REEDY POINT SOUTH

WATER QUALITY MODELING

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SUMMARY

The U.S. Army Corps of Engineers (USACE), Philadelphia District is planning to deepen the Delaware Estuary navigational channel from its current federally authorized depth of 40 feet MLW to 45 feet MLW. Current plans call for the dredging to start late in the year 2001 or early 2002. The Reedy Point South Confined Disposal Facility (CDF), managed by the Philadelphia District, is proposed to be used for the placement of dredged material from the deepening project. The Reedy Point South upland CDF is located on the southern part of the mouth of the Chesapeake and Delaware (C&D) Canal on the shore of the Delaware River. Water quality for this project was modeled to determine the potential levels of exposure for aquatic organisms to contaminants mobilized into the water column by dredging activities. Mobilization of contaminants into the water column can occur at two points of exposure, the point of dredging and the point of weir discharge from an upland CDF. The equilibrium partitioning model was used to predict levels of contaminants that will become dissolved near the point of dredging and in the weir discharge from the CDF. The CORMIX model was used to predict dissipation of contaminants discharged from the weir.

The results of the equilibrium partitioning model indicate that four contaminants, copper, lead, mercury, and nickel may exceed water quality criteria near the cutterhead and weir. A June 2001 study of the Oldmans CDF (Versar 2001) indicated that the equilibrium-partitioning model may overestimate dissolved metals concentrations. In spite of the conservative nature of the model, only copper would exceed acute water quality criteria, which range from 2.4 μg/l for NJDEP to 5.3 μg/l for DRBC. None of the other contaminants would exceed acute water quality criteria near the cutterhead or weir. Once mixing was considered for the weir discharge, it was determined that at flood and ebb tides, all water quality criteria would be met within 2 meters of the weir. While water quality during slack tide may exceed criteria to a distance of 44 meters, when the tide begins to flood or ebb, the slack tide plume will dissipate rapidly.

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1.0 INTRODUCTION

The U.S. Army Corps of Engineers (USACE), Philadelphia District is planning to deepen the Delaware Estuary navigational channel from its current federally authorized depth of 40 feet MLW to 45 feet MLW. Current plans call for the dredging to start late in the year 2001 or early 2002. The Reedy Point South Confined Disposal Facility (CDF), managed by the Philadelphia District, is proposed to be used for the placement of dredged material from the deepening project. The Reedy Point South upland CDF is located on the southern part of the mouth of the Chesapeake and Delaware (C&D) Canal on the shore of the Delaware River.

Water quality for this project was modeled to determine the potential levels of exposure for aquatic organisms to contaminants mobilized into the water column by dredging activities. Mobilization of contaminants into the water column can occur at two points of exposure, the point of dredging and the point of weir discharge from an upland CDF. To describe both scenarios, two different models were utilized. The equilibrium partitioning model is a relatively simple model that is used to predict levels of contaminants present in sediments that may become dissolved in water. The Cornell Mixing Zone Model (CORMIX) is used to predict how contaminants dissolved in the water column will behave as mixing and tidal action disperses them from their source. Therefore, the equilibrium partitioning model was used to predict levels of contaminants that may become dissolved at the point of dredging and in the weir discharge from the CDF. The CORMIX model was used to predict dissipation of contaminants discharged from the weir.

Contaminant concentrations expected from the weir were estimated at different distances from the discharge pipes. Probable mixing of discharge plumes from these sites were described and compared with acute and chronic water quality criteria. The study design used a first-order screening model (CORMIX), along with the most restrictive contaminant dilution criteria applicable to this area, to identify the probable mixing zones from the Delaware River dredging project.

2.0 METHODS

2.1 CHEMICAL ANALYTICAL DATA

Bulk sediment concentrations from the area proposed for dredging were collected in 1991 and 1994. Eight samples were collected by the USACE from the Reedy Island range of the main Delaware River navigation channel scheduled to be dredged and placed in the Reedy Point South CDF (Figure 2-1). These sediment concentrations are presented in Table 2-1.

Table 2-1. Bulk sediment data from several sites in the Delaware River representing what would be placed in the Reedy Point South CDF (units in mg/kg)

Contaminant	Location							
	DRV13-0.0	DRV13-3.5	DRV14-0.0	DRV14-7.9	DRV-13	S-1-0.0	S-1-8.75	S-1-14.67
Arsenic	1.56	1.96	1.29	4.53	2.77	13	17.5	2.8
Cadmium	1.1	2.21	0.955	0.809	1	0.35	0.075	0.028
Chromium	ND	ND	ND	ND	10.5	55.6	46.3	10.8
Copper	2.35	2.33	3.87	2.89	9	13.7	11.9	5.4
Lead	7.29	12.1	5.38	9.37	12.5	13.8	10.6	3.5
Mercury	0.056	0.055	0.056	0.055	0.009	0.095	0.145	0.055
Nickel	4.34	4.26	5.11	4.73	15	29.2	30.6	7.2
Selenium	31	53.2	19.3	18.3	0.125	0.95	1.45	0.28
Silver	0.281	0.273	0.279	0.273	0.25	0.095	0.145	0.055
Zinc	14.1	15.4	12.9	29.5	43	79.2	73	17.2

2.2 DESCRIPTION OF THE DISPOSAL SITE

The Reedy Point South CDF is located on the Delaware shore of the Delaware River, approximately one half of a mile south of the outlet of the C&D Canal into the Delaware River. Water is discharged from the site directly into the Delaware River through two 36-inch diameter pipes that terminate close to the shoreline (Figs. 2-2 and 2-3). The area of the discharge is a shallow tidal flat that extends several hundred feet into the river.

NOAA maps (NOAA 1998 and NOAA 1983) were used to calculate the average depth of the Delaware River from the point of discharge across the river, and the depth of the river near the point of discharge. The location of the outfall on the map was determined by finding the distance between the outfall and a jetty on an aerial photograph, then applying that distance to the NOAA map.

