Dredge Discharge and Bottom Deposition Analysis

for Open Water Placement of Dredged Material at the Mouth of Calibogue Sound, South Carolina

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Executive Summary

The South Island Dredging Association (SIDA) is applying for a permit to dredge and place approximately 300,000 cubic yards of silt, clay, and sand materials south of the mouth of Calibogue Sound. Proposed dredge areas include Harbour Town Marina, Gull Point Marina, South Beach Marina, Port Villas, Baynard Cove Creek's Community Dock, and channels leading to these areas. The dredging is needed because shoaling of these areas and the existing shallow depths prevent navigation of recreational and commercial vessels in many areas during much of the tidal cycle. SIDA proposes to place the material at an inland open water site located in Calibogue Sound south of Hilton Head Island since this is the only feasible alternative (GEL Engineering, 2012). This report summarizes an evaluation of the dredged material fate. This includes estimates of the effects of the proposed discharge on the water column suspended sediment concentrations. It also includes estimates of the extent of the sediment deposit that will settle on the bottom at the placement site.

Approximately 99 percent of the material at the placement site will initially descend to the bottom as a fluid mud layer within the placement area. This fluid mud will spread and flow along the bottom as an underflow (Figure ES-1). Some of the sediments from the underflow will be entrained into the overlying water column during placement and dispersed by the ambient tidal currents. The sediments that are not entrained into the overlying water column settle to the bottom in a deposit. This deposit initially has very low density and gradually gains cohesive strength and decreases in thickness as it consolidates over a period of days. Given the high tidal current velocities at the site and the low density of the sediments, the placement site is dispersive. This means that the tidal currents will then erode this deposited sediment from the bottom and incorporate the material in to the natural sediment transport system.

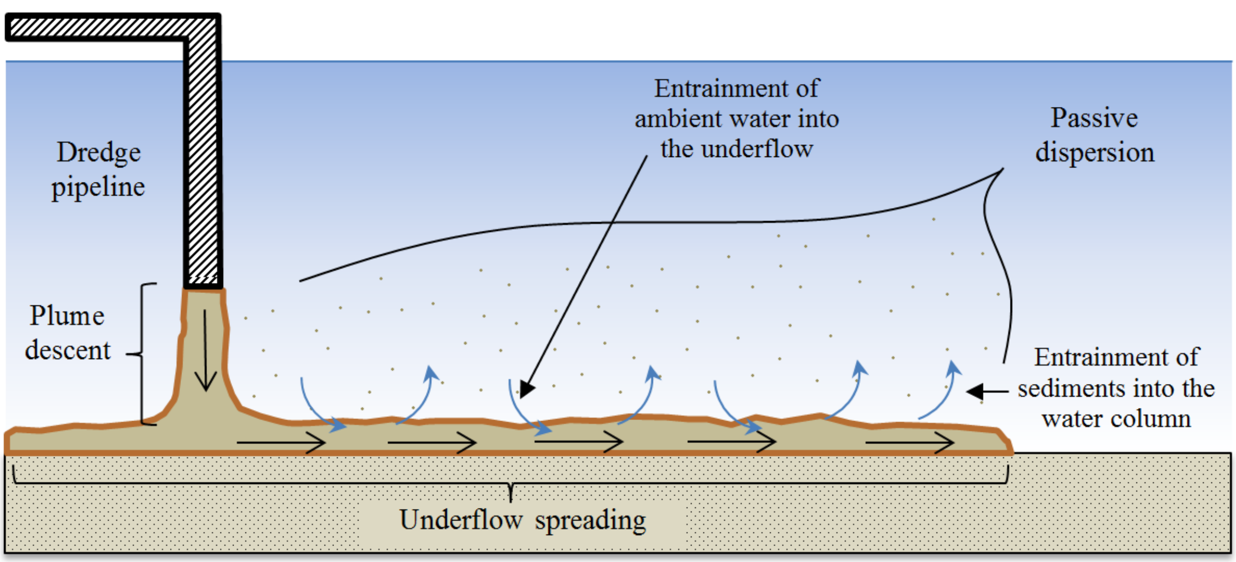

Figure ES-1 – Dispersion phases of discharge from a pipeline (adapted from Teeter, in Thovenot et al., 1992).

Methodology

This analysis used four different models to addresses different phases of the discharge process:

1. CORMIX was used to evaluate the initial near-field mixing of the plume up to the point of the initial underflow formation. CORMIX is a US Environmental Protection Agency (EPA) supported modeling system for the analysis of plumes and mixing zones.

2. The Pipeline Discharge FATE (PDFATE) model was used to evaluate the underflow spreading and predict the deposition of sediments on the bottom and the entrainment of sediments into the overlying water column. The results from the CORMIX model are used as input to the PDFATE model.

3. The long-term stability of the sediments deposited on the bottom was evaluated using the Environmental Fluid Dynamics Code (EFDC) coupled with the SEDZLJ sediment transport model (EFDC-SEDZLJ). The sediment deposited on the bottom predicted by PDFATE was used as input to this model.

4. The far-field dispersion model described by Kuo et al. (1985) and used by the USACE's DREDGE model (Hayes and Je, 2000) was used to predict the dispersion of the sediments in the ambient flow field. The results of the PDFATE model and the EFDC-SEDZLJ model are used as input to the far-field dispersion model.

Results

Based on the results of the CORMIX and PDFATE models, sediments will deposit from this underflow on the bottom within a radius extending 410 meters (1,350 feet) from the discharge location. The underflow is a density current that will flow in a down-slope direction, and the path of the flow will change over time as sediments are temporarily deposited on the bottom. The maximum bottom area potentially affected by the underflow is approximately 56 acres of existing sandy bottom. The area of 56 acres is based on conservative model inputs, and the actual area may be smaller. Regardless, it will not cover any of the identified hard bottom areas in Calibogue Sound. It should be noted that the bottom area potentially affected by the underflow is an irregular shape covering 56 acres. The proposed placement area defined for permitting purposes is rectangular with an area of 106 acres. Not all of the bottom in the rectangular placement area would be affected by the underflow.

Following deposition of the sediments on the bottom from the underflow, the tidal currents will begin to erode the sediments. Given the high tidal current velocities at the site and the low density of the sediments, the placement site is dispersive. This means that the tidal currents will then erode this deposited sediment from the bottom and incorporate the material in to the natural sediment transport system. This erosion process will occur continuously throughout the 6-month project as sediments are placed at the site. The sediments will be completely eroded from the placement site within weeks after the project is completed. The project will not cause any permanent or long-term changes to the bottom.

The sediments entrained into the water column and carried away by the currents will create a plume of suspended sediments. The contributions from three sources are included in estimates of the sediment plume concentrations: entrainment at the pipe outfall; entrainment along the underflow surface; and erosion of sediments recently deposited on the bottom. The resulting water column concentrations are relatively low because the underflow of fluid mud is spread along the bottom. Therefore, the source of entrained sediments is spread over an area on the bottom rather than a point source at the end of the dredge pipe.

The peak ebb and flood currents cause temporary total suspended sediment (TSS) concentrations up to 11 mg/L above ambient background concentrations within 3 feet above the bottom over a localized area downstream from the underflow. For reference, Applied Technology and Management (ATM) measured a background concentration of 68 mg/L in 1999 (ATM, 2000a). There is no explicit South Carolina water quality standard for TSS. However, the South Carolina water quality standard for turbidity of 25 NTU is approximately equivalent to a TSS concentration of about 37 mg/L. Therefore, the natural ambient concentrations routinely exceed the water quality standard for turbidity at this location. The 11 mg/L TSS plume concentrations are equivalent to 16 percent of the observed background concentration, and approximately 30 percent of the concentration equivalent to the turbidity water quality standard.

Concentrations exceeding 10 mg/L above the background concentration would extend a maximum distance of 1,900 feet from the discharge point at 3 feet above the bottom. Because the sediment source is at the bottom, the highest concentrations occur at the bottom and concentrations gradually decrease as the sediments disperse vertically in the water column. Concentrations at elevations more than 6 feet above the bottom are minimal. No effects on suspended sediments would be detectable at the water surface.

Current speeds equal to half of the peak current speed show very low suspended sediment concentrations. The lower current speed causes much lower entrainment of sediment from the underflow into the overlying water column (5 percent of the peak value). Therefore, the project would cause only a very small increase in suspended sediment concentrations for much of the tidal cycle. Additionally, the predicted far-field suspended sediment concentrations from the proposed open water placement are within the natural range of concentrations experienced during typical conditions. Overall, the proposed project would have minor effects on suspended sediment concentrations in Calibogue Sound.

The net transport of sediments at the placement site is towards the ocean. In general, tidal inlets exhibit a net transport in the flood direction near the margins of the inlet (i.e., close to the shorelines), and a net ebb transport in the main channel. Because the placement site is located in the ebb channel of the inlet, it is expected that the net transport of sediments from the site will be in the ebb direction primarily towards the south-southeast. Therefore, a majority of the sediments placed at the site will ultimately be transported towards the ocean.

The bottom deposition of sediments from the proposed project is negligible in areas outside of the placement site in the vicinity of the Calibogue Sound entrance. Sediments suspended into the water column will ultimately settle in quiescent areas with low current velocities. Dispersion of the sediments in areas beyond the immediate Calibogue Sound entrance area would be in very low concentrations. As a result, the deposition thickness of these sediments in quiescent areas would be indistinguishable from the deposition caused by ambient sediments in the environment. Based on these results, and given the distance between the selected placement area and inland areas of concern (such as the Cooper and May Rivers), there would be no appreciable increase in suspended sediment concentration or sedimentation in locations further inland, such as these two rivers. Furthermore, these suspended sediments will not cause appreciable deposition in the vicinity of Calibogue Sound inlet or Barrett Shoals because the high current speeds in the area will keep these fine sediments in suspension.

One management technique considered to minimize potential project effects is to limit dredging to only the ebbing phase of the tide. However, given the negligible potential effects of the proposed project on areas north of the Calibogue Sound entrance, it is not recommended to restrict dredging placement activities to ebbing tides. The tidal restriction would extend the duration of the project by a factor of two in order to complete the same maintenance dredging volume. In return for this extended project duration, there would be negligible benefit by reducing effects on areas north of the Calibogue Sound entrance.

Potential project effects on other water quality variables were also evaluated, including dissolved oxygen, salinity, temperature and pH. The project will have minimal, if any, adverse effect on dissolved oxygen concentrations and will not cause a violation of the water quality standard. The project will have negligible effects on salinity, temperature and pH in Calibogue Sound.

Conclusions

The proposed placement of dredged material in Calibogue Sound south of Hilton Head Island will result in a layer of mud on the bottom temporarily affecting a small portion of Calibogue Sound (within an area less than 56 acres). The placement site is dispersive, and therefore and sediments deposited on the bottom will be eroded and transported away by tidal currents within a period of weeks. The project will not cause permanent or long-term changes to the bottom.

The proposed project will cause temporary effects on the water column suspended sediment concentrations during the dredging operations. Because the placement method discharges the material very close to the bottom, the effects on the overlying water column are minor. These effects will vary over time, and the greatest effects will occur during peak tidal current conditions. The water column effects are limited to the vicinity of the placement site in Calibogue Sound south of Hilton Head Island, and the maximum effects are within the range of concentrations that naturally occur in the area. The project would contribute minimal sediments to the water column for much of the tidal cycle. The project will not cause violation of the water quality standard for dissolved oxygen, and the project will have negligible effects on salinity, temperature and pH in Calibogue Sound.

1 Introduction

The South Island Dredging Association (SIDA) is applying for a permit to dredge and place approximately 300,000 cubic yards of silt, clay, and sand materials south of the mouth of Calibogue Sound. Proposed dredge areas include Harbour Town Marina, Gull Point Marina, South Beach Marina, Port Villas, Baynard Cove Creek's Community Dock, and channels leading to these areas. The dredging is needed because shoaling of these areas and the existing shallow depths prevent navigation of recreational and commercial vessels in many areas during much of the tidal cycle. SIDA proposes to place the material at an inland open water site located in Calibogue Sound south of Hilton Head Island since this is the only feasible alternative (GEL Engineering, 2012).

The placement site location is shown in Figure 1-1. As shown in Figure 1-1, the site is located in Calibogue Sound between Barrett Shoals and Grenadier Shoal. This site is within the inland waters of Calibogue Sound. As shown by Figure 1-2, the site is on the landward side of the baseline points and tangents from which the territorial sea is measured. "Ocean waters" are defined as the waters of the open seas lying seaward of the baseline.

The purpose of this analysis is to evaluate the fate of the dredged material. This includes estimates of the effects of the proposed discharge on the water column suspended sediment concentrations. It also includes estimates of the extent of the sediment deposit that will settle on the bottom at the placement site.

1.1 General Description of Continuous Dredge Discharge in Open Water

This section describes some basic concepts related to continuous pipeline discharge of dredged material in open water. The discharge of the mixture creates a negatively buoyant plume (i.e., the discharge is denser than the ambient water) that descends down through the water column to the bottom. This initial mixing of the effluent jet between the discharge port and the bottom is referred to as the near-field mixing process. As described by Teeter in Thovenot et al. (1992), the far-field processes include spreading of a dense fluid mud underflow along the bottom, and passive dispersion in the overlying water column. The underflow is a flowing fluid mud separated from the overlying water by a sharp density gradient. Passive dispersion is defined as advection and diffusion driven by the ambient turbulence and currents.

Figure 1-3 shows the three dispersion phases of an open water discharge that affect the initial dispersion of the discharged dredged material, as described by Teeter in Thovenot et al. (1992). The phases include:

1. Initial descent of the dense plume to the bottom, entrainment of ambient water into the plume, and the formation of an underflow;
2. Bottom spreading of material and entrainment of the underflow into the overlying water column; and

