 167.60
LD = 5.70 NOPEN = 3 SPAC = 2.85
D0 = 0.406 A0 = 0.130 H0 = 0.91 SUB0 = 2.14
Nozzle/port arrangement: unidirectional_without_fanning
GAMMA = 180.00 THETA = 22.50 SIGMA = 90.00 BETA = 90.00
U0 = 2.859 Q0 = 1.112 =0.1112E+01
RHO0 = 1007.8700 DRHO0 =0.1350E+01 GP0 =0.1312E-01
C0 =0.6667E+01 CUNITS= deg.C
IPOLL = 3 KS =0.7165E-05 KD =0.0000E+00
FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
q0 =0.1952E+00 m0 =0.5580E+00 j0 =0.2560E-02 SIGNJ0= 1.0
Associated 2-d length scales (meters)
lQ=B = 0.068 lM = 29.71 lm = 6.00
lmp = 99999.00 lbp = 99999.00 la = 99999.00
FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
Q0 =0.1112E+01 M0 =0.3180E+01 J0 =0.1459E-01
Associated 3-d length scales (meters)
LQ = 0.36 LM = 19.71 Lm = 5.85 Lb = 0.51
Lmp = 99999.00 Lbp = 99999.00
Tidal: Tu = 0.3753 h Lu = 49.081 Lmin = 5.847
NON-DIMENSIONAL PARAMETERS
FR0 = 95.53 FRD0 = 39.15 R = 9.37 PL = 3.
(slot) (port/nozzle)
RECOMPUTED SOURCE CONDITIONS FOR RISER GROUPS:
Properties of riser group with 1 ports/nozzles each:
U0 = 2.859 D0 = 0.406 A0 = 0.130 THETA = 22.50
FR0 = 95.53 FRD0 = 39.15 R = 9.37
(slot) (riser group)

2. Slack Condition

2222222222222222222222222222222222222222222222222222222222222222222222222222222
CORMIX MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX2: Multiport Diffuser Discharges
CORMIX Version 5.0GT
HYDRO2 Version 5.0.0.0 March 2007

CASE DESCRIPTION
Site name/label: Calvert Cliffs
Design case: Discharge System for CCNPP Unit 3 - Slack
FILE NAME: C:\...IX 5.0\MyFiles\CCNPP Unit 3 Discharge (slack).prd
Time stamp: Wed May 16 14:34:58 2007
ENVIRONMENT PARAMETERS (metric units)
Unbounded section
HA = 4.00 HD = 3.05
Tidal Simulation at TIME = 0.000 h
PERIOD= 12.60 h UAmax = 0.305 dUa/dt= 0.137 (m/s)/h
UA = 0.000 F = 0.020 USTAR =0.0000E+00
UW = 1.000 UWSTAR=0.1071E-02
Uniform density environment
STRCND= U RHOAM = 1009.2200
DIFFUSER DISCHARGE PARAMETERS (metric units)
Diffuser type: DITYPE= unidirectional_parallel
BANK = RIGHT DISTB = 167.60 YB1 = 167.60 YB2 = 167.60
LD = 5.70 NOPEN = 3 SPAC = 2.85
D0 = 0.406 A0 = 0.130 H0 = 0.91 SUB0 = 2.14
Nozzle/port arrangement: unidirectional_without_fanning
GAMMA = 180.00 THETA = 22.50 SIGMA = 90.00 BETA = 90.00
U0 = 2.859 Q0 = 1.112 =0.1112E+01
RHO0 = 1007.8700 DRHO0 =0.1350E+01 GP0 =0.1312E-01
C0 =0.6667E+01 CUNITS= deg.C
IPOLL = 3 KS =0.7165E-05 KD =0.0000E+00
FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
q0 =0.1952E+00 m0 =0.5580E+00 j0 =0.2560E-02 SIGNJ0= 1.0
Associated 2-d length scales (meters)
lQ=B = 0.068 lM = 29.71 lm = 99999.00
lmp = 99999.00 lbp = 99999.00 la = 99999.00
FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
Q0 =0.1112E+01 M0 =0.3180E+01 J0 =0.1459E-01
Associated 3-d length scales (meters)
LQ = 0.36 LM = 19.71 Lm = 99999.00 Lb = 99999.00
Lmp = 99999.00 Lbp = 99999.00
Tidal: Tu = 0.2975 h Lu = 43.704 Lmin = 5.847
NON-DIMENSIONAL PARAMETERS
FR0 = 95.53 FRD0 = 39.15 R = 99999.00 PL = 3.
(slot) (port/nozzle)
RECOMPUTED SOURCE CONDITIONS FOR RISER GROUPS:
Properties of riser group with 1 ports/nozzles each:
U0 = 2.859 D0 = 0.406 A0 = 0.130 THETA = 22.50
FR0 = 95.53 FRD0 = 39.15 R = 99999.00
(slot) (riser group)