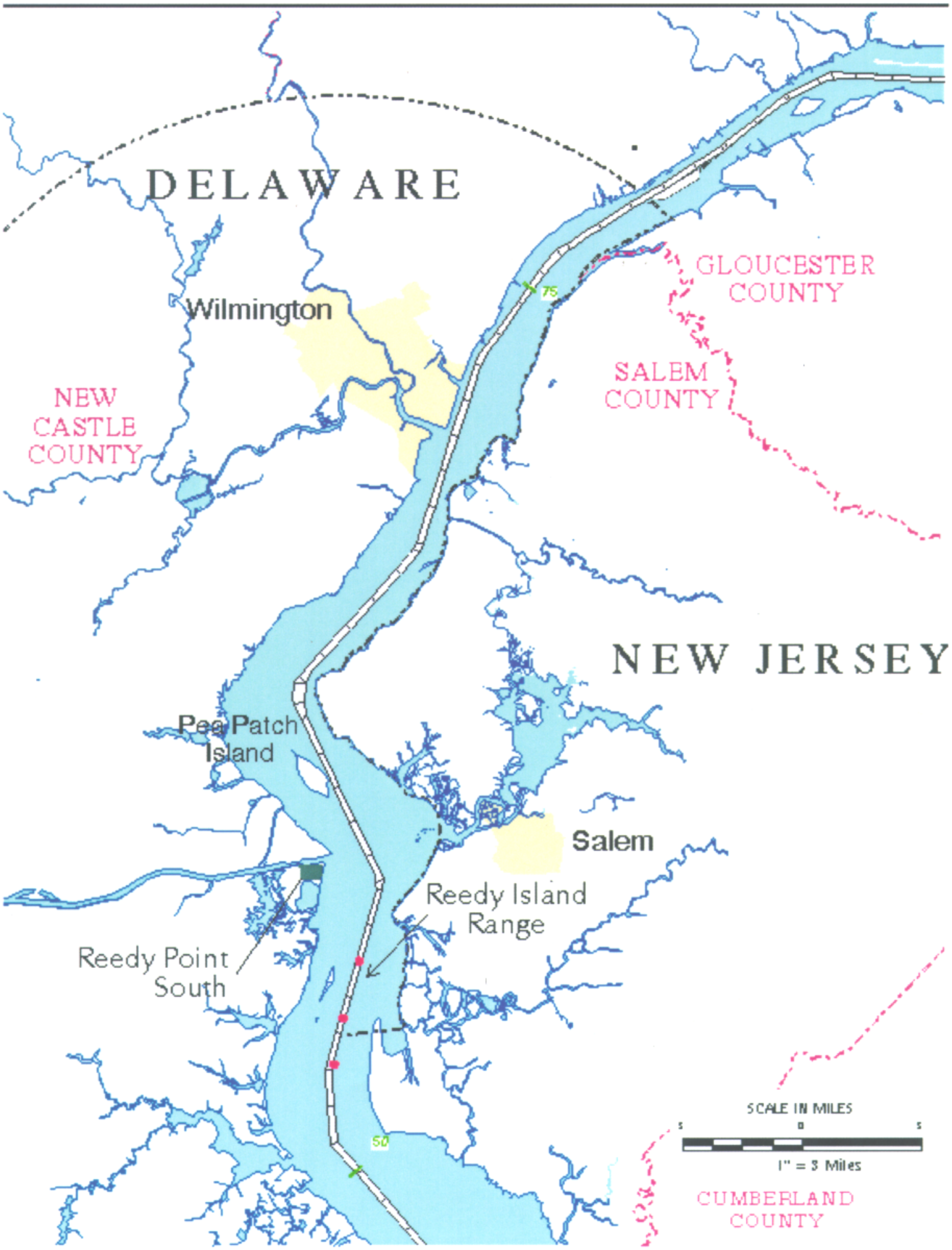

Figure 2-1. Sediment sampling locations in the Reedy Island range of the Delaware River navigation channel

Figure 2-2. Reedy Point South CDF discharge channel to Delaware River; outlet pipes visible in the lower portion of the picture

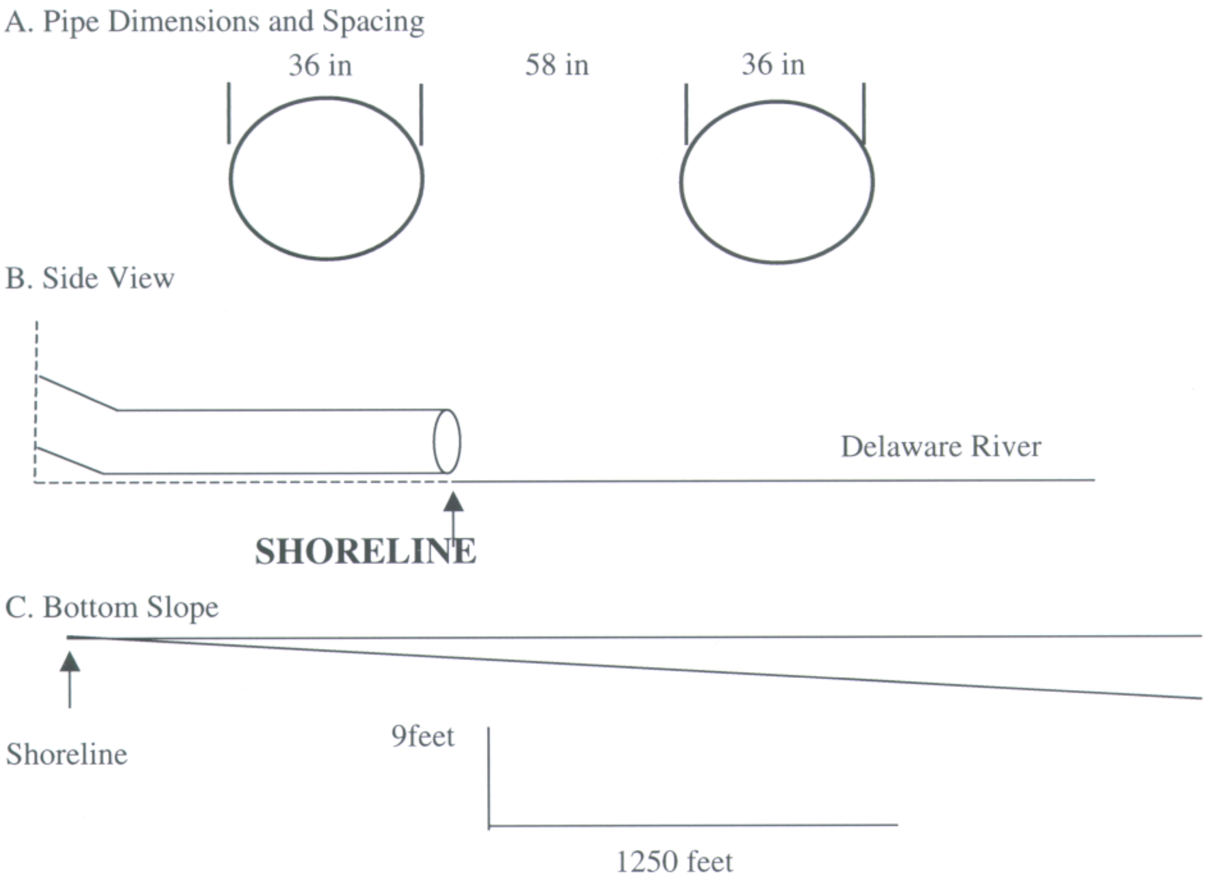

Figure 2-3. Reedy Point South CDF outfall configuration

The discharge pipes are located near the center of the eastern side of the Delaware River, 823 meters south of the mouth of the C&D Canal, and are oriented perpendicular to the shoreline. During a dredged material operation, each pipe is assumed to discharge at a rate of 15 cfs (Versar 1996a). The area of the Reedy Point South facility is 142 acres (USACE 1999). The depth of new material placed in the CDF will most likely be between three to six feet high (from base to the rim). If the height were three feet, the volume of the facility would be 426 acre-feet (18,557,000 ft^3, or 138,813,000 gallons). If the entire disposal area were filled with a sediment and water mixture, it could maintain this discharge (30 cfs) for about 5 days (129 hours), assuming 75% of the material placed in the CDF is water, 25% is sediment, and most of the sediment is retained in the CDF. If the height were six feet, the volume of the facility would be 852 acre-feet (37,113,000 ft^3, or 277,625,000 gallons). If the entire disposal area were filled, it could maintain this discharge (30 cfs) for about 11 days (258 hours). In an actual discharge event, the total amount of water that may be pumped into a CDF depends on the sediment/water ratio and the dredging schedule. The outflow rate can also be varied (using a weir) to control sediment discharge.