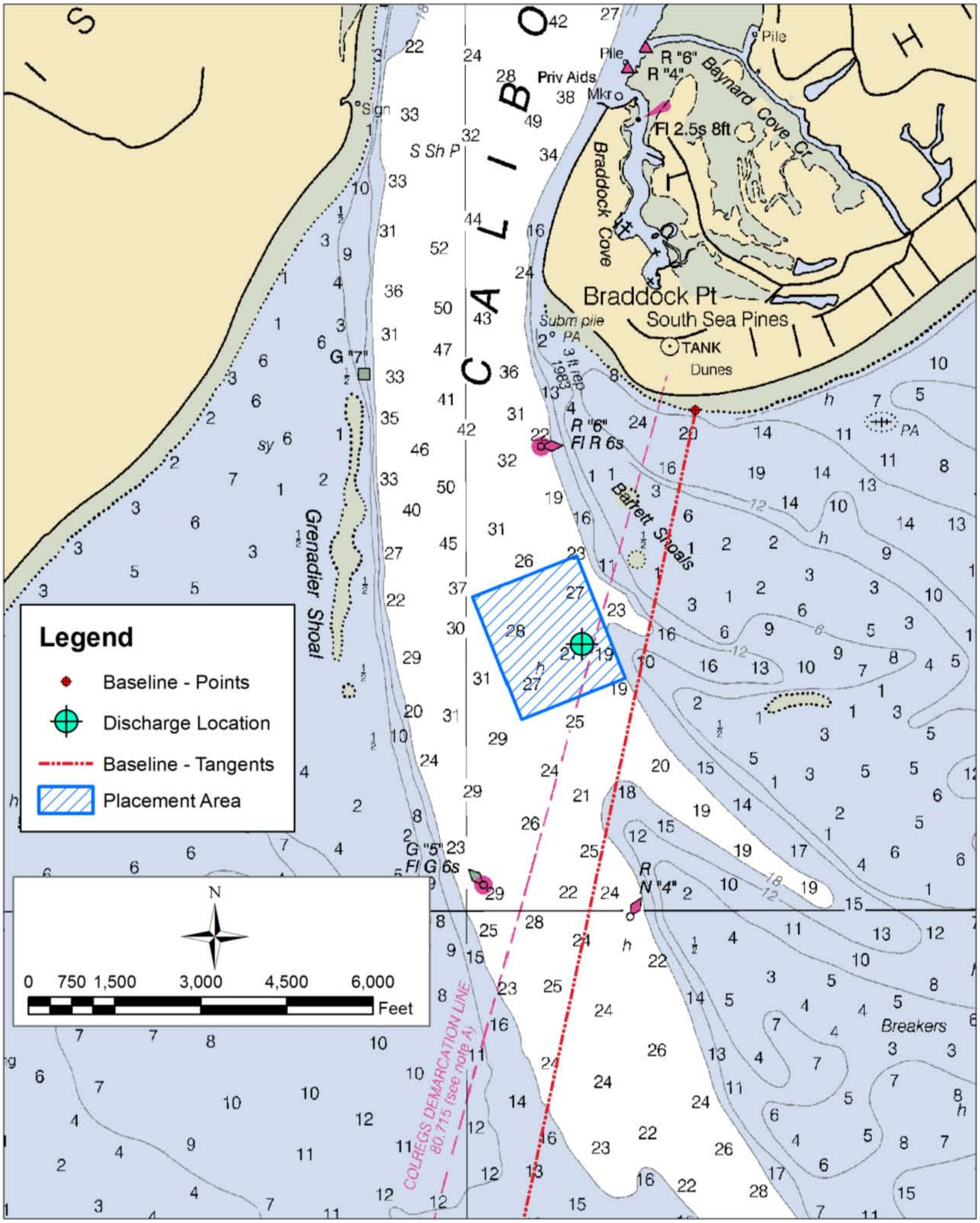

Figure 1-1 – Proposed discharge and placement area location

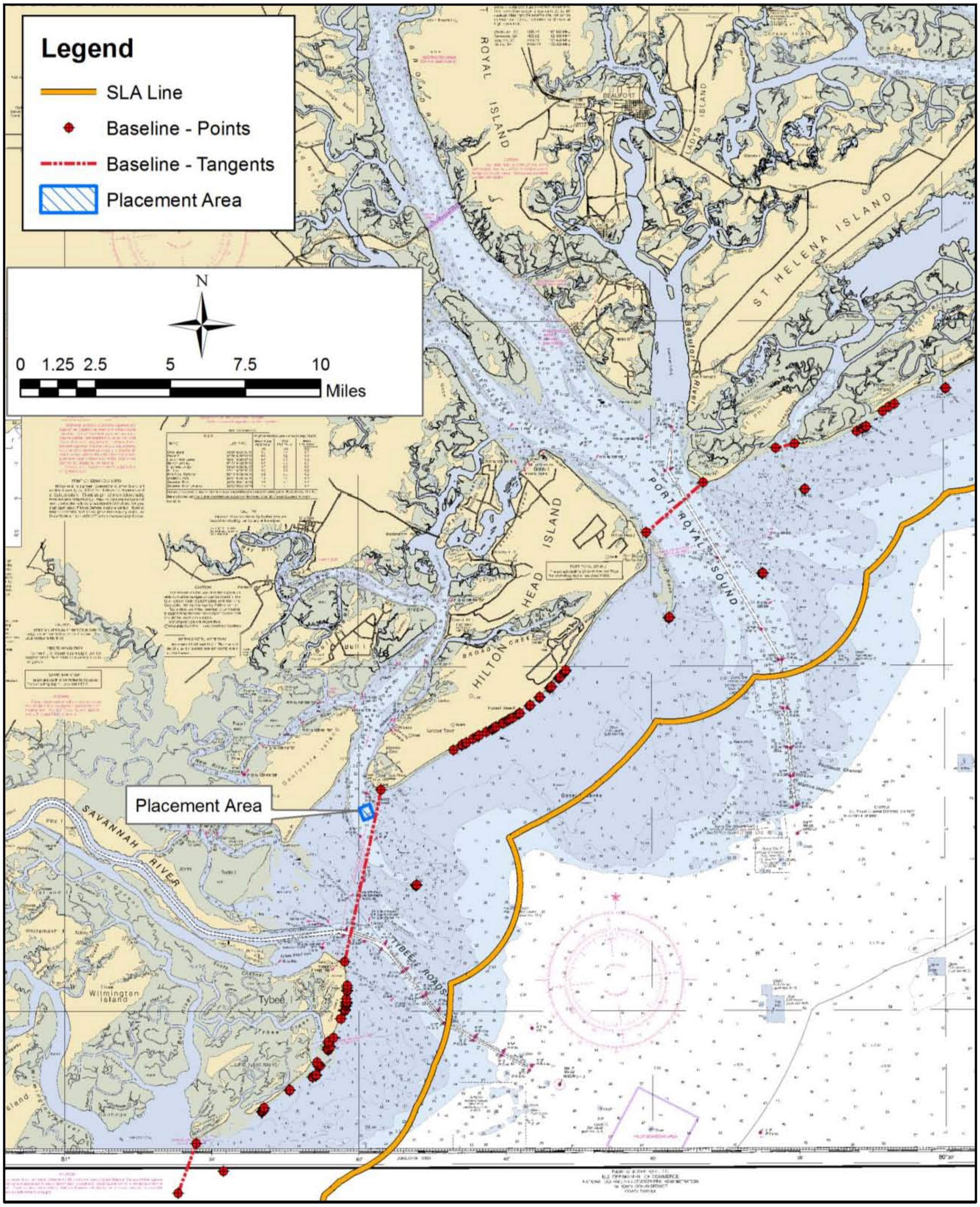

Figure 1-2 – Proposed placement area, baseline points and baseline tangents

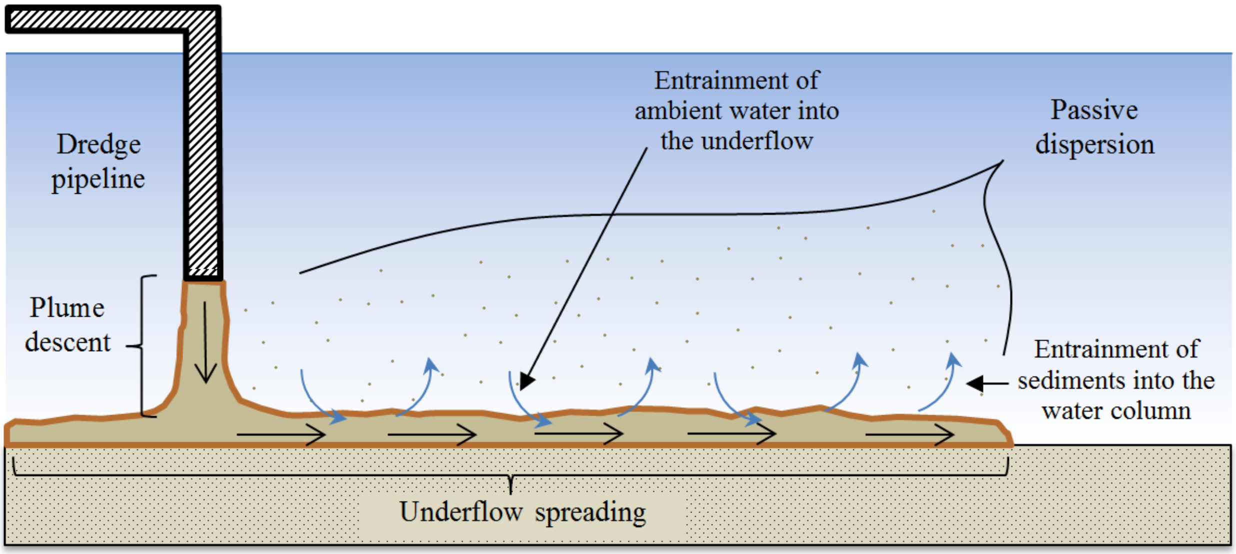

Figure 1-3 – Dispersion phases of discharge from a pipeline (adapted from Teeter, in Thovenot et al., 1992).

3. Incorporation of dredged material stripped from the descending plume and entrained from the underflow into the ambient suspended sediments field.

The sediments that are not entrained into the overlying water column settle to the bottom in a deposit. This deposit initially has very low density and gradually gains cohesive strength and decreases in thickness as it consolidates over a period of days to weeks. However, even as the deposit is consolidating, it is subject to erosion by the natural tidal currents at the site.

1.2 Analysis Methodology

The discharge was analyzed using four different models. Each model addresses a particular phase of the discharge process:

1. CORMIX was used to evaluate the initial near-field mixing of the plume up to the point of the initial underflow formation. CORMIX is a US Environmental Protection Agency (EPA) supported modeling system for the analysis of plumes and mixing zones. The model application is presented in Section 3 of this report.

2. The Pipeline Discharge FATE (PDFATE) model was used to evaluate the underflow spreading and predict the deposition of sediments on the bottom and the entrainment of sediments into the overlying water column. The results from the CORMIX model are used as input to the PDFATE model. The PDFATE model application is presented in Section 4 of this report.

3. The long-term stability of the sediments deposited on the bottom was evaluated using the Environmental Fluid Dynamics Code (EFDC) coupled with the SEDZLJ sediment transport model

(EFDC-SEDZLJ). The sediment deposited on the bottom predicted by PDFATE was used as input to this model. The EFDC-SEDZLJ model application is presented in Section 5 of this report.

4. The far-field dispersion model described by Kuo et al. (1985) and used by the USACE's DREDGE model (Hayes and Je, 2000) was used to predict the dispersion of the sediments in the ambient flow field. The results of the PDFATE model and the EFDC-SEDZLJ model are used as input to the far-field dispersion model. The far-field plume analysis is presented in Section 6 of this report.

Section 2 of this report presents a description of the existing environment at the project placement site. This is followed by the above mentioned modeling Sections 3 through 6, and the analysis conclusions in Section 7.

2 Existing Environment

This section describes the existing environment at the proposed placement site, including the location, water depths, tides, currents, waves and suspended sediment concentrations.

2.1 Site Location and Bathymetry

The proposed inland open water placement site is located south of Hilton Head Island, South Carolina at coordinates 32° 5’ 46” N, 80° 49’ 37” W (Figure 1-1). For the purposes of this report, the “placement site” is the area within which the sediments are expected to settle to the bottom and form a deposit of measureable thickness, and the “discharge location” is the point at which the pipeline outfall will be located. The pipeline discharge is located approximately 4,600 feet from the shoreline of Hilton Head Island and approximately 8,100 feet from the shoreline of Daufuskie Island. The placement area outline within which the material will settle on the bottom (based on the results of this analysis, as described in Section 4 of this report), is a rectangular area with dimensions of 2,300 feet by 2,000 feet.

The bathymetry in the vicinity of the placement site is shown on the navigation chart in Figure 2-1. The placement site is situated between the two shallow shoal areas: Barrett Shoals to the east and Grenadier Shoal to the west. The site is also located in the main ebb channel of the inlet to Calibogue Sound, which is about one mile north of the site.

As described by ATM (2000), Calibogue Sound is the southernmost major inlet or embayment on the South Carolina Coast. The drainage system of Calibogue Sound is completely tidal and serves the back-barrier areas of Daufuskie Island and a portion of Hilton Head Island.

The inlet to Calibogue Sound consists of a single, deeply scoured tidal channel that exceeds 60 feet in depth in several places. It is likely that the deep tidal channel of the Sound is anchored in resistant Tertiary beds similar to Port Royal Sound, accounting for its long-term stability (Zarillo et al., 1985). Figure 2-1 shows the depths from 1974 and 1995 surveys. Comparison of these depth data shows that the inlet is stable over the 21-year period between surveys.

A bathymetric dataset for the site vicinity was developed using multiple data sources, including:

- A December 15, 2011 GEL Engineering survey of the inlet throat, proposed placement area and Barrett Shoals;
- National Oceanic and Atmospheric Administration (NOAA) National Ocean Survey (NOS) survey number 10629 from 1995 (used for parts of Calibogue sound north and south of the GEL Engineering survey coverage, and nearshore areas west of Gaskin Bank);
- NOS survey number 9459 from 1974 (used for area south and west of the GEL Engineering survey coverage); and
- NOS survey number 9197 from 1973 (used for parts of Barrett Shoals south of the GEL Engineering survey coverage).

Contours of this data set are shown in Figure 2-2. As shown by Figure 2-2, the proposed discharge is in water depths of approximately 25 feet relative to the Mean Lower Low Water (MLLW) datum.

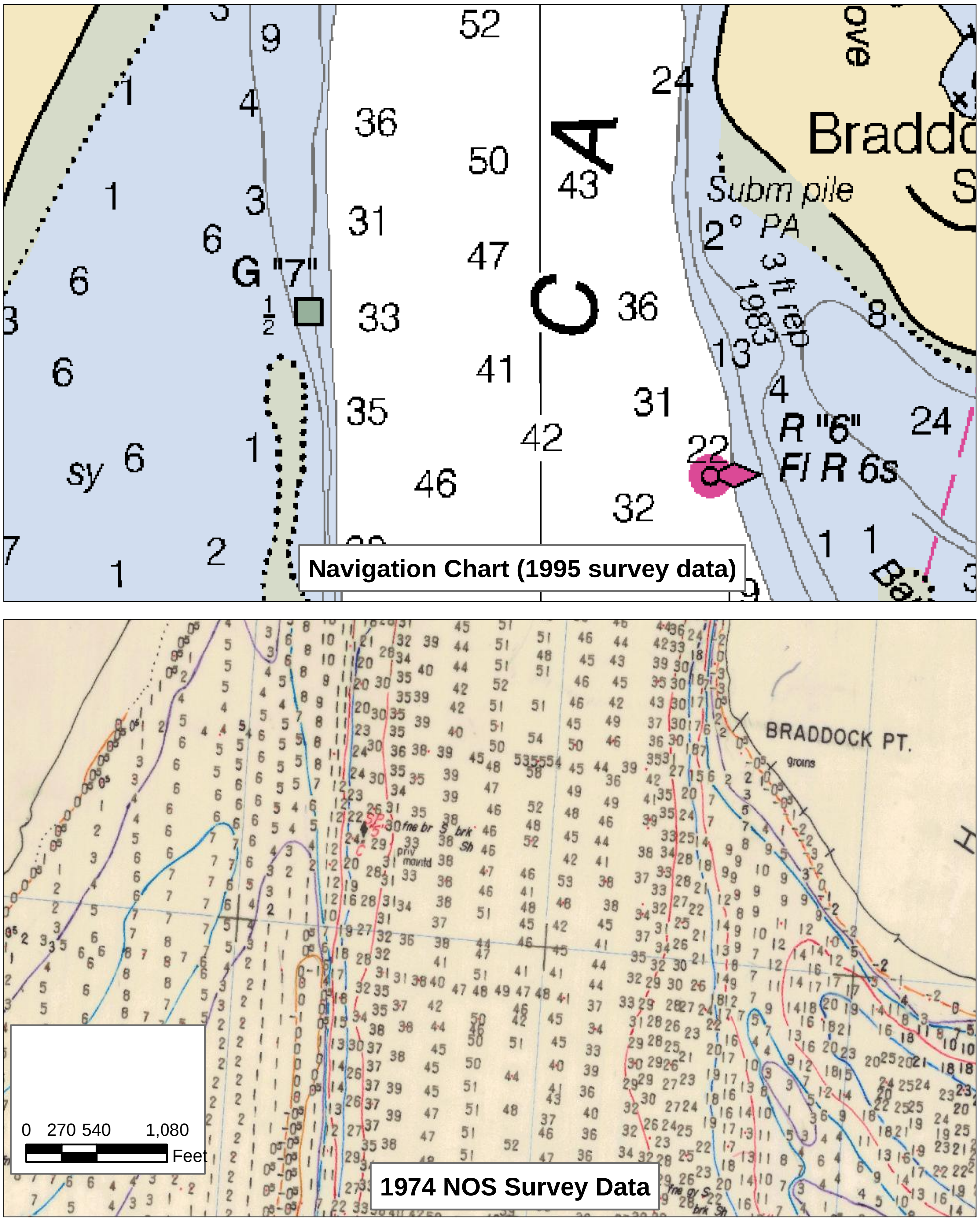

Figure 2-1 – Calibogue Sound inlet depths in 1974 and 1995

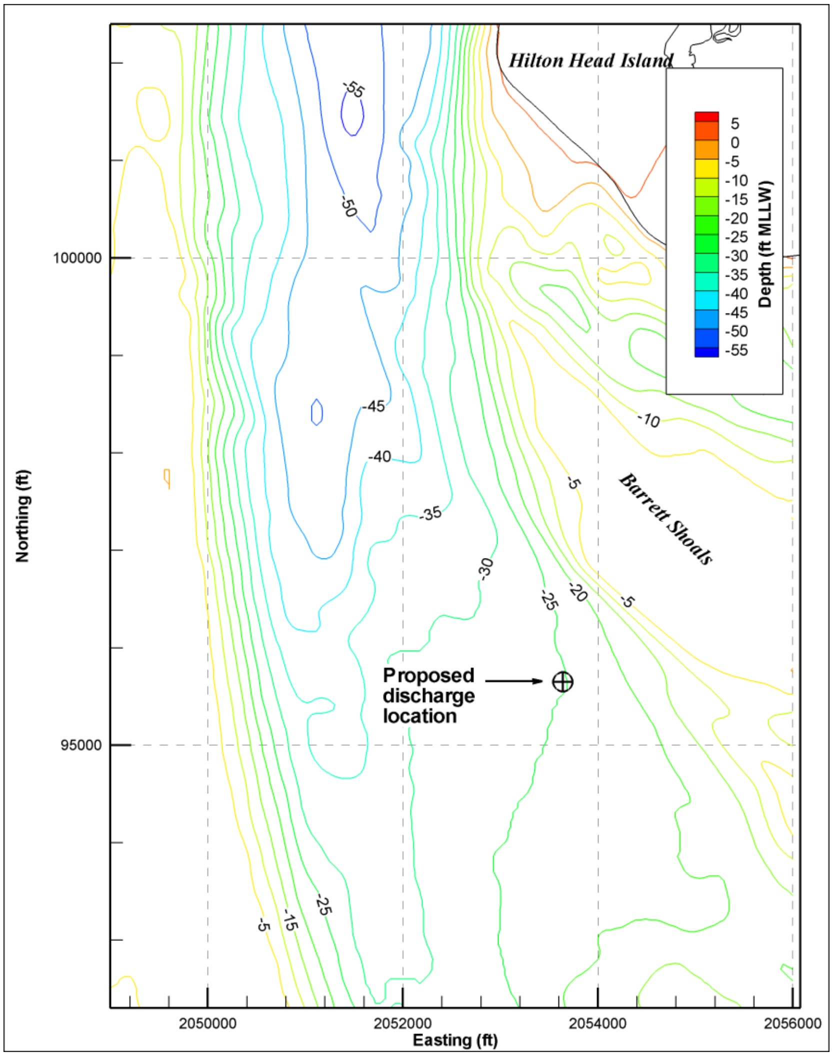

Figure 2-2 – Bathymetric contours in the vicinity of the proposed discharge

2.2 Tides and Currents

The tidal datums at the NOAA Fort Pulski tide gage are shown in Table 2-1. The mean tide range is 6.91 feet. The depths in this report are reported relative to MLLW, which is 3.67 feet below the Mean Tide Level (MTL).