3. Mid-Tide before Slack

```
2222222222222222222222222222222222222222222222222222222222222222222222222
                    CORMIX MIXING ZONE EXPERT SYSTEM
        Subsystem CORMIX2:  Multiport Diffuser Discharges
                      CORMIX Version 5.0GT
                   HYDRO2 Version 5.0.0.0 March 2007
-------------------------------------------------------------------------
-------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:   Calvert Cliffs
 Design case:       Discharge System for CCNPP Unit 3 - Before Slack
 FILE NAME:         C:\...MIX 5.0\MyFiles\CCNPP Unit 3 Discharge (mrbs).prd
 Time stamp:        Wed May 16 14:39:41 2007
ENVIRONMENT PARAMETERS (metric units)
 Unbounded section
 HA    =     4.00  HD    =     3.05
 Tidal Simulation at TIME =    -1.575 h
 PERIOD=   12.60 h UAmax =     0.305 dUa/dt=     0.137 (m/s)/h
 UA    =     0.216 F     =     0.020 USTAR =0.1074E-01
 UW    =     1.000 UWSTAR=0.1071E-02
 Uniform density environment
 STRCND=  U        RHOAM = 1009.2200
DIFFUSER DISCHARGE PARAMETERS (metric units)
 Diffuser type:     DITYPE= unidirectional_parallel
 BANK  =  RIGHT     DISTB =    167.60  YB1   =    167.60  YB2   =    167.60
 LD    =     5.70  NOPEN =    3       SPAC  =     2.85
 D0    =     0.406 A0    =     0.130 H0    =     0.91  SUB0  =     2.14
 Nozzle/port arrangement:   unidirectional_without_fanning
 GAMMA =    180.00  THETA =     22.50  SIGMA =     90.00  BETA  =     90.00
 U0    =     2.859 Q0    =     1.112       =0.1112E+01
 RHO0  = 1007.8700  DRHO0 =0.1350E+01  GP0   =0.1312E-01
 C0    =0.6667E+01  CUNITS=  deg.C
 IPOLL =  3        KS    =0.7165E-05  KD    =0.0000E+00
FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
 q0    =0.1952E+00  m0    =0.5580E+00  j0    =0.2560E-02  SIGNJ0=     1.0
 Associated 2-d length scales (meters)
 lQ=B  =     0.068 lM    =     29.71  lm    =     11.96
 lmp   =  99999.00  lbp   =  99999.00  la    =  99999.00
FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
 Q0    =0.1112E+01  M0    =0.3180E+01  J0    =0.1459E-01
 Associated 3-d length scales (meters)
 LQ    =     0.36  LM    =     19.71  Lm    =     8.26  Lb    =     1.45
                                  Lmp   =  99999.00  Lbp   =  99999.00
 Tidal:           Tu    =  0.2975 h Lu    =    43.704 Lmin  =     5.847
NON-DIMENSIONAL PARAMETERS
 FR0   =     95.53  FRD0  =     39.15  R     =     13.24  PL    =     3.
 (slot)            (port/nozzle)
RECOMPUTED SOURCE CONDITIONS FOR RISER GROUPS:
 Properties of riser group with  1 ports/nozzles each:
 U0    =     2.859 D0    =     0.406 A0    =     0.130 THETA =    22.50
 FR0   =     95.53  FRD0  =     39.15  R     =     13.24
 (slot)            (riser group)
```