2.3 POINTS OF EXPOSURE

During dredging, there are several possible pathways for exposure of contaminants in the dredged sediments to aquatic life. The first route of possible exposure occurs when the dredge cutterhead disturbs the sediment in the area being dredged. Sediment resuspended into the water column results in dissolution of substances previously sorbed to the sediment. Unlike particulate substances bound to sediment, dissolved substances are available for potential uptake by aquatic organisms. Another possible exposure pathway during dredging is through the discharge of water from the CDF. This section of the report describes how modeling is conducted to determine the levels and extent of contaminant mobilization from the points of exposure. These models are used to evaluate how quickly (spatially and temporally) contaminants will be diluted by physical mixing processes to acceptable levels for protection of aquatic life.

2.3.1 Contaminant Mobilization at the Point of Dredging

Equilibrium partitioning theory is a simple mathematical method of estimating the proportion a chemical sorbed to sediment to the chemical dissolved in water. With a known concentration of chemical per unit weight of sediment/soil, and a known weight of total sediment/soil, this method can be used to determine the concentration of the chemical in the water. This model was first proposed by Samuel W. Karickhoff (Karickhoff et al. 1979; Karickhoff 1981). Assuming linear relationships between sediment concentration, fraction of organic carbon, and the octanol/water partition coefficient, concentrations of chemicals in sediment can be multiplied by a factor to yield a concentration of that chemical in the water column. The model was later refined by R. V. Thomann and J. A. Mueller in 1987. Their model states that the partition coefficient is a function of not only the fraction of organic carbon and the octanol/ water partition coefficient, but a function of TSS as well. Their model goes farther than Karickhoff's by assuming that for all metals, eighty percent of the sorbed concentration will dissolve in the water column.

DNREC (1998) describes a procedure to calculate the dissolved contaminant concentration in the water column from the sorbed contaminant concentration in the sediment. Results from bulk sediment analysis are presented with the units mass of analyte per mass of sediment, Cs. The TSS values obtained from McLellan, et. al. (1989), are assumed to be the mass of sediment in the water column. The various TSS concentrations, in units of mass per volume, are multiplied by the bulk sediment concentrations to yield the sorbed concentrations in the water column, Cp,w, in units of mass of sorbed chemical per volume.

$$C_{p,w} = C_s * TSS \qquad (1)$$

Once the sorbed pollutant concentration in the water column has been calculated, the amount of pollutant that leaves the particulate phase and becomes dissolved in the water column may be calculated. The dissolved contaminants may become mobilized and exceed water quality standards. Equilibrium partitioning theory assumes that the distribution of contaminants between particulate and dissolved phases occurs rapidly and continuously. The fraction of organic compounds that dissolve (fd) in the water column is a function of TSS, the fraction of organic carbon, foc, in the sediment, and the octanol/water partition coefficient, Kow, according to Thomann and Mueller (1989). The fraction of the total amount of chemical in the water column that stays sorbed (fp) is defined by:

$$fp = 1 - fd \qquad (2)$$

As a conservative approach for metals, fd and fp remain constant (Thomann and Mueller 1987). Eighty percent of the metal is assumed to dissolve and twenty percent is assumed to remain sorbed.

Once the fractions are calculated, the total chemical concentrations in the water column, CT,w, (sorbed plus dissolved) and the dissolved chemical concentrations in the water column, Cd,w, are estimated.

$$CT,w = Cp,w / fp \qquad (3)$$

$$Cd,w = CT,w - Cp,w \qquad (4)$$

2.3.2 Contaminant Mobilization at the Point of Weir Discharge

The Cornell Mixing Zone Expert System (CORMIX) is a software package with a series of modules for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies (Jirka et al. 1996). It was initially developed under cooperative funding agreements for the Environmental Protection Agency and is the recommended analysis tool in key guidance documents (USEPA 1991a, 1991b) on the permitting of industrial discharges to receiving waters. Although the system's major emphasis is on predicting the geometry and dilution characteristics of the initial mixing zone so that compliance with acute and chronic regulatory constraints may be evaluated, the system also predicts the behavior of the discharge plume at larger distances. The EPA's CORMIX distribution page is http://www.epa.gov/ceampubl/softwdos.htm. The CORMIX-GI homepage is http://steens.ese.ogi.edu/; this is the most usable version of the model and has a Windows interface for interacting with the model.

Among the factors that led to developing CORMIX were:

- the considerable complexity of mixing processes in the aquatic environment;
- the failure of previously existing models to predict often routine discharge situations adequately;
- additional EPA guidelines for the permitting of toxic aqueous discharges;
- the emergence of expert systems as a computerized technique for making the expert's knowledge and experience in dealing with complex engineering problems accessible to the uninitiated user.

CORMIX is intended as a first-order screening/design model. It does not carry out detailed hydrodynamic calculations using the exact geometry of the discharge location, nor does it explicitly handle dynamic ambient currents (i.e., tides). It uses a simplified representation of the physical conditions at the discharge location to approximate the fundamental behavior of the plume. The general nature of the plume simulation is described in Subsection 2.3.2.1, and the modifications that can be made to adapt the results to tidal situations are discussed in Section 2.3.2.2.

The dilution ratio is the physical basis for defining mixing zones. In order to define mixing zone boundaries, the pollutant concentrations in the discharge water and ambient river water must be used to determine the dilution ratio required to meet the regulatory criterion for that pollutant.

The dilution factor reported by CORMIX is defined as:

$$\frac{1}{\text{[concentration as a fraction of concentration at pipe]}}$$

Thus, a dilution ratio of 2 corresponds to a concentration half as large as initially discharged, assuming that the ambient concentration is zero.

Dissolved contaminant concentrations in the weir discharge were conservatively assumed to be equal to dissolved contaminant concentrations predicted by the equilibrium partitioning model at the cutterhead. This assumption is considered to be conservative because this is the maximum dissolved contaminant concentration that will occur, and does not account for processes that may reduce the aqueous contaminant load within the CDF. The CORMIX model was used to evaluate how the effluent diluted in the ambient water under a variety of conditions likely to occur in the area of the discharge. The concentration of metals was calculated from the CORMIX output of dilution ratios and the predicted effluent concentrations. In some of the tables and on the maps, concentration values are reported in percent of original concentration. To convert dilution ratio to percent of original concentration, the inverse of the dilution ratio is multiplied by one hundred. Although average metal concentrations predicted by the simplified equilibrium method were used to represent the CDF effluent values, other effluent values could also be used for comparison to water quality criteria.

2.3.2.1 Basic Plume Behavior

The outflow from a discharge port will, in general, be different from the receiving water in several physical characteristics, including velocity, temperature, and contaminant concentration. These characteristics, along with the physical configuration of the receiving channel and its flow characteristics, determine how rapidly mixing occurs, and where mixing occurs in the receiving water body.

Near the discharge port, the plume tends to behave as a coherent jet dominated by its initial momentum and buoyancy. Eventually, these are dissipated by interaction with the surrounding medium, and the plume becomes a diffuse mass carried along by the ambient current. Mixing initially occurs by turbulent flows at the boundaries of the plume, and later primarily by pure diffusion processes. Depending on the geometry of the port and of the receiving water body, the plume may be freestanding in open water, become bank attached, bottom attached, or both, or fill a bounded area bank to bank.

To make predictions of an effluent discharge's dilution and plume trajectory, CORMIX typically breaks the prediction problem into several stages. In each stage, a steady-state solution to the simplified flow patterns that characterize that stage is calculated. These solutions are combined to provide a complete analysis from the outflow point, all the way to the distance limit set by the user. The expert system attempts to match conditions at the boundaries between stages, and informs the user when these matches cannot be made successfully (i.e., when the approximations that define the stages break down).