The currents at the site were evaluated by ATM (2000) with both field measurements and numerical modeling. The field measurements consisted of Acoustic Doppler Current Profiler (ADCP) measurements in the inlet throat of Calibogue Sound. The location for the ADCP measurements is shown in Figure 2-3.

The peak ebb and peak flood measurements are shown in Figure 2-4. As described by ATM (2000), the maximum ebb velocity is approximately 1.0 m/s (3.3 ft/s) and the maximum flood velocity is approximately 0.8 m/s (2.6 ft/s). These measurements were taken on December 13, 1999, a day when the tide range was about 6 feet, which is smaller than the average tide range. Currents during spring tide conditions are greater than those measured by ATM in 1999. Maximum flow rates through the inlet measured by ATM were about 360,000 cfs.

Table 2-1 Tidal datums at Fort Pulaski

Datum		Elev (ft)
Highest observed water level (10/15/1947)		10.90
Mean Higher High Water	MHHW	7.50
Mean High Water	MHW	7.13
North American Vertical Datum	NAVD88	4.05
Mean Sea Level	MSL	3.82
Mean Tide Level	MTL	3.67
Mean Low Water	MLW	0.22
Mean Lower Low Water	MLLW	0.00
Lowest observed water level (03/20/1936)		-4.60

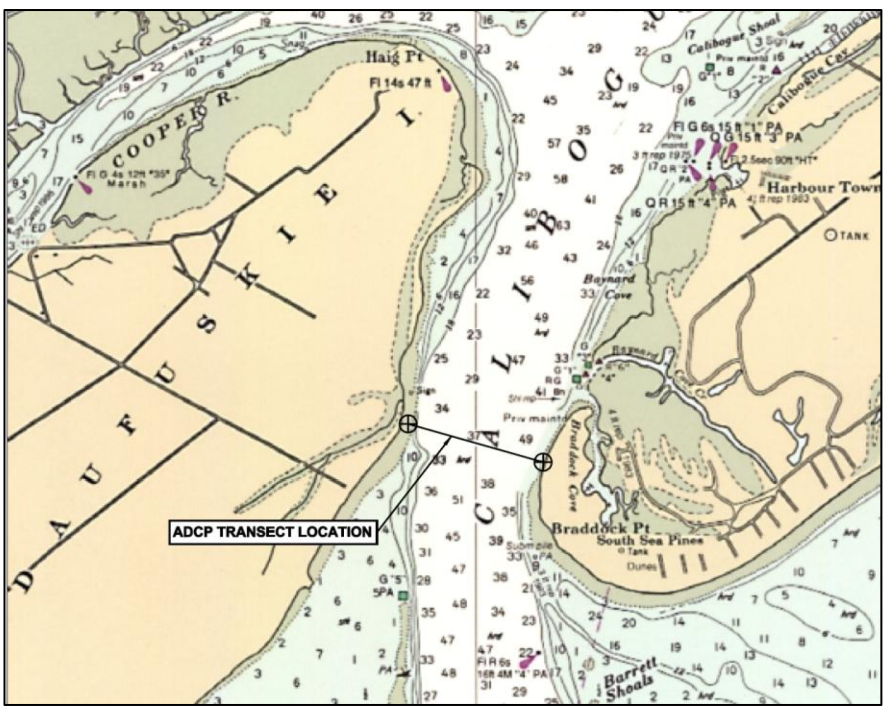

Figure 2-3 – ADCP measurement location (source: ATM, 2000)

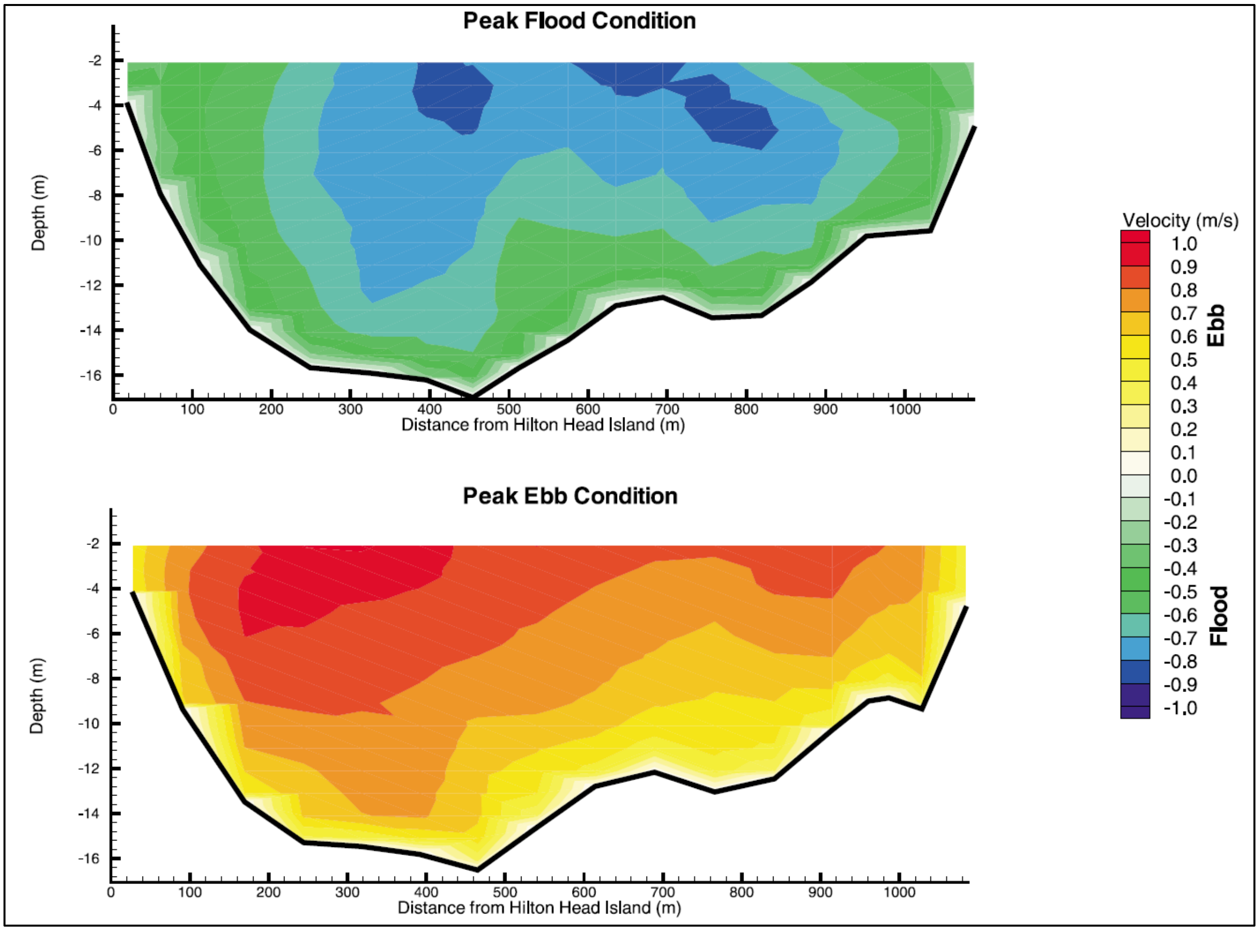

Figure 2-4 – ADCP current measurements at peak flood and peak ebb conditions on December 13, 1999 (source: ATM, 2000a)

ATM used a two-dimensional hydrodynamic model to simulate the current patterns throughout Calibogue Sound the areas surrounding Hilton Head Island. The model setup and calibration are described in detail by ATM (2000). The results from that study are used here to characterize the current environment in the vicinity of the proposed placement area. Figure 2-5 shows the simulated peak ebb currents in the project area, and Figure 2-6 shows the simulated peak flood currents. Based on the model results, the maximum depth-averaged current velocity at the proposed placement site is 0.77 m/s.

2.3 Waves

The proposed placement area is subjected to waves from the east. Barrett Shoals limits the wave heights by breaking on the shallow shoals. Given the very shallow water depths over Barrett Shoals, and the fact that the proposed placement site is approximately 25 feet deep (MLLW), the effects of waves on bottom sediment transport within the proposed placement area is minimal as compared to the tidal current effects. Wave energy, however, is a principal factor affecting sediment transport on Barrett Shoals.

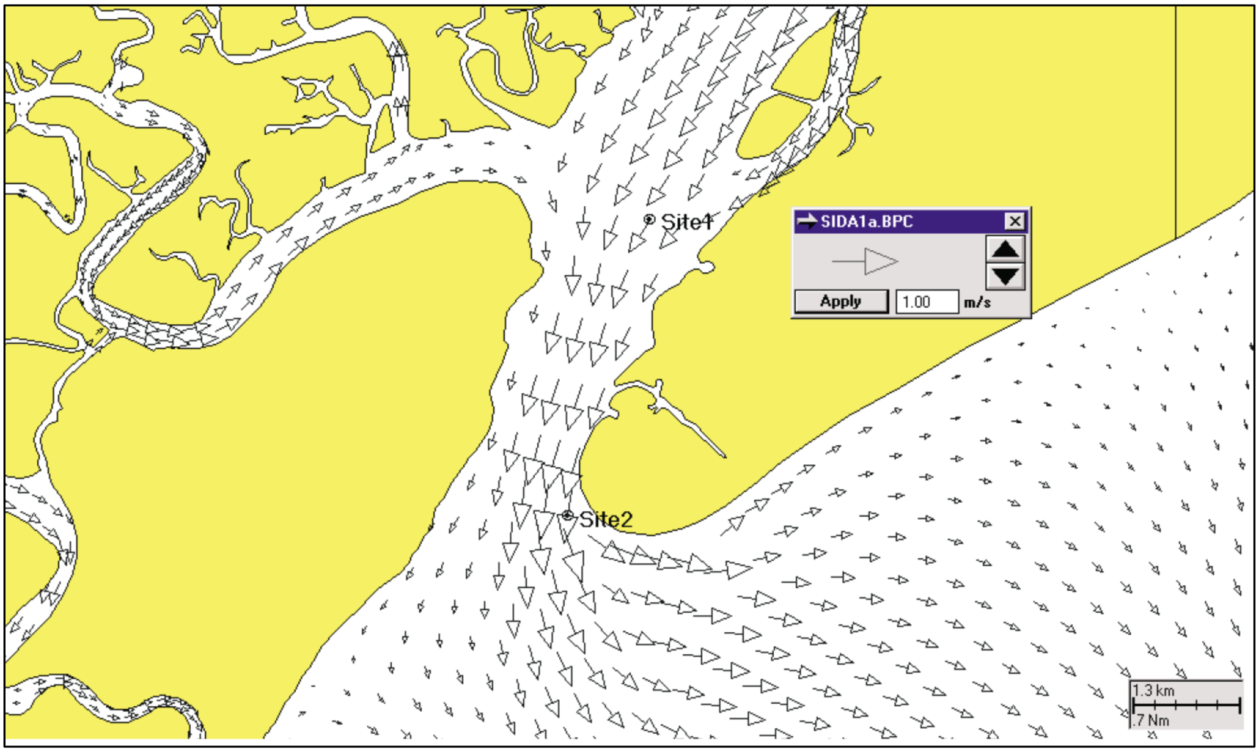

Figure 2-5 – Simulated peak ebb currents (source: ATM, 2000a)

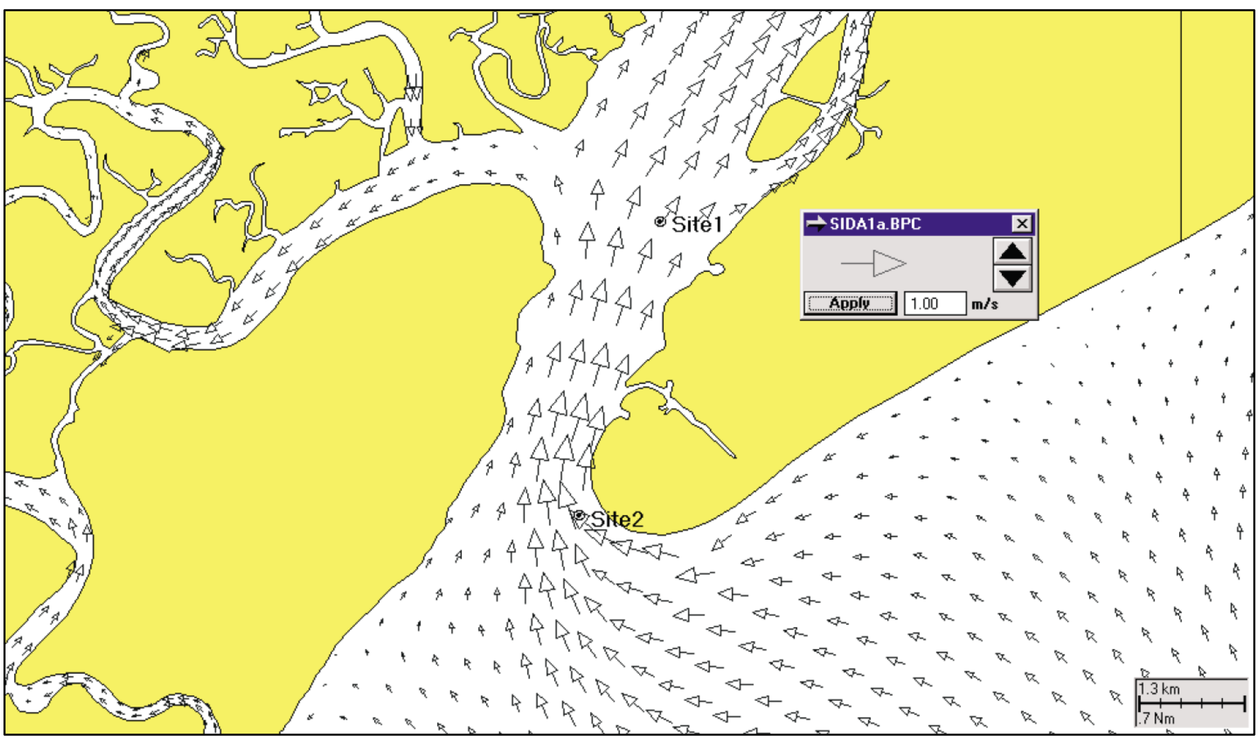

Figure 2-6 – Simulated peak flood currents (source: ATM, 2000a)

2.4 Suspended Sediments

As described in ATM (2000), Browkaw and Oertel (1977) collected and analyzed suspended sediment data from the coastal waters of Georgia. The report found that the band of turbid water is widest adjacent to the Savannah River entrance and attenuates towards the south near Jacksonville, Florida and towards the north near Cape Romain, South Carolina. The report also concluded that concentrations are highest near the shoreline and lowest offshore. As part of the study, total suspended sediment (TSS) concentrations were measured in the Calibogue Sound ebb channel south of Hilton Head Island in water depths of 9.1-m on November 11, 1974. The surface measurement was 19.3 mg/l and the measurement 1-m above the bottom was 61.0 mg/l. A TSS concentration of 68 mg/l was measured at mid-depth in the Calibogue Sound in December 1999 by ATM (2000).

Suspended sediment concentrations are typically higher during spring tide conditions that occur twice a month. Increases in current speed conditions associated with spring tides cause increased shear stress on the bottom sediments, and as a result, there is increased erosion of sediments from the bottom and increased suspended sediment concentrations in the overlying water column. Aerial photographs of the project site show high turbidity plumes in the project area caused by flooding currents flowing over Barrett Shoals (Figure 2-7). The photograph was taken during calm wave conditions, which supports the conclusion that the tidal currents are the primary cause for the high suspended sediments observed at the time of the photograph. Storm conditions can increase suspended sediment concentrations by one to two orders of magnitude. There are no measured data at the proposed placement site to quantify the suspended sediment concentrations that typically occur during spring tide conditions or storm conditions, but it is very likely that spring tides cause suspended sediment concentrations at the site in excess of 100 mg/L near the bottom of the water column, and storm conditions cause much higher concentrations.

Figure 2-7 – Aerial imagery showing high turbidity conditions in the vicinity of Barrett Shoals and the proposed placement area (source: Google Earth, January 28, 2011 image).