4. Mid-Tide after Slack

```
2222222222222222222222222222222222222222222222222222222222222222222222222222
                 CORMIX MIXING ZONE EXPERT SYSTEM
        Subsystem CORMIX2:  Multiport Diffuser Discharges
                  CORMIX Version 5.0GT
                 HYDRO2 Version 5.0.0.0 March 2007
---------------------------------------------------------------------------
---------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:   Calvert Cliffs
 Design case:       Discharge System for CCNPP Unit 3 - After Slack
 FILE NAME:         C:\...MIX 5.0\MyFiles\CCNPP Unit 3 Discharge (mras).prd
 Time stamp:        Wed May 16 14:38:26 2007
ENVIRONMENT PARAMETERS (metric units)
 Unbounded section
 HA    =      4.00  HD    =      3.05
 Tidal Simulation at TIME =      1.575 h
 PERIOD=    12.60 h UAmax =      0.305 dUa/dt=      0.137 (m/s)/h
 UA    =      0.216 F     =      0.020 USTAR =0.1074E-01
 UW    =      1.000 UWSTAR=0.1071E-02
 Uniform density environment
 STRCND=  U         RHOAM = 1009.2200
DIFFUSER DISCHARGE PARAMETERS (metric units)
 Diffuser type:     DITYPE= unidirectional_parallel
 BANK  =  RIGHT     DISTB =    167.60  YB1   =    167.60  YB2   =    167.60
 LD    =      5.70  NOPEN =    3       SPAC  =      2.85
 D0    =      0.406 A0    =      0.130 H0    =      0.91  SUB0  =      2.14
 Nozzle/port arrangement:   unidirectional_without_fanning
 GAMMA =    180.00  THETA =     22.50  SIGMA =     90.00  BETA  =     90.00
 U0    =      2.859 Q0    =      1.112       =0.1112E+01
 RHO0  = 1007.8700  DRHO0 =0.1350E+01  GP0   =0.1312E-01
 C0    =0.6667E+01  CUNITS=  deg.C
 IPOLL =  3         KS    =0.7165E-05  KD    =0.0000E+00
FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
 q0    =0.1952E+00  m0    =0.5580E+00  j0    =0.2560E-02  SIGNJ0=      1.0
 Associated 2-d length scales (meters)
 lQ=B  =      0.068 lM    =     29.71  lm    =     11.96
 lmp   =  99999.00  lbp   =  99999.00  la    =  99999.00
FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
 Q0    =0.1112E+01  M0    =0.3180E+01  J0    =0.1459E-01
 Associated 3-d length scales (meters)
 LQ    =      0.36  LM    =     19.71  Lm    =      8.26  Lb    =      1.45
                          Lmp   =  99999.00  Lbp   =  99999.00
 Tidal:             Tu    =  0.2975 h Lu    =     43.704 Lmin  =      5.847
NON-DIMENSIONAL PARAMETERS
 FR0   =     95.53  FRD0  =     39.15  R     =     13.24  PL    =      3.
 (slot)             (port/nozzle)
RECOMPUTED SOURCE CONDITIONS FOR RISER GROUPS:
 Properties of riser group with  1 ports/nozzles each:
 U0    =      2.859 D0    =      0.406 A0    =      0.130 THETA =     22.50
 FR0   =     95.53  FRD0  =     39.15  R     =     13.24
 (slot)             (riser group)
```

Appendix Five: Sensitivity Test - ΔT

A test was completed to determine the sensitivity of model results to different discharge temperatures (ΔTs). In all, sixteen different calculations were completed. For each calculation, the distance along the shoreline from the point of origin to the location where a dilution of about 5.1 was calculated was noted. The plume width at this location was also recorded.

As shown in Table 5-1, greater temperature differences (*i.e.*, ΔTs) generally produce larger plumes. The only exception to this rule applies to the slack tide scenario where the plume size is slightly larger for ΔTs less than 6.66 deg. C.

Table 5-1: ΔT Sensitivity Analysis Results
(distance from point of origin and plume top width, units are meters)

Flow Condition	**Delta T**			
	6.66 deg. C	**3.33 deg. C**	**1.66 deg. C**	**0.83 deg. C**
Ebb and Flow	197 x 42	188 x 32	176 x 25	160 x 20
Slack Tide	6 x 4	8 x 4	8 x 4	8 x 4
Mid-Tide before Slack	232 x 66	226 x 52	217 x 41	203 x 32
Mid-Tide after Slack	139 x 46	137 x 38	139 x 30	139 x 24

The results of this sensitivity test indicate that the size of the thermal plume envelope (ref. Figure 2) would be smaller, and that dilution factors would be greater if modeled ΔTs were reduced.

Appendix Six: CORMIX References

User's Manual

1. Jirka, G. H., Doneker, R.L., and S.W. Hinton, "User's Manual for CORMIX: A Hydro-Dynamic Mixing Zone Model and Decision Support System for Pollutant Discharges into Surface Waters", EPA#: 823/B-97-006.