2.3.2.2 Adapting CORMIX to Tidal Situations

For a tidal situation, as encountered in the Delaware River, the dynamic change in ambient velocity further complicates the behavior. For an outflow entering from the shoreline perpendicularly to the river flow, the river current will push the plume either upstream or downstream, depending on the phase of the tidal cycle. Over time, the plume behavior can be visualized as wagging back and forth, from the bank to the left of the discharge point to the bank to the right of the discharge point.

The dilution of contaminants under these dynamic conditions is not simple to model. Multiple CORMIX predictions, at different times in the tidal cycle, are often required to approximate the plume behavior. In general, discharges into a tidally reversing cross-current can be split, on physical grounds, into three temporal regimes:

- Before Reversal - The discharge is advected downstream at the instantaneous ambient velocity, producing a quasi-steady-state plume.

- Around Slack Tide - A pool of discharge water forms near the outfall site with a magnitude proportional to the time during which the ambient can be considered stagnant. This highly time-dependent phenomenon cannot be predicted using steady-state models.
- After Reversal - Water discharged prior to reversal returns to the pool around the discharge point and may be dynamically entrained into the discharge jet. Pollutant buildup far from the discharge may also result from this return of partially diluted water. Steady-state models must be modified to consider effects of this re-entrainment.

If rapid dilution does not occur in a discharge plume, due to the magnitude of the discharge or the physical characteristics of the discharge location, the pollutant levels may continue to build up over several tidal cycles, until a balance is reached between the input rate and the capability of the receiving water to dilute the effluent at the extended boundaries of the plume. In all cases, the critical (minimum) dilution occurs near, and during, the low velocity period immediately following slack tide. It may therefore be necessary to conduct multiple simulations in this time period to estimate mixing zone boundaries.

It should be noted that two formal attempts have been made to adapt CORMIX to tidal situations. The Delaware River Basin Commission (DRBC) undertook an effort to automate version 2.10 of CORMIX for mixing zone evaluations in tidal waters, specifically the Delaware River Estuary, and to provide post-processing capabilities (DRBC 1995). The fundamental approach was simply to run multiple CORMIX simulations at even time intervals throughout a tidal cycle, with the preprocessing program adjusting ambient water heights and velocity parameters automatically. In this method, the normal CORMIX prediction files are produced, and it is incumbent upon the user to interpret these and apply them on a case-by-case basis to understand the plume dynamics. In some cases, the DRBC tidal version can be a useful screening tool, but for shallow surface discharges it forces assumptions about changes in water depth in the discharge channel that may not be realistic.

In a separate effort, the Maryland Department of Natural Resources (MDDNR) funded the CORMIX team at Cornell to develop and incorporate a module to deal with tidal situations, particularly with respect to heated discharges of power plant cooling water. This work, which is incorporated in CORMIX version 3.2 and higher, actually tried to develop a model of plume behavior during tidal current reversal. Based on laboratory experiments, a set of pseudo-steady-state variables was defined that allow the standard CORMIX solutions to be modified for some tidal effects. These modifications can improve the plume boundary predictions somewhat in the interval near slack tide, but they do not account for contaminant build-up and re-entrainment over multiple tidal cycles.

In addition to the items mentioned above, the user must overcome several inherent limitations to applying CORMIX in tidal simulations. As noted in the DRBC analysis (DRBC 1995), these include the following:

- Problems with simulating effluent plumes during near-slack (i.e., low ambient current) conditions. These occur partly because steady-state solutions take much longer to be realized than the typical duration of the low current conditions and there is no way to modify the CORMIX input to account for the developing high-concentration pool near the discharge point.

- Problems with simulating effluent plumes from outfalls located in shallow waters. CORMIX uses average depths and a rectangular water body geometry, which can be critically unrealistic in these situations.
- Inability to simulate effluent plumes from surface discharge pipes over a full range of tidal conditions. The flow solutions used by CORMIX depend on assumption that the discharge is from a well-defined channel of specified depth or a fully submerged pipe. These assumptions may not be satisfied throughout the tidal cycle, causing CORMIX to fail.

Shoreline geometries and current velocities may create multiple cycle build-up potential. Therefore, we concluded that neither modified approach was completely satisfactory. We adopted a somewhat different, case-specific approach, based on identifying river current speeds that characterized significantly different phases of the plume behavior (e.g., flood tide vs. ebb tide vs. slack tide). Within these phases, it was possible to analyze the average or characteristic plume and describe the limits (if not the dynamics) of the dilutions achieved. The exact approximations that were made will be described in more detail below.

2.3.2.3 Baseline Model

CORMIX uses a simplified representation of the complex physical conditions that may be present at a discharge location to determine the basic flow characteristics. This representation is based on input parameters about the river width, depth, and flow characteristics; the discharge port configuration; and the nature and flow rate of the discharged material. Table 2-2 indicates the modeling parameters that were derived for the Reedy Point South site from the data supplied by the USACE and other relevant sources. The baseline case includes a set of "most reasonable" values. There were three baseline cases created: flood tide, ebb tide, and slack tide. Since dredging activities typically occur during winter, summer temperatures were not explicitly simulated. However, the initial behavior of a discharge plume is affected primarily by the density difference between the discharge and ambient water. Thus, the simulations performed are equivalent to a summer temperature difference about 0.4°C between the discharge and receiving water. To evaluate the sensitivity of the baseline results to variations that may be experienced under actual conditions, a range of plausible values (minimum and maximum) was estimated. Sensitivity analysis was performed on the two most environmentally conservative of the baseline cases (i.e., plumes with the highest concentrations).

2.3.2.4 Behavior Of The Plume

At Reedy Point South, the disposal area discharges into the waters of a shallow tidal flat. During some parts of the tidal cycle, the pipes may be above the waterline or only partially submerged. When the pipes are above the waterline, the system cannot be exactly simulated by

CORMIX. However, using the CORMIX3 module and assuming a rectangular channel flush with the shoreline at the surface, a reasonable representation can be made.

Table 2-2. Model parameters for Reedy Point South CDF discharge CORMIX simulations, including minimum and maximum values used for sensitivity analysis

Parameter	Assumptions	Baseline Value	Minimum	Maximum
Bounded / unbounded	Since plume is bank attached, width is not a factor.	unbounded	bounded	—
Channel width	NOAA navigational map[1]	2.2 nautical miles, or 4074.4 m	2332 m	—
Channel appearance	This option is not allowed if the width is unbounded. 1 = uniform channel.	—	1	—
Average water body depth	This is the average depth of the river from the point of discharge to a shallow point in the river about 700 meters out[2]	1.5 m	0.75 m	2.25 m
Depth at discharge	This value must be with 30% of average depth, minimum value allowed was used.	1.1 m	0.55 m	1.60 m
Tidal period	This was based on the cycle of the moon	12.4 hours	12.4 hours	12.4 hours
Time after / before slack	This is the maximum value allowed by CORMIX; values less than these have shorter simulation times.	3.1 hours	3.1 hours	3.1 hours
Tidal velocity at time of simulation (flood/ebb)	This value was based on 50% of the maximum velocity value for Reedy Island.[3] Sensitivities are half the velocity then quarter velocity.	0.65 m/s	0.1625 m/s	0.325 m/s
Maximum tidal velocity (flood/ebb)	This value was based on the velocity value for Reedy Island.[3] Sensitivities are half the velocity then quarter velocity.	1.3 m/s	0.325 m/s	0.65 m/s
Tidal velocity at time of simulation (slack)	CORMIX requires a non-zero value. Sensitivity is doubled.	0.01 m/s	—	0.02 m/s
Maximum tidal velocity (slack)	CORMIX requires a difference between maximum velocity and velocity at the time of simulation. Value doubled for sensitivity.	0.02 m/s	—	0.04 m/s
Manning's n	Bottom roughness is a typical estuarine Manning's N value.[4] Sensitivities are half and double.	0.02	0.01	0.04
Wind speed	This was assumed to be a non-factor. Sensitivity value represents a windy day.	0 m/s	—	4 m/s - 9 mph
Ambient temperature and salinity	Temperature values are estimates from probable temperatures during these seasons. Salinity values are estimates based on Delaware River measurements in the vicinity of the C&D Canal. Temperature sensitivities are a quarter and double the baseline temperature.	2°C (35.6°F) @ 2.5 ppt	0.5°C (32.9°F) @ 2.5 ppt	4°C (39.2°F) @ 2.5 ppt