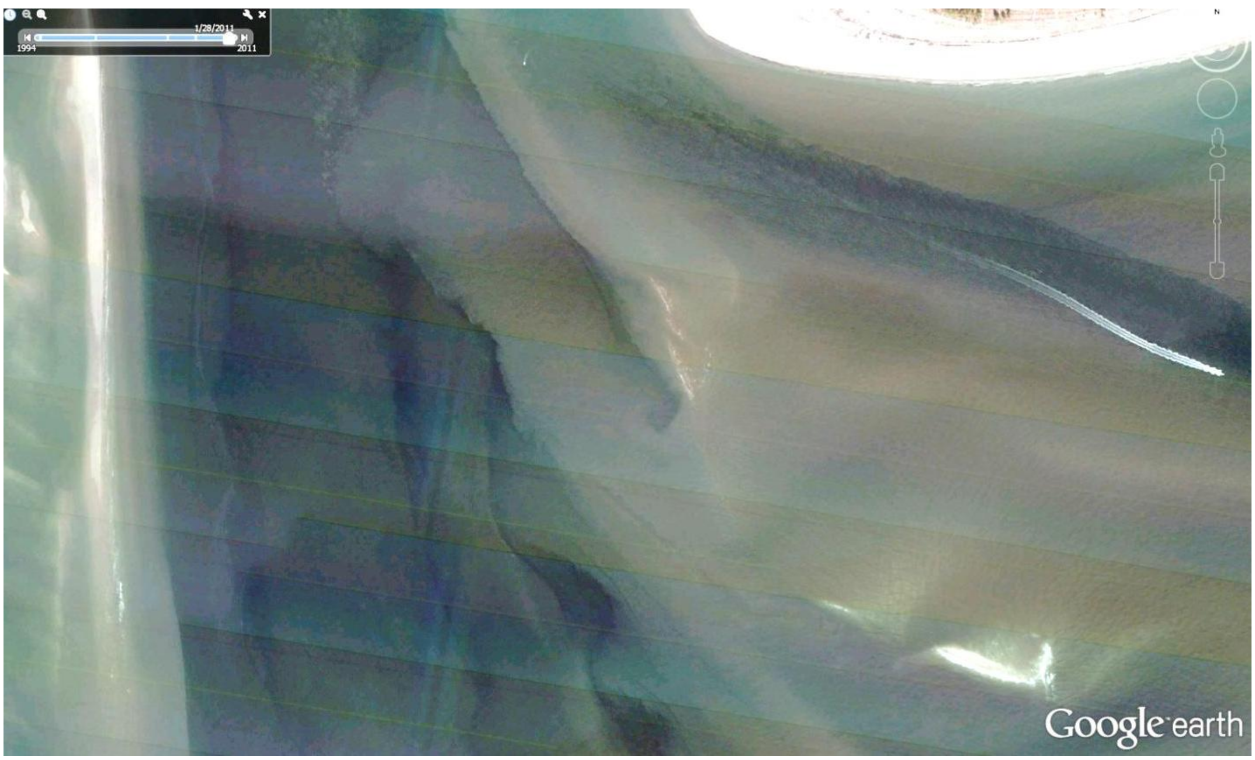

Figure 2-8 – Zoom-in of aerial imagery in the vicinity of Barrett Shoals and the proposed placement area (source: Google Earth, January 28, 2011 image; brightness increased 40%).

3 CORMIX Near-field Mixing Analysis

The CORMIX - GTS (advanced tools sediment version) model was used to simulate the initial mixing of the dredged material immediately upon submerged discharge from the dredge pipe using a tremie pipe and diffuser. The proposed discharge will be in approximately 25 feet of water (MLLW), and the discharge will be located near the bottom (simulated 3 feet above the bottom for this analysis).

3.1 Model Description

CORMIX is a US Environmental Protection Agency (EPA) supported modeling system for the analysis, prediction, and design of discharges into diverse water bodies. The major emphasis of the system is on the geometry and mixing characteristics of the initial mixing zone, including compliance with regulatory constraints as well as predicting the behavior of the discharge plume at larger distances (Doneker and Jirka, 2007). This analysis used CORMIX - GTS (advanced tools sediment version), which is a version of CORMIX for evaluating suspended sediment plume mixing for continuous dredge, drill cuttings & mud effluent discharges.

CORMIX uses a data-driven, rule-based expert systems approach. The rule-based methodology uses input data (i.e., ambient currents, discharge flow and density, etc.) to categorize the discharge jet within a set of flow classifications in order to select the appropriate core hydrodynamic model. This model is then used for simulation of the physical mixing processes contained within the given discharge-environment interaction.

3.2 Model Inputs

The model input requires environmental conditions, outfall configuration and sediment description. The input variables are summarized in Table 3-1.

The environmental conditions include the ambient current and the bottom slope. The currents input to the model were determined based on the currents simulated by ATM (2000) with a two-dimensional model, as discussed in Section 2. Both the peak current conditions (0.77 m/s) and half of the peak current conditions were evaluated.

CORMIX is limited to representing the bottom slope as either a one-slope or two-slope profile. The two-slope input used to represent the project site is shown in Figure 3-1. The plot shows the measured bottom profile at the proposed inland open water placement site based on the hydrographic survey data collected by GEL.

The outfall configuration input to the model includes: pipe discharge velocity or rate, pipe diameter, horizontal and vertical discharge angles, depth of discharge submergence, and distance of discharge from shoreline. The discharge simulated for this study was a submerged discharge, 3 feet above the ocean bottom, oriented at a 45 degree angle toward the bottom (CORMIX can't simulate a vertical downward oriented discharge). The discharge flow rate is 0.124 m^3/s based on the assumption of a 10" hydraulic dredge, and a sediment concentration of 125 kg/m^3 is a typical concentration for hydraulic dredging of fine grained sediments.   In order to minimize the discharge velocity and initial dilution of the discharge, the analysis assumes that a diffuser is used to widen the discharge pipe from 10 inches to 20 inches (0.5 m) at the outfall. Diffusers are commonly used and will be specified in the dredging plan for this project.

Table 3-1 Input data for CORMIX simulations

Input Parameter	Value
AMBIENT CONDITIONS	
Onshore slope (deg)	1.53
Distance to slope intersection (m)	274
Farshore slope (deg)	0.15
Nearshore current (m/s)	0.38, 0.77
Farshore current (m/s)	0.38, 0.77
Nearshore f	0.03
Farshore f	0.03
Windspeed (m/s)	2
Ocean clear water density at discharge (kg/m^3)	1024.76
DISCHARGE PARAMETERS	
Distance from onshore slope 0 intersect (m)	418
Vertical angle (deg)	-45
Horizontal angle (deg)	270
Diameter (at end of diffuser) (m)	0.5
Discharge rate (m^3/s)	0.124
Total depth at discharge (m)	7.7
Height of discharge above bottom (m)	1.0
Total sediment concentration (kg/m^3)	125
Effluent density (kg/m^3)	1101.43
SEDIMENT DISTRIBUTION	
chunks	0
sand	9
coarse silt	19
fine silt	35
clay	37

For sediment grain sizes, CORMIX requires sorting into five classes: chunks, sand (D > 0.062 mm), coarse silt (0.062 mm > D > 0.016 mm), fine silt (0.016 mm > D > 0.0033 mm), and clay (D < 0.0033 mm). Based on sediment sampling of the areas to be dredged and grain size analysis by GEL Engineering (2008), on average, the dredged material is 0% chunks, 9% sand, 19% coarse silt, 35% fine silt and 37% clay. The sediment grain size data is summarized in Table 3-2.

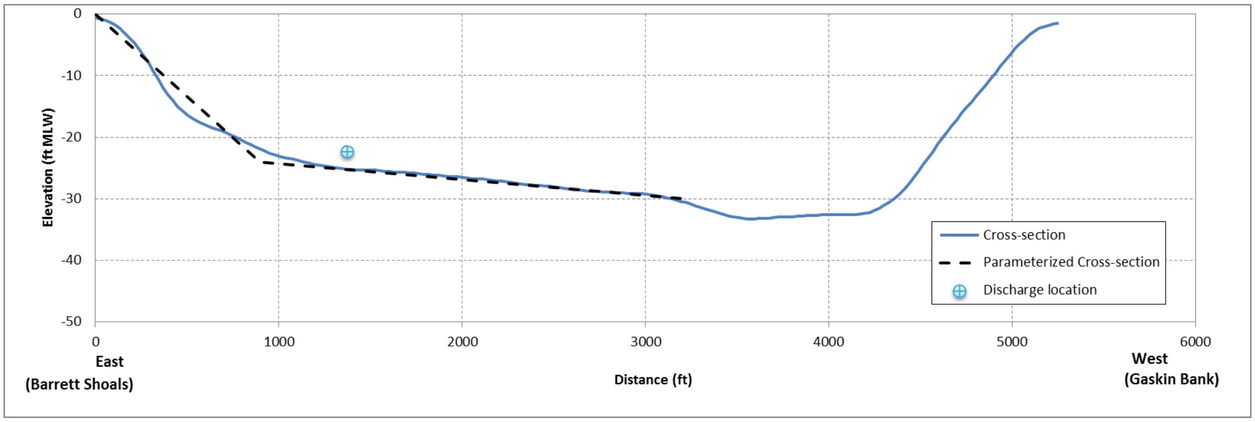

Figure 3-1 – Cross-section profile used for CORMIX analysis

Table 3-2 Sediment grain size samples and percentages in each size class

		Percentage in each grain size class			
Sample	**Location**	**Sand**	**Coarse silt**	**Fine silt**	**Clay**
HT-2	Harbour Town Marina - entrance	8	12	38	42
HT-3	Harbour Town Marina - center of basin	22	16	28	34
Gull PT-1	Gull Point Marina in Braddock Cove Creek	5	15	38	42
S. Beach-1	South Beach Marina in Braddock Cove Creek	5	21	46	28
Brad-2	Middle of Braddock Cove Creek	8	18	34	40
Bay-2	Middle of Baynard Cove Creek	6	26	30	38
CD-1	Community dock in Baynard Cove Creek	7	25	31	37
AVERAGE		9	19	35	37
Standard Deviation		6	5	6	5

3.3 Model Results

The near-field mixing results from the CORMIX model indicate that the near-field mixing is limited to within 2 meters of the discharge. After that point, the plume is attached to the bottom, and an underflow density current forms (Section 4 evaluates the underflow with the PDFATE model).

The width and height of the near-field plume is shown in Figures 3-2 and 3-3 for the peak current simulation. Similar plots are shown for the half-peak current speed in Figures 3-4 and 3-5. The predicted width at the formation of the underflow is 1.4 meters for both the peak current conditions and the half-peak current conditions. The predicted initial dilution of the sediment plume is 5.9 for peak current conditions and 3.2 for the half-current conditions.

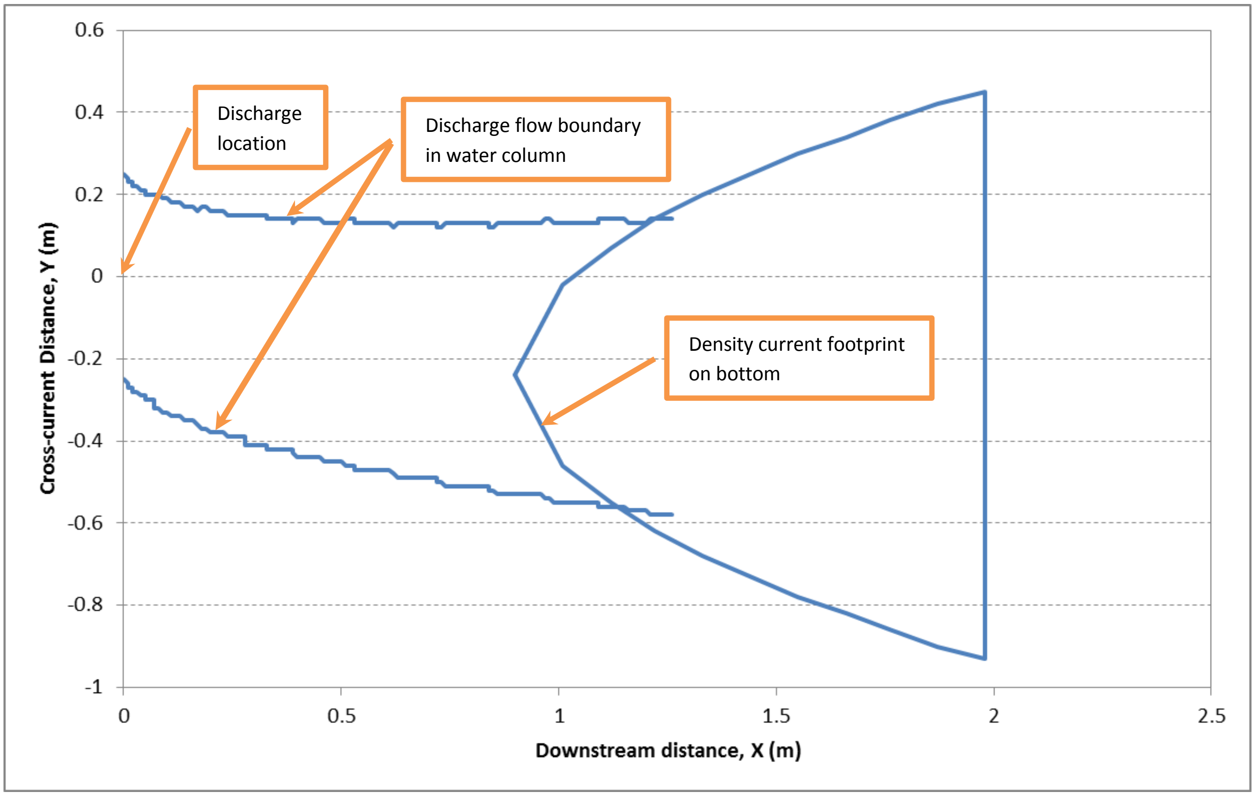

Figure 3-2 – Plan-view of predicted near-field plume width for peak current conditions

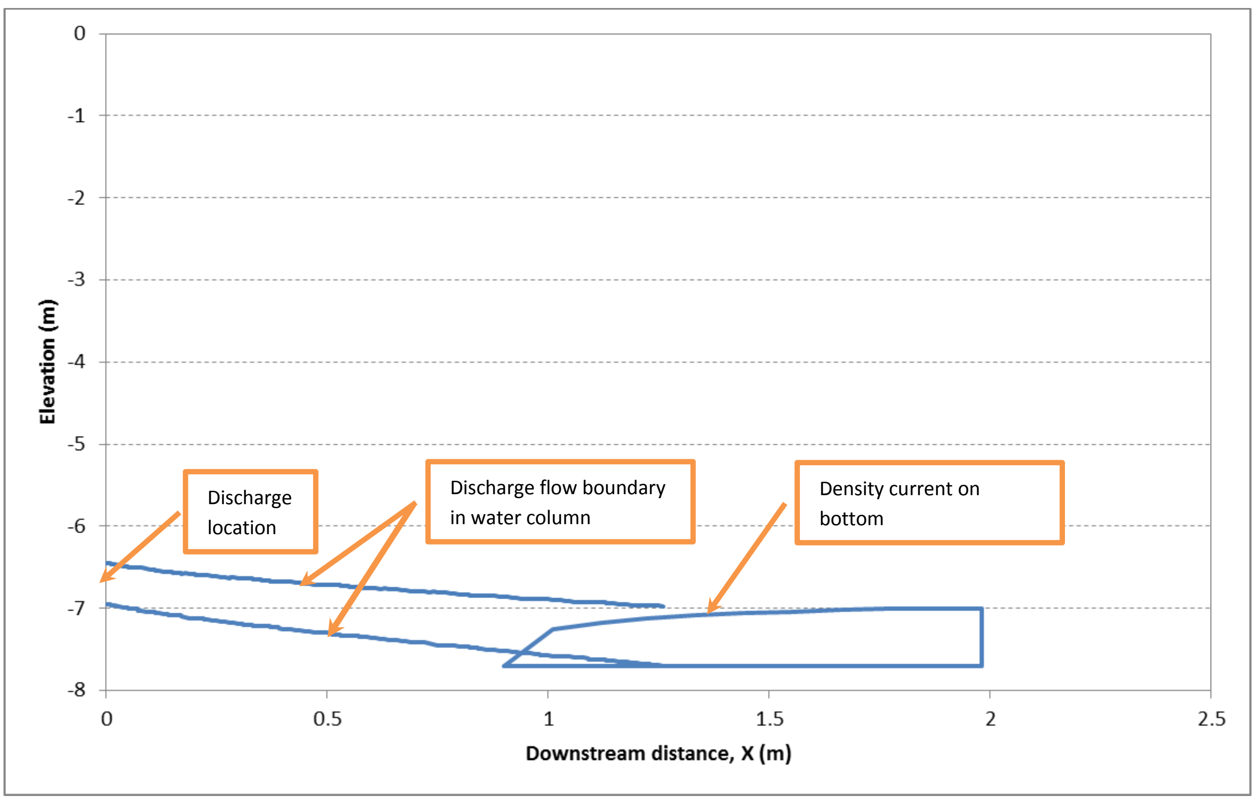

Figure 3-3 – Side-view of predicted near-field plume height for peak current conditions

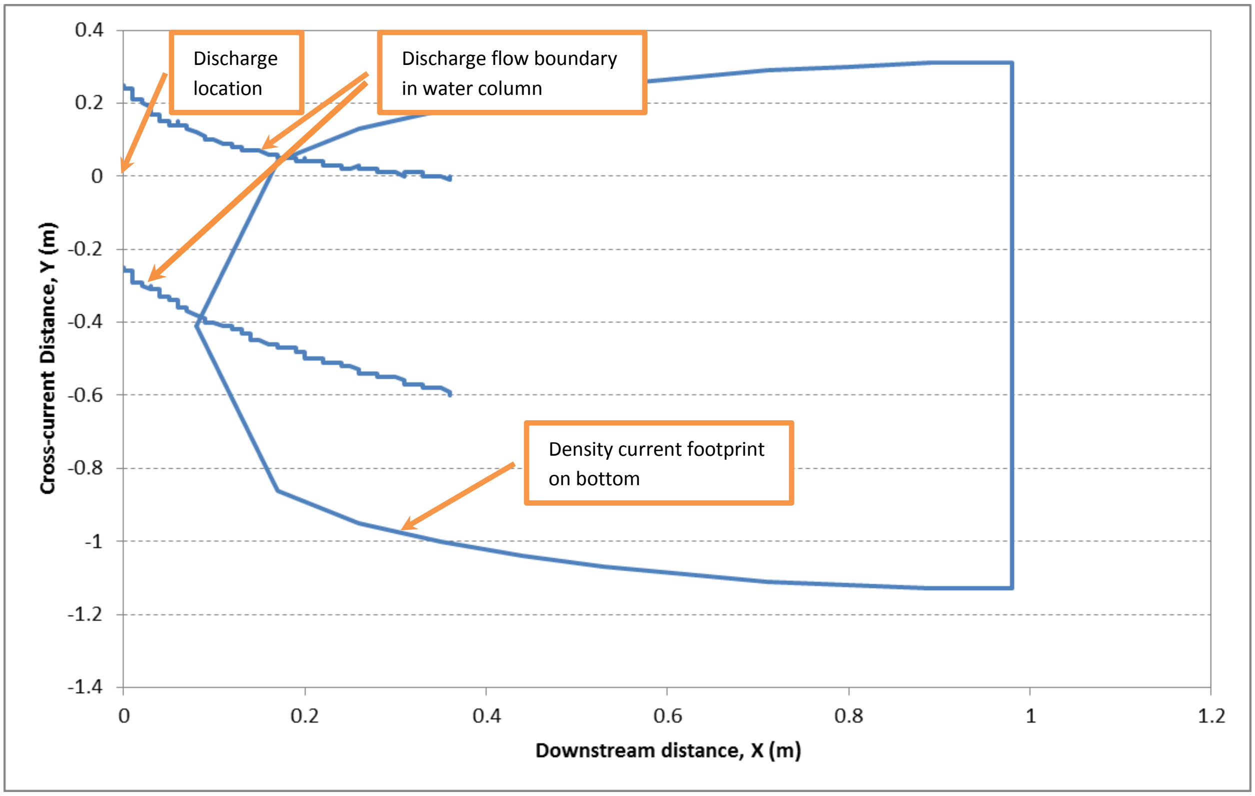

Figure 3-4 – Plan-view of predicted near-field plume height for half-peak current conditions