General Description

2. R.L. Doneker and G.H. Jirka (1990), "Expert Systems for Hydrodynamic Mixing Zone Analysis of Conventional and Toxic Single Port Discharges (CORMIX1)", Technical Report EPA/600/3-90/012, U.S. EPA Environmental Research Laboratory, Athens, GA 1990.
3. R.L. Doneker and G.H. Jirka, "Expert Systems for Design and Mixing Zone Analysis of Aqueous Pollutant Discharges", Journal of Water Resources Planning and Management, ASCE, 117, No. 6, 679-697, 1991.
4. G.H. Jirka, R.L. Doneker and T.O. Barnwell, "CORMIX: A Comprehensive Expert System for Mixing Zone Analysis of Aqueous Pollutant Discharges", Water Science and Technology, 24, No. 6, 267-274, 1991.
5. G.H. Jirka, "Use of Mixing Zone Models in Estuarine Waste Load Allocations", Part IV of "Technical Support Document for Performing Waste Load Allocations, Book III:Estuaries", R.B. Ambrose and J.L. Martin, Eds., U.S. Environmental Protection Agency, Tech. Rep., Environmental Research Laboratory, Athens, GA, 1992.
6. R. L. Doneker and G.H. Jirka, "D-CORMIX Continuous Dredge Disposal Mixing Zone Water Quality Model Laboratory and Field Validation Study", OGI Technical Report, 1997.
7. Akar, P.J. and G.H. Jirka, "Buoyant Spreading Processes in Pollutant Transport and Mixing. Part I: Lateral Spreading in Strong Ambient Current", J. of Hydraulic Research, Vol. 32, pp. 815-831, 1994.
8. Doneker, R.L., and G.H. Jirka, Discussion of "Mixing in Inclined Dense Jets", Journal of Hydraulic Engineering, ASCE, Vol.125, No.3, March 1999.
9. Doneker, R.L., and G.H. Jirka, CORMIX-GI Systems for Mixing Zone Analysis of Brine Wastewater Disposal," Desalination, 139, 2001.
10. Doneker R.L., and G.H. Jirka, "Schematization in Regulatory Mixing Zone Analysis", Journal of Water Resources Planning and Management, ASCE, Vol 128, No.1, Jan./Feb. 2002.
11. G.H. Jirka and R.L. Doneker, Discussion of "'Field Observations of Ipanema Beach Outfall", Journal of Hydraulic Engineering, ASCE, Vol. 128, No. 2, February 2002.
12. R.L. Doneker, R.L. and G.H. Jirka, Discussion of "'Sensitivity Analysis and Comparative Performance of Outfalls with Single Buoyant Plumes", Journal of Environmental Engineering, ASCE, Vol. 128, No. 2, February 2003, in print.

Technical Scientific Background (CORMIX1):

13. R.L. Doneker and G.H. Jirka (1990), "Expert System for Hydrodynamic Mixing Zone Analysis of Conventional and Toxic Submerged Single Port Discharges (CORMIX1)", Technical Report EPA/600/3-90/012.
14. G.H. Jirka and R.L. Doneker, "Hydrodynamic Classification of Submerged Single Port Discharges", Journal of Hydraulic Engineering, ASCE, 117, No.9, 1095-1112, 1991.

Technical Scientific Background (CORMIX2):

15. P.J. Akar and G.H. Jirka, "CORMIX2: An Expert System for Hydrodynamic Mixing Zone Analysis of Conventional and Toxic Submerged Multiport Diffuser Discharges", Technical Report EPA/600/3-91/073, U.S. Environmental Research Laboratory, Athens, Georgia, 1991.
16. G.H. Jirka and P.J. Akar, "Hydrodynamic Classification of Submerged Multiport Diffusers Discharges", Journal of Hydraulic Engineering, ASCE, 117, No.9, 1113-1128, 1991.

Technical Scientific Background (CORMIX3):

17. G.R. Jones and G.H. Jirka, "CORMIX3: An Expert System for the Analysis and Prediction of Buoyant Surface Discharges", Tech. Rep., DeFrees Hydraulics Laboratory, Cornell University, 1991, (also to be published by U.S. EPA, Environmental Research Lab, Athens, Georgia, 1993).

Tidal Applications

18. 18. J.D. Nash, "Buoyant Discharges into Reversing Ambient Currents", MS Thesis, Defrees Hydraulics Laboratory, Cornell University, Ithaca, NY. 1995.

CorJet Near-Field Integral Model

19. G.H. Jirka, "Integral Model for Turbulent Buoyant Jets in Unbounded Stratified Flows Part 1: Single Round Jet", Environmental Fluid Mechanics, Vol. 4: 1-56. Kluwer Academic Publishers, 2004.
20. G.H. Jirka, "Integral Model for Turbulent Buoyant Jets in Unbounded Stratified Flows Part 2: Plane Jet Dynamics Resulting from Multiport Diffuser Jets", Environmental Fluid Mechanics, Vol. 6, Num. 1, Feb.2006, pp: 43 - 100, Springer.