Table 2-2 (continued).				
Parameter	**Assumptions**	**Baseline Value**	**Minimum**	**Maximum**
Ambient density	Density is computed from the given temperature and salinity.[5]	1001.97 kg/m3	1001.91 kg/m3	1001.98 kg/m3
Location of discharge	Discharge is on the west side of the river, during ebb and slack tide, river is flowing south, and during flood tide the river is flowing north. Direction is based on an observer facing downstream.	left(flood) right(ebb/slack)	—	—
Configuration	During a visit the outlet was about several feet from the river, CORMIX cannot model this however, so a flush configuration was assumed.	flush	flush	flush
Horizontal angle	The pipes are directly perpendicular to the river. Sensitivity values are ± 20°.	90°	70°	110°
Depth at discharge	This value must be greater than or equal to depth of discharge, minimum value was used.	0.398 m	0.71 m	—
Width of discharge	The baseline case uses the width of the two pipes plus the space between them. Sensitivity values is the width of the two pipes only.	3.302 m	1.83 m	—
Depth of discharge	This value was obtain by dividing the area of the pipe outlets by the width used above.	0.398 m	0.71 m	—
Bottom slope	Value obtained from NOAA map.[2] Sensitivity values are ± 50% of baseline.	0.73%	0.365%	1.1%
Flow rate	Baseline value was assumed from previous work and assumed to be the maximum probable flowrate.[6] Sensitivities values are incremental decreases.	15 pipe/pipe, channel flowrate 0.85 m^3/s	5 pipe/pipe, channel flowrate 0.283 m^3/s	10 pipe/pipe, channel flowrate 0.566 m^3/s
Temperature and salinity of discharge	Temperature values estimated from probable temperatures during these seasons. Salinity values assumed to be equal to ambient salinity.	0°C (32°F) @ 2.5 ppt	0°C @ 2.5 ppt	0°C @ 2.5 ppt
Density of discharge	Density is computed from the given temperature and salinity.[5]	1001.88 kg/m^3	1001.88 kg/m^3	1001.88 kg/m^3

[1] (NOAA 1998)
[2] (NOAA 1983)
[3] (Versar 1992)
[4] (Jones and Jirka 1991)
[5] (Millero and Poisson 1981)
[6] (Versar 1996)

3.0 RESULTS

Dissolved concentrations of various constituents in the water column near the cutterhead or weir discharge from a CDF were compared with applicable water quality criteria. Values exceeding criteria are indicated in the results tables.

3.1 POINT OF DREDGING RESULTS

Predicted dissolved concentrations of contaminants in the vicinity of the dredge cutterhead shown in Table 3-1 assume that TSS levels are 250 mg/l within an allowable 200-foot mixing zone around the point of dredging. Results of the comparison of predicted dissolved contaminant concentrations from the equilibrium partitioning model and regional regulatory criteria indicate that the some inorganics may exceed water quality criteria in the vicinity of the cutterhead (Table 3-2). Copper, lead, mercury, and nickel each may exceed at least two of the marine water quality criteria. For copper, which may exceed all applicable criteria, the New Jersey Department of Environmental Protection (NJDEP) chronic and acute criteria are the lowest regulatory criteria (both 2.4 µg/l) and the DRBC acute criterion of 5.3 µg/L is the highest. Lead may exceed the DRBC and Delaware Department of Natural Resources and Environmental Control (DNREC) chronic criterion, as could mercury (for which the DRBC and DNREC chronic criteria are equal). Nickel may exceed all three agencies' chronic criteria of 8.2 and 8.3 µg/L.

These results are very conservative. A Fall 2000 dredge monitoring study (Versar, 2001) found that the highest TSS concentration was 68 mg/l among all surface and mid-water column samples collected within 200 feet downstream of a working dredge. At this TSS concentration, the conservative equilibrium partitioning method would predict that water quality criteria would be met for all metals tested.

3.2 POINT OF WEIR DISCHARGE RESULTS

All of the simulations described below used the CORMIX3 module of CORMIX version 3.2, as implemented in CORMIX-GI version 4.01b. The CORMIX3 module is appropriate to use with buoyant surface discharges that result when an effluent enters a larger water body laterally, through a canal, channel, or near-surface pipe. It is limited to positively or neutrally buoyant effluents. When interpreting the output of this module, the x-direction is parallel to the shoreline, which is assumed to be parallel with the direction of the ambient current. The y-direction is across the body of water, perpendicular to the ambient current. The origin is the point of discharge.

Figures 3-1 and 3-2 show the flood, ebb, and slack tide results, projected onto a map and showing the plume dilution relative to the shoreline and discharge. The maps also show the amount of time it takes the plume to reach 25 meters (Fig. 3-1), the maximum distance that could be accurately simulated from the point of discharge (POD), and the dilution of plume along its

Table 3-1. Predicted particulate and dissolved metal concentrations from likely TSS levels.

Contaminant	Average Measured Sediment Concentration, Cs (mg/kg)	Assumed TSS (mg/L)	K, for Metals (L/kg)	fd, fraction of dissolved metal	fp, fraction of sorbed metal	Sorbed metal concentration in the water column, Cp,w (mg/L)	Total metal concentration in the water column, Ct,w (mg/L)	Dissolved metal concentration in the water column, Cd,w (mg/L)
Arsenic	5.68	250.00	1000.00	0.80	0.20	0.0014	0.0071	0.0056763
Cadmium	0.82	250.00	1000.00	0.80	0.20	0.0002	0.0010	0.0008159
Chromium	30.80	250.00	1000.00	0.80	0.20	0.0077	0.0385	0.0308000
Copper	6.43	250.00	1000.00	0.80	0.20	0.0016	0.0080	0.0064300
Lead	9.32	250.00	1000.00	0.80	0.20	0.0023	0.0116	0.0093175
Mercury	0.07	250.00	1000.00	0.80	0.20	0.0000	0.0001	0.0000658
Nickel	12.56	250.00	1000.00	0.80	0.20	0.0031	0.0157	0.0125550
Selenium	15.58	250.00	1000.00	0.80	0.20	0.0039	0.0195	0.0155756
Silver	0.21	250.00	1000.00	0.80	0.20	0.0001	0.0003	0.0002064
Zinc	35.54	250.00	1000.00	0.80	0.20	0.0089	0.0444	0.0355375

Table 3-2. Results of equilibrium partitioning theory calculation of dissolved contaminant concentrations near the cutterhead (all units in µg/L).