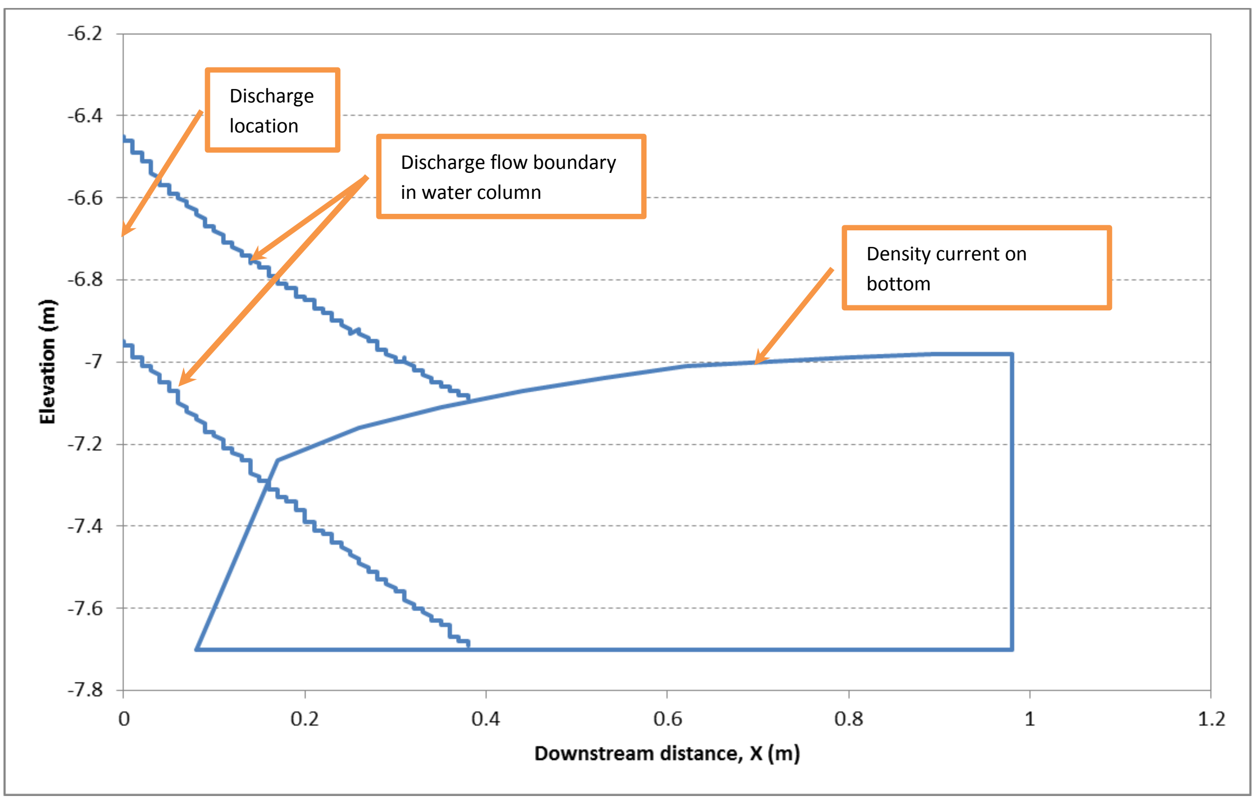

Figure 3-5 – Side-view of predicted near-field plume height for half-peak current conditions

4 PDFATE Underflow Analysis

The PDFATE model was used to evaluate the underflow spreading and predict the deposition of sediments on the bottom and the entrainment of sediments into the overlying water column.

4.1 Model Description

The PDFATE model simulates the spreading dynamics of a particle laden, dense underflow under the effect of gravity. As described by Teeter (2001), the model formulation includes:

- Deposition of sediment particles according to concentration dependent settling rates and shear stress thresholds related to sediment characteristics;
- Entrainment of overlying water into the underflow according to the local Richardson number of the underflow;
- Appropriate flow properties of the underflow suspension;
- Lateral spreading of the underflow; and
- Variable bottom slope.

PDFATE is a quasi-steady state model in which the time derivatives are ignored in the governing equations. However, the model updates at discrete time intervals by solving for time of travel at every location along the underflow and updating bed elevations based on the cumulative depositional thickness from the preceding time steps.

4.2 Model Inputs

The PDFATE model requires two input files:

- *puf_file*, which specifies the discharge characteristics, the transition condition, underflow sediment conditions, run control parameters, and initial depth data; and
- *bc*_file, which specifies the ambient current velocity time series.

The inputs to the *puf_file* are listed in Tables 4-1 through 4-4. The discharge characteristics are listed in Table 4-1. Similar to the inputs to the CORMIX model, the discharge rate of 0.124 m^3/s is based on the assumption of a 10" hydraulic dredge, and a sediment concentration of 125 kg/m^3 is a typical concentration for hydraulic dredging of fine grained sediments.

The transition condition inputs are listed in Table 4-2. Based on the results of the CORMIX model, the mixing prior to underflow is 3.2, and the width at the point of underflow formation is 1.4 m. The bulk Richardson number, Ri, for the flow is defined as

$$Ri = \frac{g\Delta\rho h \cos\theta}{\rho U^2}$$

where g is acceleration due to gravity, $\Delta\rho$is the density difference between the underflow and the overlying ambient suspension, h is the depth, θ is the bottom slope, ρ is the layer density, and U is the underflow speed. The critical Richardson number for a plunging underflow is about 1 (Fang and Stefan 1998). This value was reduced to a value of 0.95 to increase model stability.

Table 4-3 provides the coefficients that are used to determine the sediment condition in the underflow. The threshold for deposition, tau_d, is the critical shear stress below which deposition of sediment on the bottom occurs. The bed density upon formation, cs, is the initial density of the mud immediately after depositing on the bottom (prior to consolidation). The settling velocity, ws1, was determined based on the grain size distribution determined for input to the CORMIX model (Section 3). As discussed in Section 3, this distribution was based on the grain size analysis results of multiple samples collected at the project site. The fraction of material within each of the grain size classes required for input to CORMIX is given in Table 4-5. Also listed in Table 4-5 is the settling velocity used by CORMIX that is representative of each sediment size class. To determine a representative settling velocity for the whole sediment mixture for input to PDFATE, a harmonic weighted mean of the fractions and settling velocities listed in Table 4-5 was calculated as 0.0003 m/s. The settling rate coefficient, b2, and settling rate exponent, b1, are used to calculate the hindered settling rate, defined as

$$Ws = ws1(1 - b2\ C)^{b1}$$

where C is the suspended sediment concentration.

Table 4-4 provides the run control group of parameters. Eight hours was the maximum duration the model would successfully execute. After that point, the bottom deposition decreases the bottom slope of the profile to the point that the underflow would switch paths to another steeper slope.

Table 4-1 Discharge group of input parameters

Symbol	Description	Value	Unit
Lat_dischg	Latitude of discharge	32.10	Degree
Long_dischg	Longitude of discharge	80.83	Degree
O_dischrg	Orientation of discharge from north	180	Degree
Q_dischg	Pipeline discharge rate	0.124	m3/sec
C_dischg	Sediment concentration in pipeline	125	kg/m3

Table 4-2 Transition condition group of input parameters

Symbol	Description	Value	Unit
Sa	Dilution prior to underflow	3.2	-
B_o	Width at the point of underflow formation	1.4	m
Ri_o	Richardson number at the point of underflow formation	0.95	-
rho_1	Ambient fluid density	1020	kg/m3

Table 4-3 Underflow sediment condition group of input parameters

Symbol	Description	Value	Unit
tau_d	Threshold for deposition	0.15	Pa
cs	Bed density upon formation	180	kg/m3
ws1	Reference settling rate	0.0003	m/sec
b2	Settling rate coefficient	0.004	m3/kg
b1	Settling rate exponent	5.29	
tuy1	Yield stress coefficient	800	Pa
tuy2	Yield stress exponent	3	
mu1	High-shear viscosity coefficient	200	
mu2	High-shear viscosity exponent	1.68	
mu3	Low-shear viscosity coefficient	1.23E-06	
mu4	Low-shear viscosity exponent	2.8	

Table 4-4 Run control group of input parameters

Symbol	Description	Value	Unit
total_t	Total discharge time	8	hours
x_step	Horizontal step-size	1	m
out_inc	Print-out x_step spacing	2	
num_sweeps	Maximum number of computational sweeps	16	
num_steps	The number of depths along x-axis at x-step interval	750	

Table 4-5 Sediment size distribution and settling velocities used by CORMIX

Sediment Class	Fraction of dredged material (%)	Particle size (um)	Ws (m/s)
sand	9	> 62	0.32
coarse silt	19	16-62	0.00628
fine silt	35	3.3-16	0.000394
clay	37	<3.3	0.000134

The input bottom profile shown in Figure 4-1 was extracted from the bathymetry shown in Figure 2-2. The data were extracted along a transect extending from the discharge point in the downslope direction to west-northwest.

Figure 4-2 shows the input current time series. The depth-averaged currents range from a peak speed of 0.77 m/s to a minimum of 0.1 m/s. The currents were adjusted from the depth-averaged values to speeds at 1-meter above the bottom using Prandtl's power law:

$$\frac{u(z)}{u_{max}} = \left(\frac{z}{d}\right)^{1/N}$$

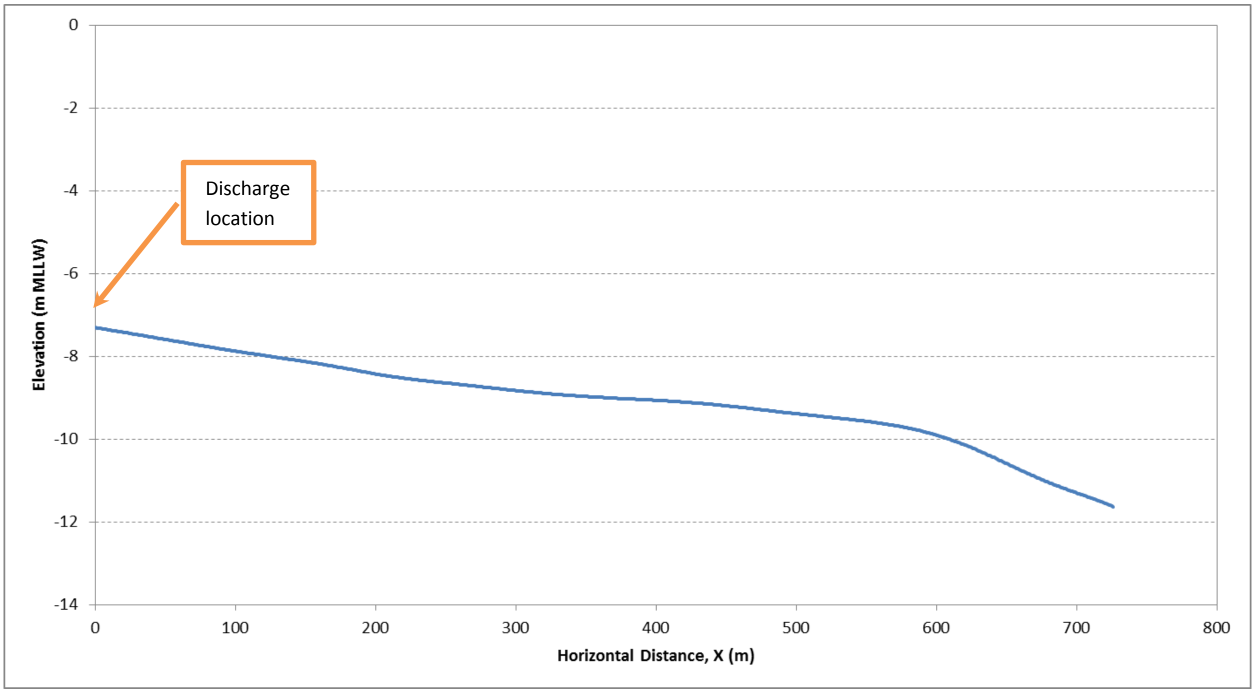

Figure 4-1 – Bottom elevation profile input to PDFATE model

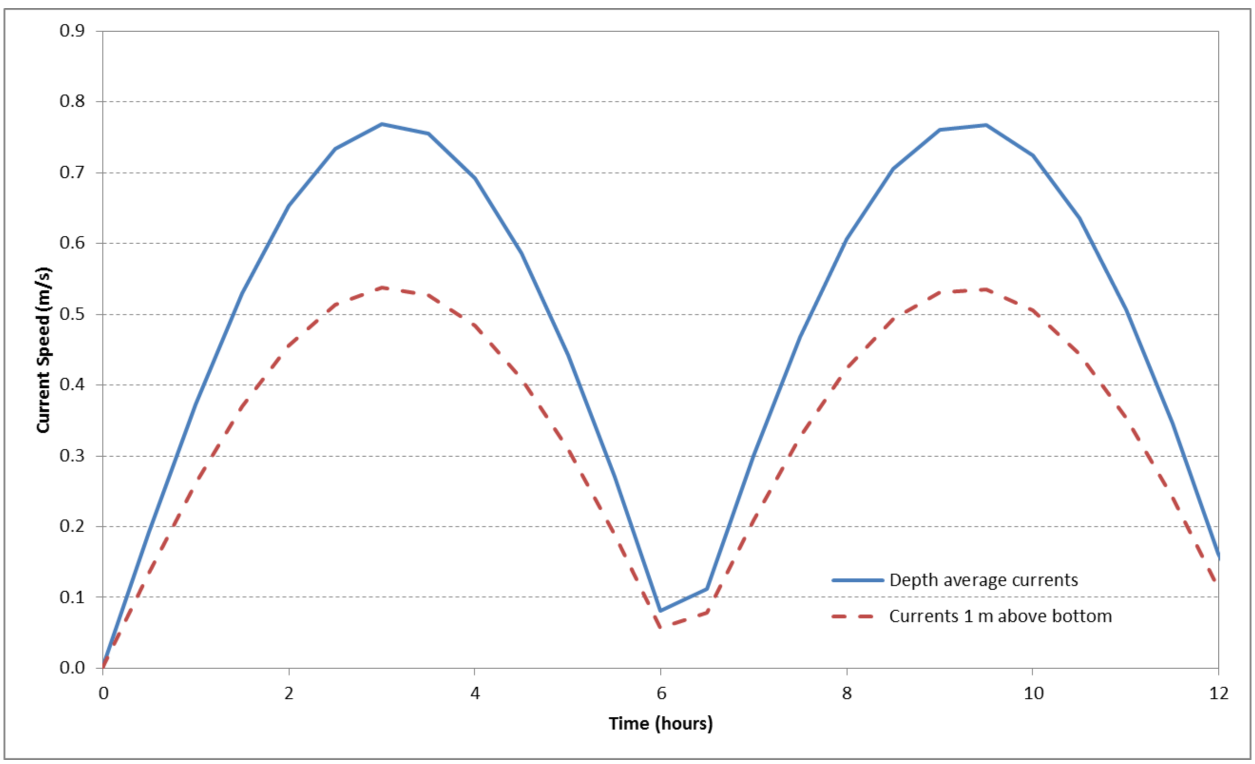

Figure 4-2 – Current speed time series input to PDFATE model

where $u(z)$ is the velocity at elevation z; u_{max} is the maximum velocity in the vertical profile; d is the water depth; and N is a coefficient ranging from 4 for wide irregular channels to 12 for deep narrow channels. A value of N equal to 4 was used for this analysis. The data are input to PDFATE at a 0.5-hour interval, as required by the model.

Two different scenarios were simulated to evaluate the appropriate range for the input yield stress coefficient (tuy1) and high-shear viscosity coefficient (mu1). The appropriate range for these variables extends up to an order of magnitude higher than those listed in Table 4-3 above. Therefore, the second simulation increased these variables by an order of magnitude (i.e., tuy1 equal to 8,000 Pa and mu1 equal to 2000). Hereafter, the lower set of values is referred to as Scenario 1, and the higher set of values is referred to as Scenario 2.