D-CORMIX Model

21. Doneker, R. L., Nash J.D., and G. H. Jirka, "Mixing Zone Analysis of Sediment Density Currents", ASCE, Journal of Hydraulic Engineering, Vol. 103, No. 4, pp. 349-359, April, 2004.
22. Doneker, R. L. and G. H. Jirka, "D-CORMIX: A Decision Support System for Hydrodynamic Mixing zone Analysis of Continuous Dredge Disposal Sediment Plumes", Proc. Of the 25th Annual Conference on Water Resources Planning and Management, ASCE, June 1998.

Other CORMIX/Mixing Zone References

23. Jirka, G.H., R.L. Doneker, and T.O. Barnwell, "CORMIX: An Expert System for Mixing Zone Analysis," Proceeding of the WATERMATIX'91 Conference on Systems Analysis in Water Quality Management, Durham, New Hampshire, June 1991.
24. Doneker, R.L. and G.H.Jirka,"CORMIX1: Advantages of and Expert System for Mixing Zone Analysis of Conventional and Toxic Discharges", Proceedings of the Twentieth Mid-Atlantic Industrial Waste Conference, Hazardous Materials Control Research Institute, Silver Spring, Maryland, 1988.
25. Jirka, G.H. and R.L. Doneker, "Expert System for Mixing Zone Analysis of Aqueous Discharges (CORMIX1): Further Developments," Proceedings, National Conference on Hydraulic Engineering, ASCE, Colorado Springs, Colorado, 1998.
26. Doneker, R. L. and G. H. Jirka, "The CORMIX-GI system for Mixing Zone Prediction, Regulatory Analysis, and Outfall Design", Marine Waste Water Disposal 2000 Conference, Genova Italy, Nov./Dec. 2000.
27. Doneker, R. L. and G. H. Jirka, "CORMIX-GI Rule-based Systems for Mixing Zone Analysis in Virtual Reality", 3rd International Symposium on Environmental Hydraulics, Tempe, AZ, December 2001.
28. Doneker, R.L. and Wu, C. "Methodologies for CORMIX Mixing Zone Model Validation of Surface Thermal Discharges in Large Rivers", PSU-CEE Technical Report #03-09-01, prepared for John Dunn, USEPA Region 7, Contract No: 1K-3230-NAEX, 167 pp., Sept. 2003.
29. Doneker, R. L. "Systems Development for Environmental Impact Assessment of Concentrate Disposal: CorVue and CorSpy Interactive Visualization Tools for CORMIX Mixing Zone Analysis", PSU-CEE Technical Report #03-04-01 USBR Agreement No. 01-FC-81-0785, 27 pp., July 2003. Also available as Report #98 at http://www.usbr.gov/pmts/water/reports.html

Appendix Seven: Selected *FLOW-3D*® References

User's Manual

1. Flow Science (2007), "FLOW-3D User's Manual Version 9.0," Flow Science, Santa Fe, NM.

General Description and Theory

2. C.W.Hirt and J.M.Sicilian, "*A Porosity Technique for the Definition of Obstacles in Rectangular Cell Meshes*," Proc. Fourth International Conf. Ship Hydro., National Academy of Science, Washington, DC, September 1985.
3. C.W.Hirt and B.D.Nichols, "*Volume of Fluid (VOF) Method for the Dynamics of Free Boundaries*," J. Comp. Phys., **39**, 201, 1981.
4. B.D.Nichols and C.W.Hirt, "*Numerical Simulation of BWR Vent Clearing Hydrodynamics*," Nuc. Sci. Eng., **73**, 196, 1980.
5. C.W.Hirt, "*Simplified Solution Algorithms for Fluid Flow Problems*," Proc. Numerical Methods for Partial Differential Equations Seminar, University of Wisconsin, Academic Press, 1978.
6. C.L.Bronisz and C.W.Hirt, "*Flows with Density Stratification: An Illustration of Higher Order Scalar Transport*," Flow Science Technical Note #32, November 1991, (FSI-91-TN32).
7. J.R.Wertz, *et al*, Spacecraft Attitude Determination and Control, Kluwer Academic Publishers, 1978.
8. J.M.Sicilian, *"Evaluation of Space Vehicle Dynamics Including Fluid Slosh and Applied Forces*," Flow Science technical report, August 1992 (FSI-92-47-01).
9. J.M.Sicilian, " ***FLOW-3D***® *Multiple Tank Model*," Flow Science report, 1995 (FSI-95-47-01).
10. C.W. Hirt and J.E. Richardson, "*The Modeling of Shallow Flows*," Technical Note #48, March 1999, (FSI-99-00-TN48R).