Contaminant	Marine Water Quality Criteria						Predicted concentration near cutterhead
	NJDEP		DRBC		DNREC		
	Chronic	Acute	Chronic	Acute	Chronic	Acute	
Arsenic	NL	NL	36	69	36	69	5.68
Cadmium	NL	NL	9.3	43	9.3	43	0.82
Chromium	NL	NL	50	1100	50	1100	30.80
Copper	2.4	2.4	3.4	5.3	NL	2.9	**6.43** [abcdf]
Lead	NL	NL	8.5	220	5.6	140	**9.32** [ce]
Mercury	NL	NL	0.025	2.1	0.025	2.1	**0.066** [ce]
Nickel	8.2	74	8.3	75	8.3	75	**12.555** [ace]
Selenium	NL	NL	71	300	71	300	15.58
Zinc	81	90	86	95	86	95	35.54

NL – No criterion listed.

a - Concentration exceeds NJDEP Chronic Marine Water Quality Criteria.
b - Concentration exceeds NJDEP Acute Marine Water Quality Criteria.
c - Concentration exceeds DRBC Chronic Marine Water Quality Criteria.
d - Concentration exceeds DRBC Acute Marine Water Quality Criteria.
e - Concentration exceeds DNREC Chronic Marine Water Quality Criteria.
f - Concentration exceeds DNREC Acute Marine Water Quality Criteria.

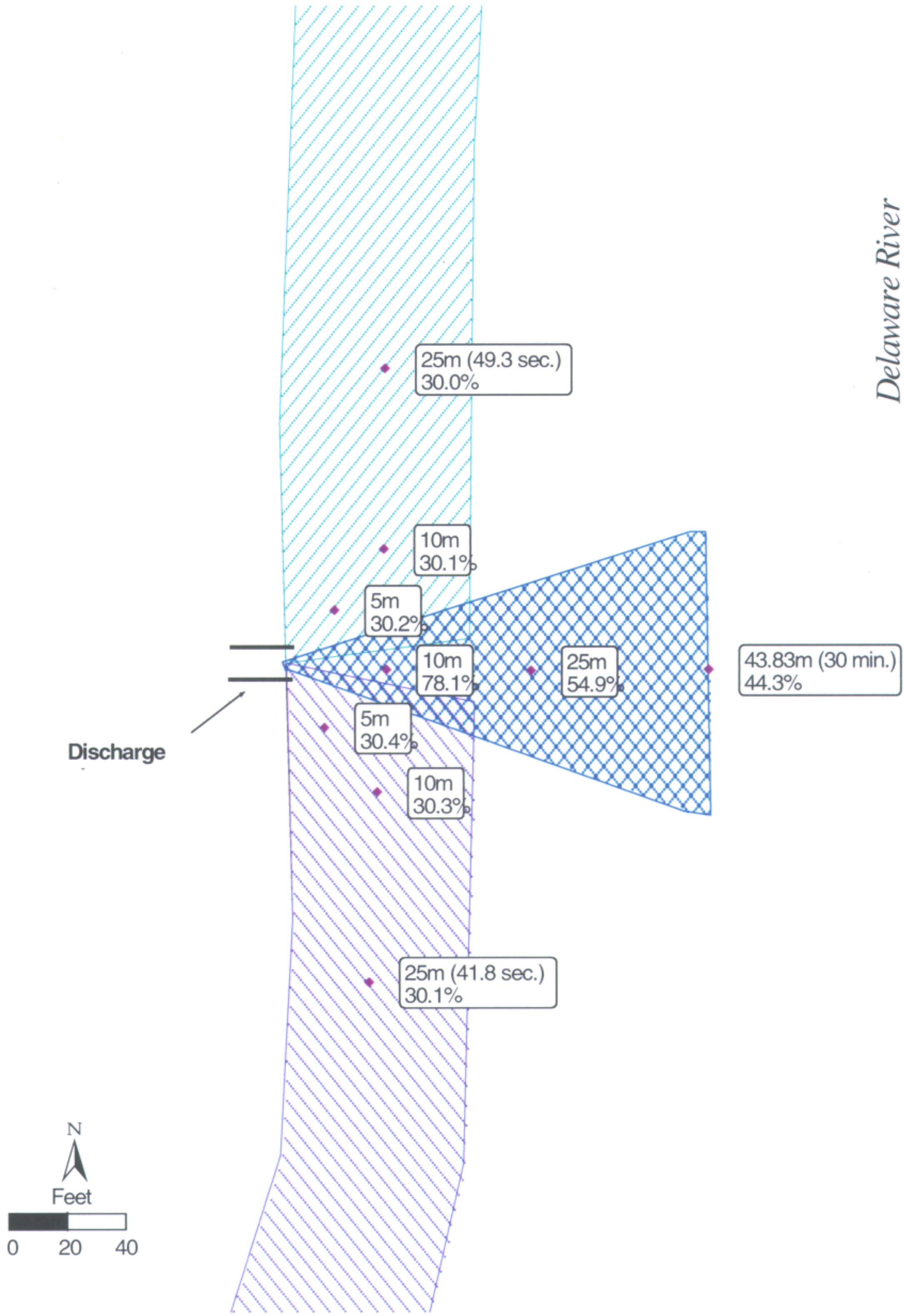

Figure 3-1. Illustration of the CORMIX prediction applied to the actual shoreline near the Reedy Point CDF