4.3 Model Results

Example computed profiles of the fluid mud underflow and deposit heights for Scenario 1 are shown in Figures 4-3 and 4-4 for 4 and 8 hours after the discharge begins. As shown in Figure 4-4, the zone of active deposition extends up to 410 meters (1,350 feet) from the discharge location. The predicted width of the underflow area is shown in Figure 4-5. The model predictions show a long, narrow underflow in the active deposition area. This deposition area does not go beyond the proposed placement area boundaries.

The results for Scenario 2 predicted a zone of active deposition extending less than 100 meters from the discharge point. These results indicate that the deposit area may be smaller than that predicted for Scenario 1 (and thicker in height), depending on the rheological properties of the dredged material. To provide a conservative estimate of potential bottom coverage impacts to bottom habitat, the Scenario 1 coverage area is used.

For Scenario 1, the PDFATE model predicts that approximately 65 percent of the discharged dredged material will be entrained into the overlying water column and dispersed with the ambient currents. For Scenario 2, approximately 48 percent of the material is entrained. The actual amount of sediment that will be entrained into the water column will likely be lower than either of these two estimates because: (1) these large fluxes will cause armoring of the underflow surface and will cause density changes by winnowing of fine particles out of the underflow; and (2) the actual entrainment rate will be limited by density stratification in the underflow that is not represented by the model. Although the actual entrainment rates are expected to be lower than the predicted rates, the model predicted rates of 65 percent is used in Section 5 to provide a conservative (i.e., high) estimate of the maximum potential suspended sediment plume caused by the underflow. The entrainment fluxes predicted for Scenario 1 are listed in Table 4-6.

Figure 4-6 shows the bottom area potentially affected by the underflow during the project. As described previously, the deposition of sediments from the underflow will change the bottom slope over time and eventually cause the underflow to switch paths to a new downslope path. To be conservative, it is assumed that the deposited sediments from the underflow could extend in all directions from the

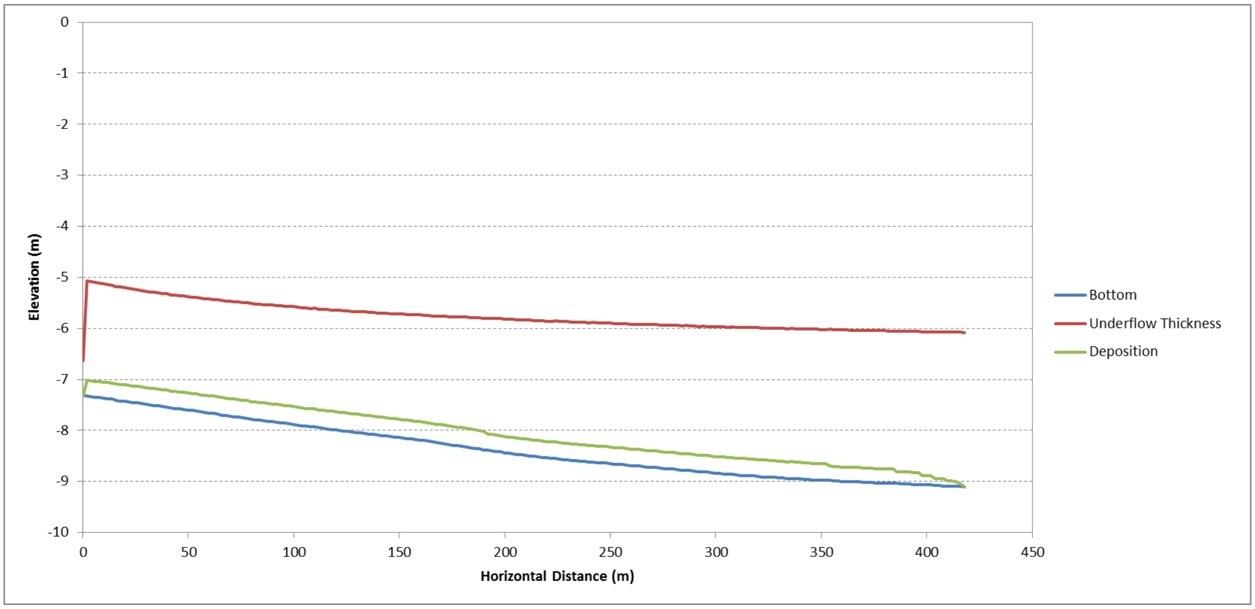

Figure 4-3 – Predicted deposition and underflow thickness after 4 hours

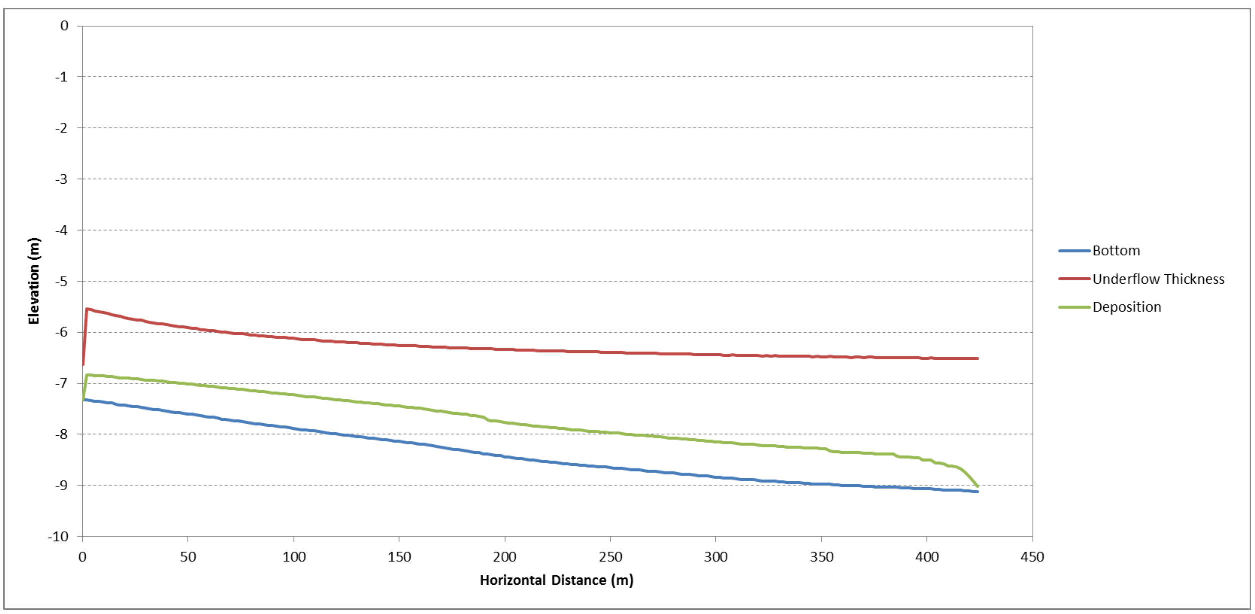

Figure 4-4 – Predicted deposition and underflow thickness after 8 hours

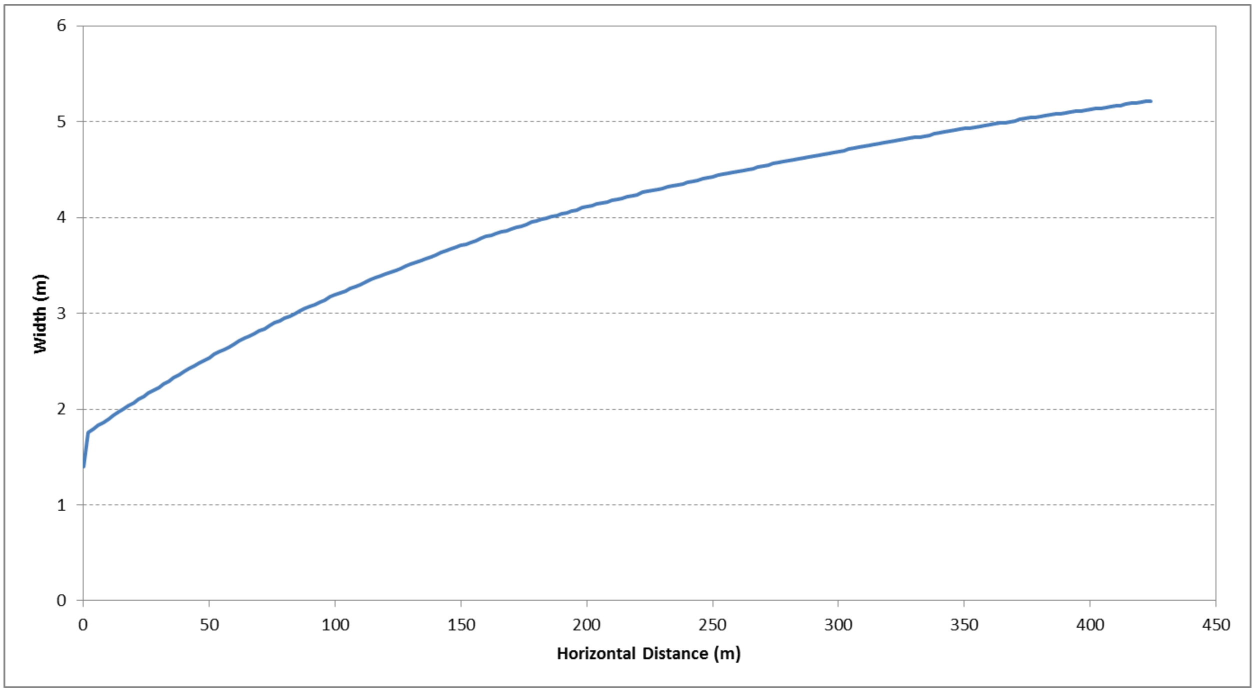

Figure 4-5 – Predicted underflow width after 8 hours

Table 4-6 Predicted entrainment flux versus ambient current speed

Ambient Current Speed (m/s)	Entrainment Flux (kg/s)
0	0
0.14	0.1
0.26	1.7
0.37	7.9
0.46	18.3
0.51	29.3
0.54	35.2
0.53	32.6
0.48	23.2
0.41	11.8
0.31	3.8
0.19	0.5
0.06	0

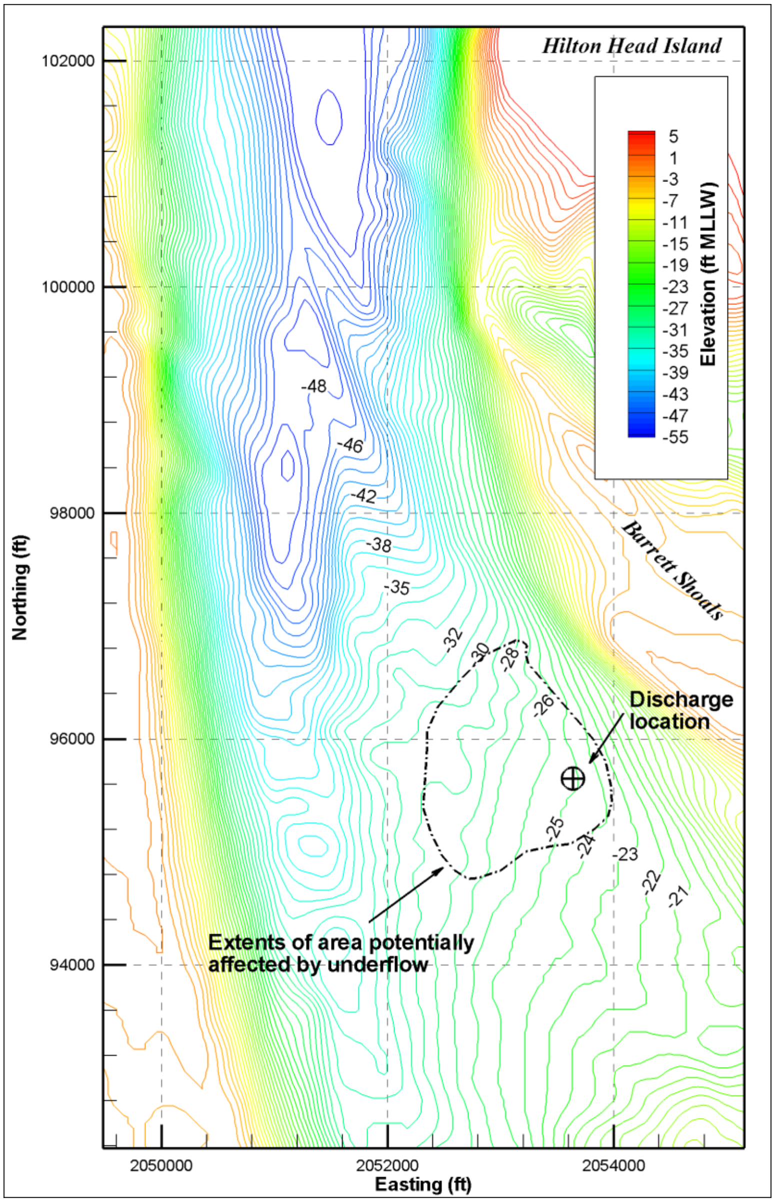

Figure 4-6 – Existing depths and estimated maximum extent of area affected by underflow.

discharge point within a 410-meter radius. The area potentially affected by the underflow was determined by extending the predicted sediment deposition slope in a radial pattern from the discharge point until intercepting the existing slope. The area potentially affected by the underflow is approximately 56 acres.

As mentioned previously, the tidal currents at the site will erode the deposited sediments, as examined in the following Section 5 of this report. The erosion of the deposited sediments will occur on each tide throughout the 6-month project. Therefore, the impacts to the bottom are expected to be much smaller than the above estimate, and as explained in Section 5, the project will not cause any permanent or long-term changes to the bottom.

The suspended sediments from the dredge outfall and underflow are entrained into the water column at a maximum rate of 35.2 kg/s. This is relatively minor as compared to sediments regularly passing through the area in the water column. For instance, based on the ADCP measurements by ATM (2000) across the Calibogue Sound inlet, the peak tidal flow rate through the inlet is about 10,200 m^3/s. At a concentration of 68 mg/L, a sediment mass flux of 693 kg/s flows through the Calibogue Sound inlet at peak ebb tide flow. Therefore, the sediments entrained from the underflow into the water column represent about 5% of the suspended sediments typically passed through Calibogue Sound inlet on each tide.

5 Long-Term Fate Analysis

The long-term stability of the sediments deposited on the bottom was evaluated using the Environmental Fluid Dynamics Code (EFDC) coupled with the SEDZLJ sediment transport model (EFDC-SEDZLJ). The goal of the analysis is to determine the stability of the sediments deposited on the bottom during the typical tidal current conditions that affect the placement site.

5.1 Model Description

EFDC is a general purpose model for simulating three-dimensional flow, transport and biogeochemical process in surface water systems (Hamrick, 1996). The EFDC model was originally developed by Dr. John Hamrick at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software. EFDC is currently supported by Tetra Tech for the U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD), EPA Region 4, and EPA Headquarters.

As described by Hamrick (1996), the physics of the EFDC model, and many aspects of the computational scheme, are equivalent to the widely used Blumberg-Mellor model. The EFDC model solves the three-dimensional, vertically hydrostatic, free surface, turbulent averaged equations of motions for a variable density fluid. EFDC also solves dynamically coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity and temperature. The transport equations use the Mellor-Yamada level 2.5 turbulence closure scheme. The EFDC model uses a stretched or sigma vertical coordinate, and curvilinear orthogonal horizontal coordinates.

Sandia National Laboratories (Sandia) modified the EFDC model to include the SEDiment dynamics algorithms as developed by Ziegler, Lick and Jones (SEDLZJ) (James, et al., 2010; Thanh et al., 2008). The state-of-the-science SEDZLJ model simulates sediment dynamics, including the processes of erosion, bedload transport, bed sorting, armoring, settling of sediment particles, and deposition. SEDZLJ uses a unified treatment of cohesive and non-cohesive sediments, and it includes the ability to incorporate site specific data to characterize sediment bed properties and erosion characteristics. SEDZLJ was designed to directly use the results obtained using the SEDflume method (McNeil et al., 1996) of testing sediment bed critical shear stresses and erosion rates. Also, for depth-averaged simulations, the model assumes a Rouse profile for the suspended noncohesive sediments, and the calculated near-bottom concentration is used in determining the deposition rate. James et al. (2010) provides a detailed description of the model formulation.

The EFDC-SEDZLJ model has been used recently by the USACE for Long-Term Fate (LTFATE) modeling analysis of sediments placed in open water, including projects at the Ocean Dredged Material Disposal Site (ODMDS) at Jacksonville, Florida (Hayter, 2010), and the Federal Navigation Project at Grays Harbor (GH), Washington (Dimerbilek, et al., 2010).

5.2 Model Inputs

5.2.1 Hydrodynamic Model Setup

The EFDC model requires specification of the model geometry (i.e., the computational grid and depths) and the model boundary conditions. For this project, the hydrodynamic model was set up as a one-dimensional depth-averaged model to test the stability of the deposited sediments under the typical tidal current conditions. The ambient depth of the model grid was set to -7.6 m MLW.

The grid includes 50 cells in the horizontal direction each with a cell width of 40 meters, for a total length of 2,000 m. As described in Section 4, the PDFATE model predicts that the sediment deposited under the density current will extend up to 410 meters from the discharge point. Therefore, the center 10 cells (400 m total) are used to represent the deposit area for the simulation.