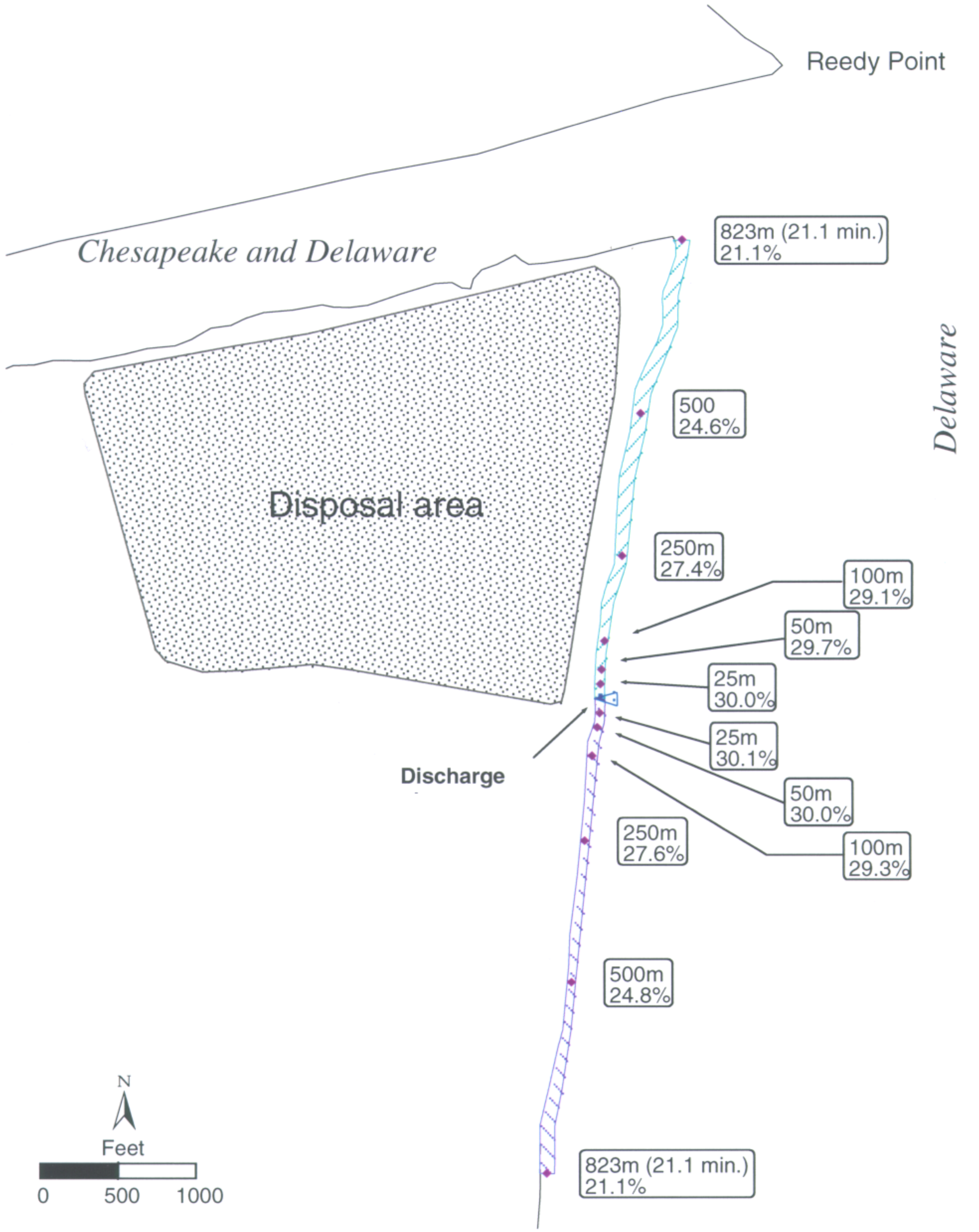

Figure 3-2. Illustration of the CORMIX prediction applied to the actual shoreline near the Reedy Point CDF

centerline from the POD to the end of the simulation (Fig. 3-2). CORMIX does not model changes to the plume when it reaches an obstruction or additional inflow such as the mouth of the C&D Canal. Therefore, the map shows the time and dilution ratio at 823 meters, the distance from the discharge pipes to the jetty at the mouth of the canal, for both flood and ebb tides. The model shoreline is away from the real shoreline because the CORMIX model assumes a straight, uninterrupted shoreline, while the real shoreline is not straight, and changes with the tides.

CORMIX simulations using the Reedy Point South baseline model parameters indicate several important features of the plumes that occur in the winter flood (and ebb) tide and the winter slack tide cases. The discharge plume for the winter flood (and ebb) tide cases has the following features:

- For the first two meters upstream (or downstream) and across the river, the discharge is carried out by its momentum;
- The discharge plume is bent over due to the ambient current;
- After the first few meters the discharge plume is shoreline attached, and mixes passively with the river.
- The modeled outlet channel occupies a significant portion of the depth of the ambient body of water; thus, the plume quickly becomes fully vertically mixed.

The discharge plume for the winter slack tide case has the following features:

- For the first five meters across the river, the discharge is jet-like;
- The discharge is flowing across the river;
- After the first five meters, the plume spreads laterally, and due to its buoyancy, the plume thins vertically;
- Deflection by the ambient current is weak because there is nearly no ambient current.

Using the input flow data, the CORMIX model categorizes the flow into different flow classifications. CORMIX divided the baseline cases into three different flow classes. As noted in Section 2.3.2.2, the dynamics of a discharge plume interacting with a tidal current are best described in terms of conditions before, during, and after slack tide. During slack tide, the plume direction pivots from one side of the discharge pipe to the other and mixing may be reduced.

To assess the plume response to tidal conditions at Reedy Point South, slack tide has been defined as the half an hour between flood and ebb tides. The average velocity at this time was assumed to be zero. However, CORMIX requires a non-zero number for velocity. Therefore, a value of 0.01 m/s was used. Between slack periods, there is an ebb tide with an average velocity of 0.65 m/s and a flood tide with an average velocity of 0.65 m/s in the opposite direction (Versar 1992).

The winter flood case resulted in a dilution ratio of 56.1 at the end of the simulation. The plume reached a distance of 3,061 meters from the discharge point before the simulation terminated due to tidal reversal (1 hour and 18.5 minutes after the start of the simulation). This time is the longest the simulation will run under tidal conditions. Normally, this distance, 3,061 meters, would be used in the analysis, however, the jetty at the mouth of the C&D Canal is 823 meters upstream of the discharge. The plume mixing in this part of the river is complicated due to the presence of the canal and its entrance jetties and CORMIX is not designed to model this complexity. Thus, for this study, the plume is considered only to 823 meters upstream where the plume has a dilution ratio of 17.0 after traveling for about 21 minutes.

The winter slack tide plume is shaped by the fact that the water is almost stagnant. The plume spreads across the river and widens as it goes. After three and a half minutes, the plume has reached nine meters and has a dilution ratio of 1.22. After a half an hour, (the assumed duration of slack tide) the plume has reached 44.5 meters across the river and has a dilution ratio of 2.3. The vertical thickness of the plume has decreased to about 0.2 meters at that point.

3.2.1 Contaminant Dilution

Tables 3-3 through 3-5 show the results for contaminant concentrations throughout the mixing zone from the weir discharge. The calculations assume that the concentration of suspended sediment discharged at the weir is 250mg/l. The tables demonstrate the distance the discharge plume must travel for contaminants to comply with regional water quality standards based on the flood condition (Table 3-3), slack condition (Table 3-4), and ebb condition (Table 3-5).

These conservative results indicate that copper, lead, mercury, and nickel may exceed some of the chronic criteria at the point of discharge, but dissipate to meet all criteria within 2 meters at winter flood tide. In addition, only copper may exceed acute criteria (NJDEP acute is equal to chronic). The same metals may exceed criteria at this distance at winter slack tide, however they may continue to exceed criteria at a distance of 10 meters. By 25 meters lead and nickel would meet regulatory criteria, but copper and mercury may exceed chronic criteria (and acute, in the case of copper) to the end of the slack tide period. Results of contaminant dissipation at ebb tide are similar to those during flood tide. By one meter from the point of discharge, lead and nickel would meet regulatory criteria, and within two meters, copper and mercury would, as well. Again, only copper may exceed an acute criterion. If suspended sediment levels are maintained at levels below the assumed 250 mg/l TSS within the equilibrium-partitioning model, concentrations of contaminants are expected to be much less than those calculated since contaminants will remain in the sediment retained in the CDF. Versar (1996 b) presented monitoring results that showed weir TSS concentrations less than 5 ranging from up to 140 mg/l (except for one sample) further confirming the conservative nature of these results.

Table 3-3. Reedy Point South CDF winter flood tide plume concentrations at various distances from the point of discharge (POD), assuming average concentrations of metals in sediments destined for Reedy Point South CDF based on equilibrium partitioning at the POD. Shaded cells indicate where any water quality criteria would be exceeded, boldface type indicates where acute criteria would be exceeded. All units are in µg/L.