The model includes an open boundary at each of the two ends of the grid. Tidal water levels were input for each open boundary based on predicted astronomical tides for August 2012 (Figure 5-1). The phase difference (i.e., the time difference) between the two boundaries was iteratively adjusted until the peak depth-averaged currents in the model reached 0.8 m/s, which is representative of the typical peak current speeds that affect the placement site. The simulated current velocities are shown in Figure 5-2.

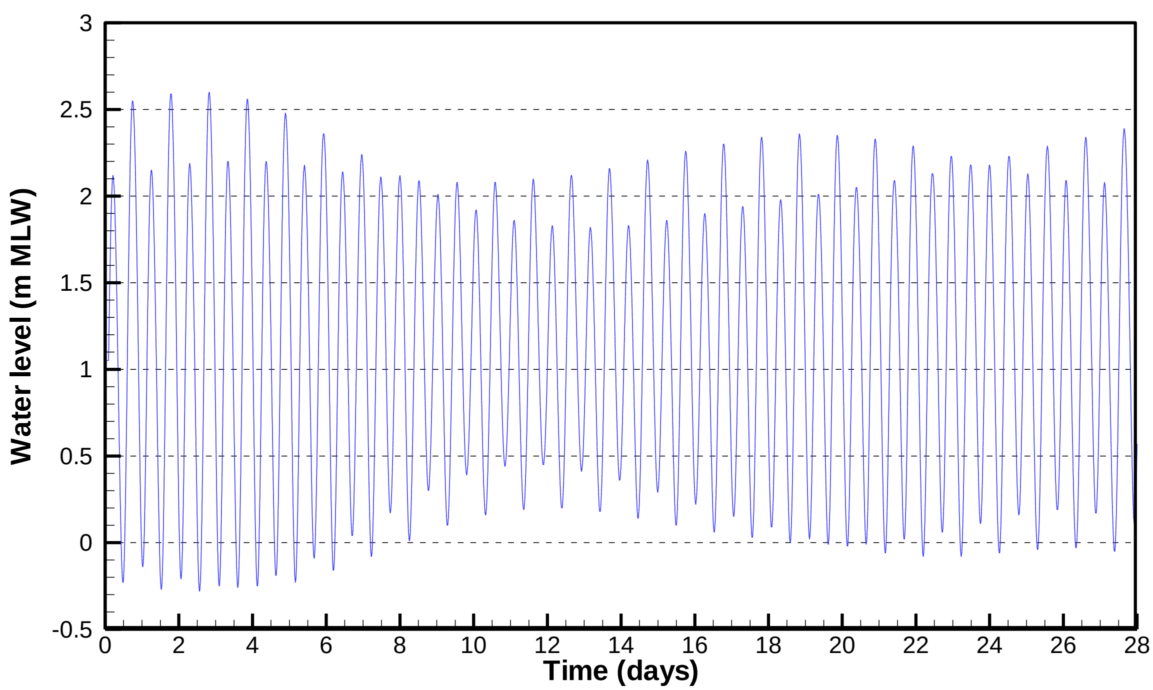

Figure 5-1 – Predicted astronomical tidal water levels used for EFDC-SEDZLJ model boundaries

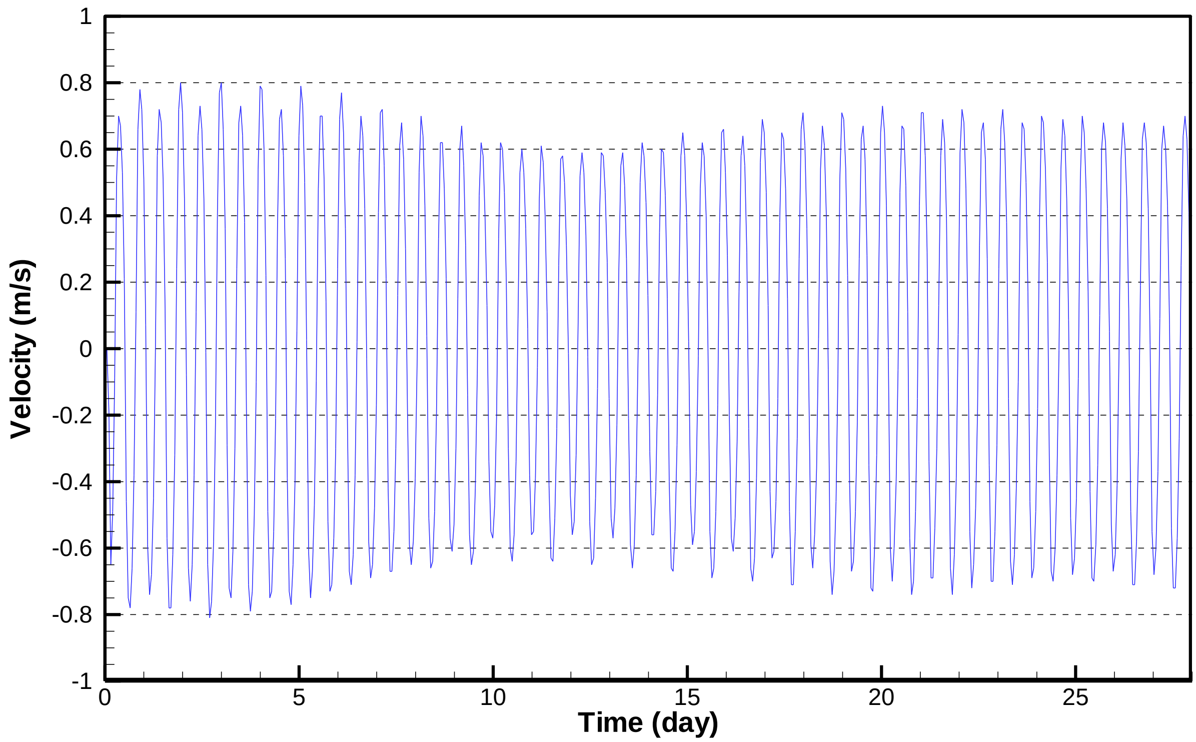

Figure 5-2 – Simulated current velocities

5.2.2 Sediment Model Setup

The SEDZLJ sediment model setup requires specification of the bottom sediment characteristics, including initial sediment particle size distribution, bed density, erosion rates, and critical shear stresses for the initiation of erosion. Although site specific sediment grain size distribution measurements are available for both the material to be dredged and the ocean bottom near the placement site (GEL, 2008), site specific measurements of other sediment bed characteristics (i.e., density, erosion rates, and critical shear stresses) is not available. Therefore, this evaluation relies on sediment testing data for sediments collected in Jacksonville Harbor (Sandia, 2007), as well as other literature values, such as sediment testing data published by Roberts et al. (1998). The site sediments for this project are expected to be similar to the values derived from these sources as described below.

Sandia (2007) tested the consolidation rates and erosion rates of the sediments to be dredged from the Mayport turning basin as part of the *Jacksonville Harbor ODMDS Dredged Material Erosion Rate Analysis*. The analysis included testing of wet sampled sediments that were mixed and allowed to consolidate for a range of durations, including: 2, 10, 30, 60 and 90 days. Bulk density was determined as a function of depth and consolidation time. These consolidated sediment cores were then tested in a flume to determine the sediment erosion rates as a function of shear stress and depth.

The Sandia (2007) analysis included three composite samples from the Mayport turning basin: SF-MP06-1, SF-MP06-2, and SF-MP06-3. A summary of the bulk properties of these sediments is given in

Table 5-1. All three sediments consolidated within a very low range as compared to many other natural sediment types.

The Mayport turning basin sediments and the SIDA sediments are similar in that they both are from marine environments, and they both have a high fraction of silt and clay. The Mayport sediments are 33 percent clay, 46 percent silt, and 21 percent fine sand (Hayter, 2010). On average, the SIDA sediments are percent 37 clay, 54 percent silt, and 9 percent sand. Therefore, the results of the Mayport sediment tests are appropriate for simulating the order of magnitude of the erosion rates for the SIDA sediments.

Table 5-1 Summary of Mayport turning basin bulk sediment properties (Sandia, 2007)

Sediment Name	Bulk Density Range (g/cm^3)	Mean Particle Size (µm)	Mean Organic Content (% by mass)
SF-MP06-1	1.167-1.208	34.4	4.7
SF-MP06-2	1.166-1.210	30.3	4.9
SF-MP06-3	1.153-1.180	31.6	5.3

Given that site specific sediment erosion data are not used for this analysis, sediment testing data for fine grained sediment from another site were also used in order to evaluate a range of potential erosion rates. Similar sediment testing as that described above was conducted for four sediments retrieved from the Canaveral ODMDS and Harbor. CDS-1 and CDS-2 are from the ODMDS, CH-B-2 is from the West Turning Basin of the Canaveral Harbor, and CH-EC-S-1 was a composite of samples collected from a barge with sediments dredged from the Canaveral Harbor Entrance Channel (Sandia, 2001). The CH-EC-S-1 and CHB-2 sediments were much finer in particle size and more cohesive than the other sediments, and therefore they are more appropriate for use in this evaluation. A summary of the bulk properties of the Canaveral Harbor and ODMDS sediments is given in Table 5-2.

Table 5-2 Summary of Canaveral Harbor and ODMDS bulk sediment properties (Sandia, 2001)

Sediment Name	Bulk Density Range (g/cm^3)	Mean Particle Size (µm)	Mean Organic Content (% by mass)
CDS-1	1.33-1.44	52.2	3.21
CDS-2	1.55-1.65	92.2	2.23
CH-EC-S-1	1.20-1.25	23.3	4.37
CHB-2	1.21-1.27	27.1	3.57

The sediment erosion rates were measured using a SEDflume for shear stresses of 0.1 to 10 Pa for the Canaveral sediments and for shear stresses between 0.5 and 8.0 Pa for the Mayport sediments. These data were fit to the equation:

$$E = A\tau^n \rho^m \qquad (5.1)$$

where E is the erosion rate (cm/s), τ is the shear stress (Pa), ρ is the bulk density (g/cm3), and n, m, and A are constants. The constants determined by Sandia (2001 and 2007) are summarized in Table 5-3. Equation 5.1 was used with the constants in Table 5-3 to determine the critical shear stress for erosion and the erosion rates as a function of density.

Table 5-3 Equation 5.1 constants for Mayport and Canaveral sediments (Sandia 2001 and 2007)

Sediment	n	m	A
SF-MP06-1	2.56	-113	6.20E+04
SF-MP06-2	2.5	-137	3.00E+06
SF-MP06-3	2.32	-170	1.00E+08
CDS-1	2.32	-43.9	1055
CDS-2	2.71	-66.8	3.35E+10
CH-EC-S-1	2.73	-107.1	1.33E+06
CHB-2	2.51	-105.2	4.85E+06

The lowest density and highest organic content sample (SF-MP06-3 from the Mayport turning basin) was assumed to be the best sample representative of the SIDA sediments for two reasons. First, the SIDA sediments also have a high organic content (an average of 9 percent, based on sampling conducted by ATM [ATM, 2000b]). Second, the SIDA sediments will also have a very low density upon initial placement.

The sediment bed in the model has 5 layers. The SEDZLJ model initializes the first two layers as zero thickness, and these layers are used for the active and depositional zones of the model. The subsequent layers 3, 4 and 5 are used to characterize the existing sediment bed. The sediment bed in the SEDZLJ model was set up to include two different bed types: the deposited sediments, and the surrounding sand bottom. Each bed type is referred to as a "Core" in the model. The input bed characteristics are listed in Table 5-4. The critical shear stresses for the deposit sediment (layer 3 of Core 1) listed in Table 5-4 are based on the SF-MP06-3 data, and the surrounding fine sand bottom characteristics (Core 2) are the same as that used for the Jacksonville ODMDS study (Hayter, 2010).

Table 5-4 Input bed characteristics for cores 1 and 2

	Core 1			Core 2		
Layer	3	4	5	3	4	5
Thickness (cm)	10	1	80	10	1	80
Density (g/cm3)	1.155	1.155	1.92	1.92	1.92	1.92
Critical shear stress (Pa)	0.07	0.07	0.38	0.38	0.38	0.38
Shear (Pa)	E (cm/s)			E (cm/s)		
0	1.00E-09	1.00E-09	1.00E-09	1.00E-09	1.00E-09	1.00E-09
2	5.49E-05	5.49E-05	5.97E-05	5.97E-05	5.97E-05	5.97E-05
4	2.74E-04	2.74E-04	5.97E-04	5.97E-04	5.97E-04	5.97E-04
8	1.37E-03	1.37E-03	5.96E-03	5.96E-03	5.96E-03	5.96E-03
16	6.83E-03	6.83E-03	5.95E-02	5.95E-02	5.95E-02	5.95E-02
32	3.41E-02	3.41E-02	5.94E-01	5.94E-01	5.94E-01	5.94E-01

The grain size distributions of the sediments were grouped into four grain size classes: 3, 70, 250 and 375 µm. The grain size distributions input to the model are shown in Table 5-5. The grain size distribution for the layer 3 in Core 1 is based on the average of the sediment distributions measured by GEL (2008) for the dredge areas. The distribution for the surface layer in the surrounding areas (layer 3 of Core 2) is based on the distribution of the ocean reference grab sample analyzed by GEL (2008), which was taken from the bottom near the proposed placement site.

Table 5-5 Input sediment particle sizes for cores 1 and 2

	Core 1			Core 2		
Layer	3	4	5	3	4	5
Particle Size (µm)	Percent			Percent		
3	72	72	3	3	3	3
70	25	25	17	17	17	17
250	3	3	68	68	68	68
375	0	0	12	12	12	12

As described in Section 4, the PDFATE model predicts that the underflow will extend up to 410 meters from the discharge point at a width of about 10m. Sediment deposited under the density current will be approximately 0.6 m thick. The thickness of the initial deposit from the underflow is based on an initial density of 0.18 g/cm^3. This deposit will quickly consolidate and increase in density. The density of the sediments used for the sediment deposit at the beginning of the EFDC-SEDZLJ simulation is based on the lowest density sample from Mayport (SF-MP06-3). The initial density testing of that sample after 2-days showed densities in the range of 1.15 to 1.16 g/cm^3. Assuming a density of 1.15 g/cm^3, the deposited sediments from the underflow will decrease in thickness to approximately 0.1 m. Therefore, the initial grid depths represent a 0.1 m deposit across a 400 meter section in the middle of the grid.

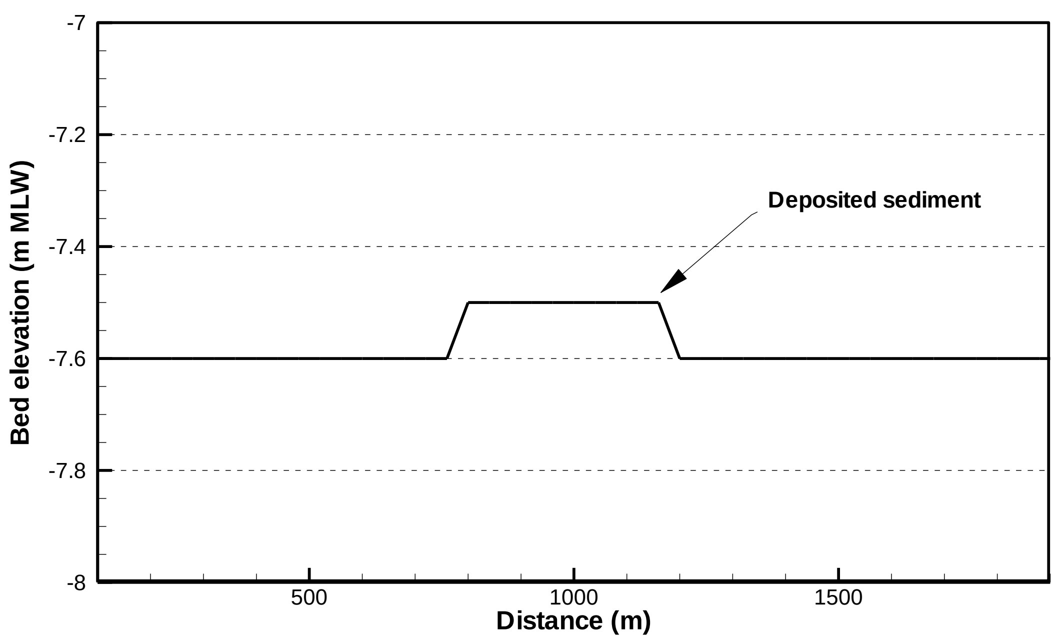

Figure 5-3 – Initial EFDC-SEDZLJ model bottom elevation

5.3 Model Results

The model was used to simulate the erosion of the deposited sediment during neap tide conditions. The hydrodynamic simulation started at day 10.7 of the tidal signal shown in Figure 5-1, and after one day of spin-up, the sediment transport model started on day 11.7. Neap tide conditions exhibit lower current velocities as compared to spring tide conditions, and therefore this simulation represents the low end of expected erosion rates. Higher velocities and erosion rates will occur during spring tide conditions.

The simulated change in bed elevation is shown in Figure 5-4. Approximately half of the deposit is eroded within 1 day, and nearly 80 percent is eroded within 2 days.

The simulated percent of the original deposit volume versus time is plotted in Figure 5-5, along with the simulated shear stress and depth-averaged current velocities. As shown by the bottom shear stresses in Figure 5-5, on every tidal cycle the simulated shear stress exceeds the critical shear stress for erosion of the deposited sediments, which is estimated as 0.07 Pa. Therefore, the deposited sediments will be eroded on every tidal cycle. These results show that the deposit quickly erodes to 20 percent of the initial volume. The last 20 percent erodes more slowly because of coarsening of the top surface of the sediments by fine sand that causes an armoring effect. Altogether, most of the sediments erode over a period of two days, and the remainder erodes over a period of weeks.