Contaminant	Marine Water Quality Criteria						Distance from pipe (meters)	0m	0.5 m	1 m	2 m	5	9	10	25	50	100
	NJDEP Chronic	NJDEP Acute	DRBC Chronic	DRBC Acute	DNREC Chronic	DNREC Acute	% original plume concentration	100%	69.73	39.45	30.62	30.17	30.13	30.11	29.95	29.67	29.11
Arsenic	NL	NL	36	69	36	69		5.68	3.96	2.24	1.74	1.71	1.71	1.71	1.70	1.68	1.65
Cadmium	NL	NL	9.3	43	9.3	43		0.82	0.57	0.32	0.25	0.25	0.25	0.25	0.24	0.24	0.24
Chromium	NL	NL	50	1100	50	1100		30.80	21.48	12.15	9.43	9.29	9.28	9.27	9.22	9.14	8.97
Copper	2.4	2.4	3.4	5.3	NL	2.9		**6.43**	**4.48**	**2.54**	1.97	1.94	1.94	1.94	1.93	1.91	1.87
Lead	NL	NL	8.5	220	5.6	140		9.32	6.50	3.68	2.85	2.81	2.81	2.81	2.79	2.76	2.71
Mercury	NL	NL	0.025	2.1	0.025	2.1		0.066	0.046	0.026	0.020	0.020	0.020	0.020	0.020	0.020	0.019
Nickel	8.2	74	8.3	75	8.3	75		12.56	8.75	4.95	3.84	3.79	3.78	3.78	3.76	3.73	3.65
Selenium	NL	NL	71	300	71	300		15.58	10.86	6.14	4.77	4.70	4.69	4.69	4.66	4.62	4.53
Zinc	81	90	86	95	86	95		35.54	24.78	14.02	10.88	10.72	10.71	10.70	10.64	10.54	10.34

NL - No criterion listed.
Shaded cells indicate concentration exceeds at least one chronic criteria.
Bold type indicates concentration exceeds at least one acute criteria.

Table 3-4. Reedy Point South CDF winter slack tide plume concentrations at various distances from the point of discharge (POD), assuming average concentrations of metals in sediments destined for Reedy Point South CDF based on equilibrium partitioning at the POD. Shaded cells indicate where any water quality criteria would be exceeded, boldface type indicates where acute criteria would be exceeded. All units are in µg/L.

Contaminant	Marine Water Quality Criteria						Distance from pipe (meters)	0m	1	2	4	5	9	10	25	43.83
	NJDEP Chronic	NJDEP Acute	DRBC Chronic	DRBC Acute	DNREC Chronic	DNREC Acute	% original plume concentration	100%	100.00	100.00	100.00	98.34	82.16	78.12	54.87	44.28
Arsenic	NL	NL	36	69	36	69		5.68	5.68	5.68	5.68	5.58	4.66	4.43	3.11	2.51
Cadmium	NL	NL	9.3	43	9.3	43		0.82	0.82	0.82	0.82	0.80	0.67	0.64	0.45	0.36
Chromium	NL	NL	50	1100	50	1100		30.80	30.80	30.80	30.80	30.29	25.31	24.06	16.90	13.64
Copper	2.4	2.4	3.4	5.3	NL	2.9		**6.43**	**6.43**	**6.43**	**6.43**	**6.32**	**5.28**	**5.02**	**3.53**	**2.85**
Lead	NL	NL	8.5	220	5.6	140		9.32	9.32	9.32	9.32	9.16	7.66	7.28	5.11	4.13
Mercury	NL	NL	0.025	2.1	0.025	2.1		0.066	0.066	0.066	0.066	0.065	0.054	0.051	0.036	0.029
Nickel	8.2	74	8.3	75	8.3	75		12.56	12.56	12.56	12.56	12.35	10.32	9.81	6.89	5.56
Selenium	NL	NL	71	300	71	300		15.58	15.58	15.58	15.58	15.32	12.80	12.17	8.55	6.90
Zinc	81	90	86	95	86	95		35.54	35.54	35.54	35.54	34.95	29.20	27.76	19.50	15.74

NL - No criterion listed.
Shaded cells indicate concentration exceeds at least one chronic criteria.
Bold type indicates concentration exceeds at least one acute criteria.

Table 3-5. Reedy Point South CDF winter ebb tide plume concentrations at various distances from the point of discharge (POD), assuming average concentrations of metals in sediments destined for Reedy Point South CDF based on equilibrium partitioning at the POD. Shaded cells indicate where any water quality criteria would be exceeded, boldface type indicates where acute criteria would be exceeded. All units are in µg/L.

Contaminant	Marine Water Quality Criteria						Distance from pipe (meters)	0m	0.5 m	1 m	2 m	5	9	10	25	50	100
	NJDEP Chronic	NJDEP Acute	DRBC Chronic	DRBC Acute	DNREC Chronic	DNREC Acute	% original plume concentration	100%	70.00	40.00	30.84	30.37	30.32	30.31	30.14	29.86	29.29
Arsenic	NL	NL	36	69	36	69		5.68	3.97	2.27	1.75	1.72	1.72	1.72	1.71	1.69	1.66
Cadmium	NL	NL	9.3	43	9.3	43		0.82	0.57	0.33	0.25	0.25	0.25	0.25	0.25	0.24	0.24
Chromium	NL	NL	50	1100	50	1100		30.80	21.56	12.32	9.50	9.35	9.34	9.34	9.28	9.20	9.02
Copper	2.4	2.4	3.4	5.3	NL	2.9		**6.43**	**4.50**	**2.57**	1.98	1.95	1.95	1.95	1.94	1.92	1.88
Lead	NL	NL	8.5	220	5.6	140		9.32	6.52	3.73	2.87	2.83	2.83	2.82	2.81	2.78	2.73
Mercury	NL	NL	0.025	2.1	0.025	2.1		0.066	0.046	0.026	0.020	0.020	0.020	0.020	0.020	0.020	0.019
Nickel	8.2	74	8.3	75	8.3	75		12.56	8.79	5.02	3.87	3.81	3.81	3.81	3.78	3.75	3.68
Selenium	NL	NL	71	300	71	300		15.58	10.90	6.23	4.80	4.73	4.72	4.72	4.69	4.65	4.56
Zinc	81	90	86	95	86	95		35.54	24.88	14.22	10.96	10.79	10.77	10.77	10.71	10.61	10.41

NL – No criterion listed.
Shaded cells indicate concentration exceeds at least one chronic criteria.
Bold type indicates concentration exceeds at least one acute criteria.

4.0 CONCLUSIONS

The results of the equilibrium partitioning model indicate that four contaminants, copper, lead, mercury, and nickel may exceed water quality criteria near the cutterhead and weir. These results are based on the assumptions of the model, including the conservative assumption that 80% of the sediment-bound contaminants will dissolve into the water column and that TSS concentrations would be 250 mg/l. A June 2001 study of the Oldmans CDF (Versar 2001) indicated that the equilibrium-partitioning model may overestimate dissolved metals concentrations. This study also showed that it is likely that TSS concentrations will be lower than 250 mg/l, resulting in no exceedances of water quality criteria.

Even given the conservative nature of the equilibrium partitioning model and the TSS concentration of 250 mg/l, only copper may exceed acute water quality criteria, which range from 2.4 μg/l for NJDEP to 5.3 μg/l for DRBC. None of the other contaminants were projected to exceed acute water quality criteria near the cutterhead or weir. Once mixing is considered at the weir, it was determined that at flood and ebb tides, all water quality criteria would be met within 2 meters of the weir. While water quality during slack tide may exceed chronic criteria for lead, mercury, and nickel, and acute criteria for copper, to a distance of nearly 44 meters, slack tide only lasts for a half hour and the plume is located within 0.2 meters of the surface. At the point when the tide begins to flood or ebb, the slack tide plume will dissipate in a short period of time, likely less than an hour. This limited affected area would not substantially impact water quality.

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