As a sensitivity analysis, the other sediment samples from the Mayport testing (Sandia, 2007) and the turning basin and harbor samples from the Canaveral Harbor testing (Sandia, 2001) where used for the erosion rate characteristics of the sediment deposit. The simulated percent remaining versus time for these samples is shown in Figure 5-6. These sediments show results in a similar range, although with slightly higher erosion rates.

The EFDC-SEDZLJ results indicate that the deposited sediments will quickly erode following placement on the bottom. The erosion of the deposited sediments will occur throughout the 6-month project, and the sediments will be completely eroded from the placement site within weeks after the project is completed. Therefore, the proposed placement site is a dispersive site, and the project will not cause any permanent or long-term changes to the bottom.

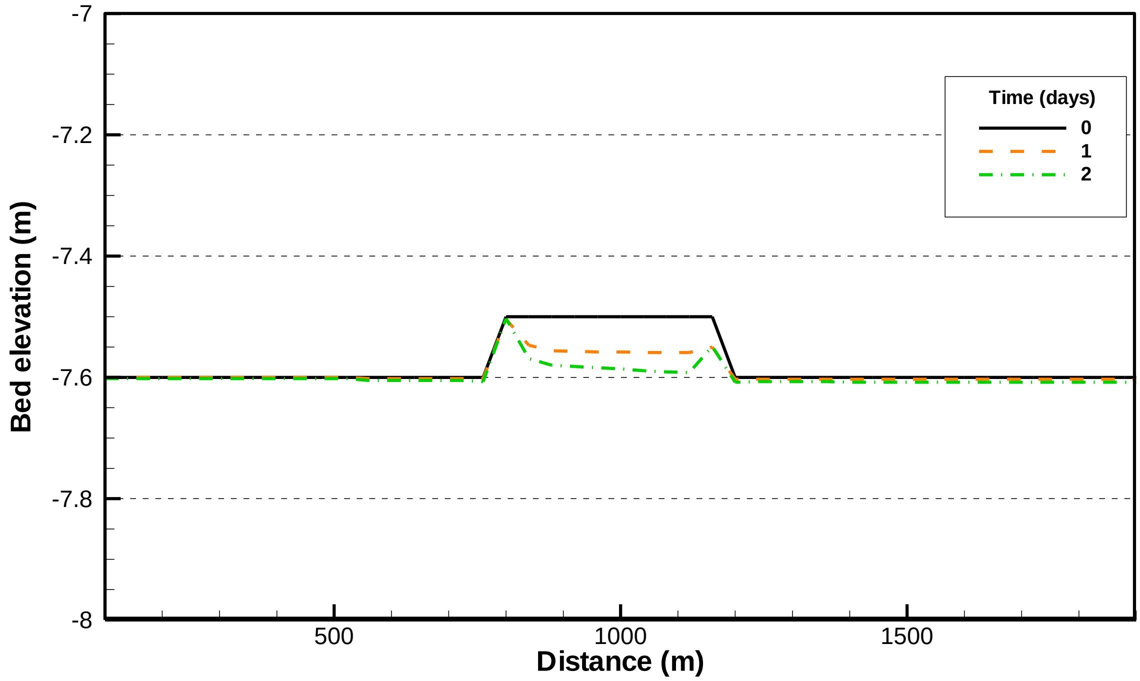

Figure 5-4 – Simulated change in bottom elevation

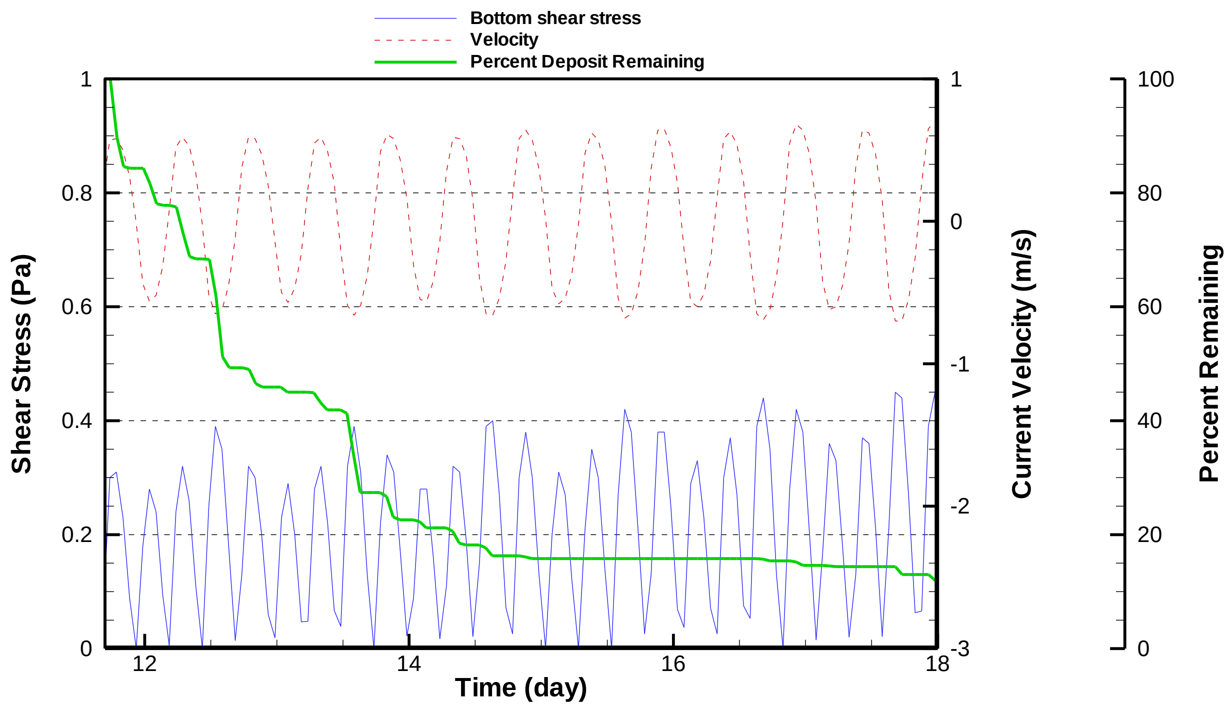

Figure 5-5 – Simulated bottom shear stress, velocity and percent sediment deposit remaining

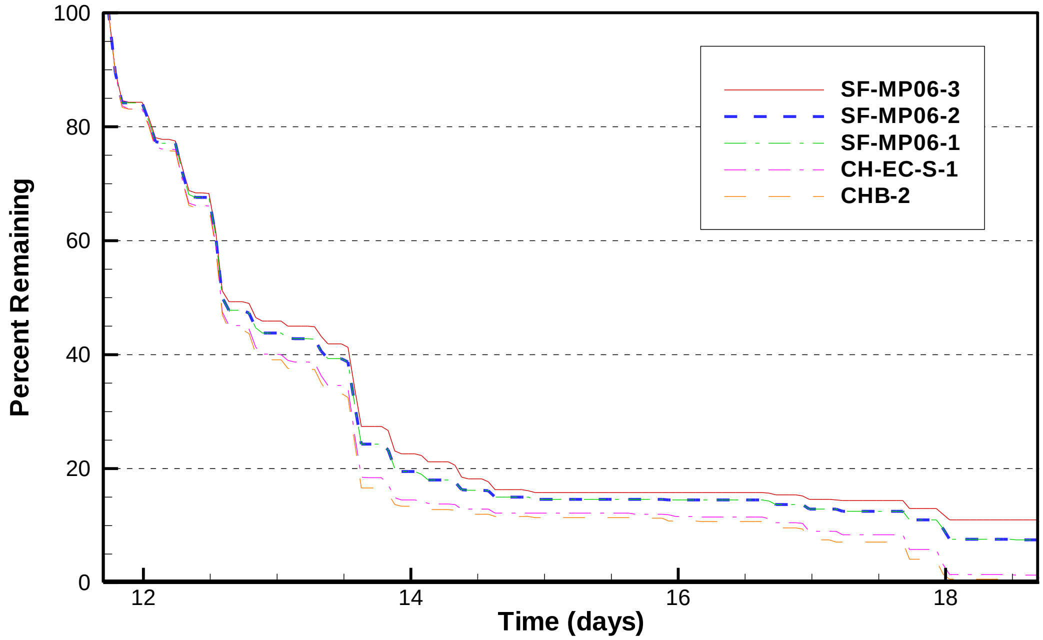

Figure 5-6 – Simulated percent sediment deposit remaining for five sediment types

6 Far-field Plume Analysis

The sediments entrained into the water column and carried away by the currents will create a plume of suspended sediments. The entrained sediments may come from three sources: entrainment at the pipe outfall; entrainment along the underflow surface; and erosion of sediments recently deposited on the bottom. The dredged material that is entrained into the overlying water column will undergo passive dispersion by the ambient currents. A far-field dispersion model described by Kuo et al. (1985) was used to predict the dispersion of the sediments in the ambient flow field.

6.1 Model Description

Kuo et al. (1985) describe a dredging induced turbidity plume model. The Kuo et al. far-field plume model is used in the USACE's DREDGE model (Hayes and Je, 2000). The plume Total Suspended Sediment (TSS) concentration is predicted by the following equation:

$$c(x,y,z) = \frac{Q}{4\pi(k_y k_z)^{1/2}x} exp\left[-\frac{(y-y')^2}{4k_y\frac{x}{u}} - \frac{\left(z-z'+\omega\frac{x}{u}\right)^2}{4k_z\frac{x}{u}}\right]$$

where

- c = TSS concentration (mg/L);
- x = horizontal distance along river channel;
- y = horizontal distance across river channel;
- (y', z') = location of point source (i.e., the dredge);
- z = vertical distance from river bottom;
- Q = source of material per unit of time;
- k_y = diffusion coefficient in the y-direction;
- k_z = diffusion coefficient in the x-direction;
- u = ambient current velocity; and
- ω = particle fall velocity.

6.2 Model Inputs

The required model inputs include the source strength (i.e., the rate at which dredge material is entrained into the ambient flow field), the diffusion coefficients, the ambient current velocity, and the particle fall velocity.

For this analysis, there are three components to the source strength:

1. The material stripped from the discharge during the initial mixing in the near-field;

2. The material entrained into the water column from the underflow by the ambient current field; and
3. The material eroded from recently deposited sediments.

The source strength for item 1 above is estimated as a fraction of the dredge discharge rate. For open water placement, Barnard (1978) estimates that 97 to 99 percent of the slurry descends rapidly to the bottom. Therefore, the fraction of material stripped from the sediment plume as it descends from the outfall to the bottom ranges between 1 and 3 percent. When the outfall is located near the bottom, however, this percentage is lower. For example, for the Tyler Beach dredge monitoring project, which monitored material discharged from an outfall 4 meters above the bottom, Teeter (1992) estimated an entrainment rate of 300 g/s (which is 0.7 percent of the total discharge rate of 43,000 g/s). For this analysis, the rate of 155 g/s was used, which 1 percent of the discharge rate of 15,500 g/s.

For the second component, the entrainment rate from the underflow, the rate varies with both the predicted underflow length and with the tidal current. For the 410 meter long underflow simulation, during peak currents, the entrainment rate predicted by PDFATE is 35.2 kg/s, and at half of the peak current conditions, the entrainment rate predicted by PDFATE is 1.7 kg/s. The water column effects are much larger during peak current conditions (by an order of magnitude), and therefore, only the peak current conditions are presented here. As discussed in Section 4, the underflow may be as short as 100 meters long. For a 100 meter long underflow, the entrainment rate is 24.5 kg/s during peak currents. The underflow source was distributed evenly along a line representing the underflow length.

The third source is from the erosion of deposited sediments. Because the underflow will change paths over time, both the entrainment from the surface of the underflow and erosion of recently deposited sediments into the water column will occur at the same time. Both of these effects are at a maximum during peak current conditions (when bottom shear stresses are highest). Based on the EFDC-SEDZLJ model results presented in Section 5, the maximum rate of erosion of the deposited sediments is 1.5×10^{-4} cm/s. For a deposit 410 meters long, this is equivalent to an erosion rate of 7.1 kg/s. This source from the eroding bottom sediments is much smaller than the entrainment rate from the underflow (a maximum of 7.1 kg/s versus a maximum of 35.2 kg/s, respectively). Therefore, the entrainment rate from the underflow is the dominant factor controlling the project effects on suspended sediment concentrations in the water column.

The model input variables are summarized in Table 6-1. Typical values for the lateral diffusion coefficient, k_y, are 10^5 cm^2/s to 10^7 cm^2/s (Hayes and Je, 2000). Hayes and Je (2000) explain that the lower values are representative of laterally bounded water bodies with widths of 100 feet or less, and the higher values are representative of water bodies sufficiently wide that the plume never strikes the boundaries. A mid-range value of 10^6 cm^2/s was used for this analysis. A value of 1×10^5 cm^2/s (the low end of the range that will result in a longer plume) was also used to evaluate the sensitivity of the model to the lateral diffusion coefficient.

Typical vertical diffusion coefficient values are 1 to 10 cm^2/sec, unless stratification exists (Hayes and Je, 2000). Given the low freshwater flow rates to Calibogue Sound, there is insignificant vertical stratification at the proposed placement site. Therefore, a mid-range value of 5 cm^2/sec was used for this analysis. A value of 10 cm^2/s (the high end of the range that will result in greater concentrations higher in the water column) was also used to evaluate the sensitivity of the model to the vertical diffusion coefficient.

Table 6-1 Input variables for far-field plume model

Variable	Input Value
Q	155 g/s at outfall + entrainment from underflow + erosion of bottom deposit
k_y	10^6 cm^2/s
k_z	5 cm^2/s
u	0.77 m/s
ω	0.0003 m/s

The results were calculated on a horizontal grid at 30 foot (10 meter) intervals. Values were also calculated at multiple elevations, including 3 and 6 feet (1 and 2 meters) above the bottom.

6.3 Model Results

Contours of calculated suspended sediment concentrations from the proposed open water placement are shown in Figures 6-1 through 6-4. These plots show concentrations for peak flood tide currents and peak ebb tide currents. The plots also show the concentrations at two elevations in the water column: 3 feet above the bottom and 6 feet above the bottom.

As shown by Figures 6-1 and 6-2, the results for the mid-range dispersion coefficients (k_y = 10^6 cm^2/s and k_z = 5 cm^2/s) show that the project will increase suspended sediment concentrations up to 11 mg/L within 3 feet above the bottom over a localized area downstream from the underflow during peak tidal current conditions. The 10 mg/L contour extends 1,900 feet from the discharge point. Because the sediment source is at the bottom, the highest concentrations occur at the bottom and concentrations gradually decrease as the sediments disperse vertically in the water column. At 6 feet above the bottom, the maximum concentrations are less than 2 mg/L, and concentrations at higher elevations are minimal.

The half-speed currents (shown in Figures 6-3 and 6-4) show much lower concentrations. The lower current speed causes much lower entrainment of sediment from the underflow into the overlying water column (1.7 kg/s versus 35.2 kg/s for the peak current condition). The resulting water column concentrations are negligible (less than 1 mg/L at 3 feet above the bottom). Therefore, for the third of the tidal cycle when current speeds are below half of the peak current speed, the effects on suspended sediment concentration are negligible.

The sensitivity test results are shown in Appendix A for the 100 m underflow length, the lower horizontal dispersion coefficient (k_y = 10^5 cm^2/s) and the higher vertical dispersion coefficient (k_z = 10 cm^2/s). The results show that the 410 meter underflow length causes higher concentrations than the shorter 100 meter underflow length. The results show that the lower horizontal dispersion coefficient results in a higher peak TSS concentration, as expected because of the resulting decreased lateral spreading of the sediment. Similarly, the higher vertical dispersion coefficient increases the peak TSS concentration because it mixes a greater amount of the sediment into the higher elevations of the water column. For the combined k_y = 10^5 cm^2/s and k_z = 10 cm^2/s, the peak concentration exceeds 25 mg/L at 3 feet above the bottom and exceeds 8 mg/L at 6 feet above the bottom (Figure A-6). This illustrates the sensitivity of the calculated TSS concentrations to the dispersion coefficients. However, as explained by Hayes and Je (2000), the lower horizontal dispersion value (i.e., k_y = 10^5 cm^2/s) is representative of laterally bounded water bodies with widths of 100 feet or less. Given the wide estuary at the placement site, the mid-range value of k_y = 10^6 cm^2/s is more appropriate, and therefore the TSS concentrations are expected to be closer to the estimate of 10 mg/L above the ambient concentrations at 3 feet above the bottom.

The above predicted concentrations are increases above the ambient concentrations. Measured ambient concentrations are less than 100 mg/L (ATM observed a mid-depth concentration of 68 mg/L in 1999). However, spring tide ambient concentrations near the bottom likely exceed 100 mg/L, and are even higher during storm events. The maximum far-field water column suspended sediment concentrations from the proposed open water placement are within the range of concentrations experienced during typical tidal conditions and storm events.

The effect of the suspended sediments on areas outside of the project area in the vicinity of the Calibogue Sound entrance is negligible. Sediments suspended into the water column will ultimately settle in quiescent areas with low current velocities. Because of the wide dispersion of the sediments, the deposition thickness of these sediments in quiescent areas would be indistinguishable from the deposition caused by ambient sediments in the environment. Furthermore, these suspended sediments will not cause appreciable deposition in the vicinity of Calibogue Sound inlet or Barrett Shoals because the high current speeds in the area will keep these fine sediments in suspension.

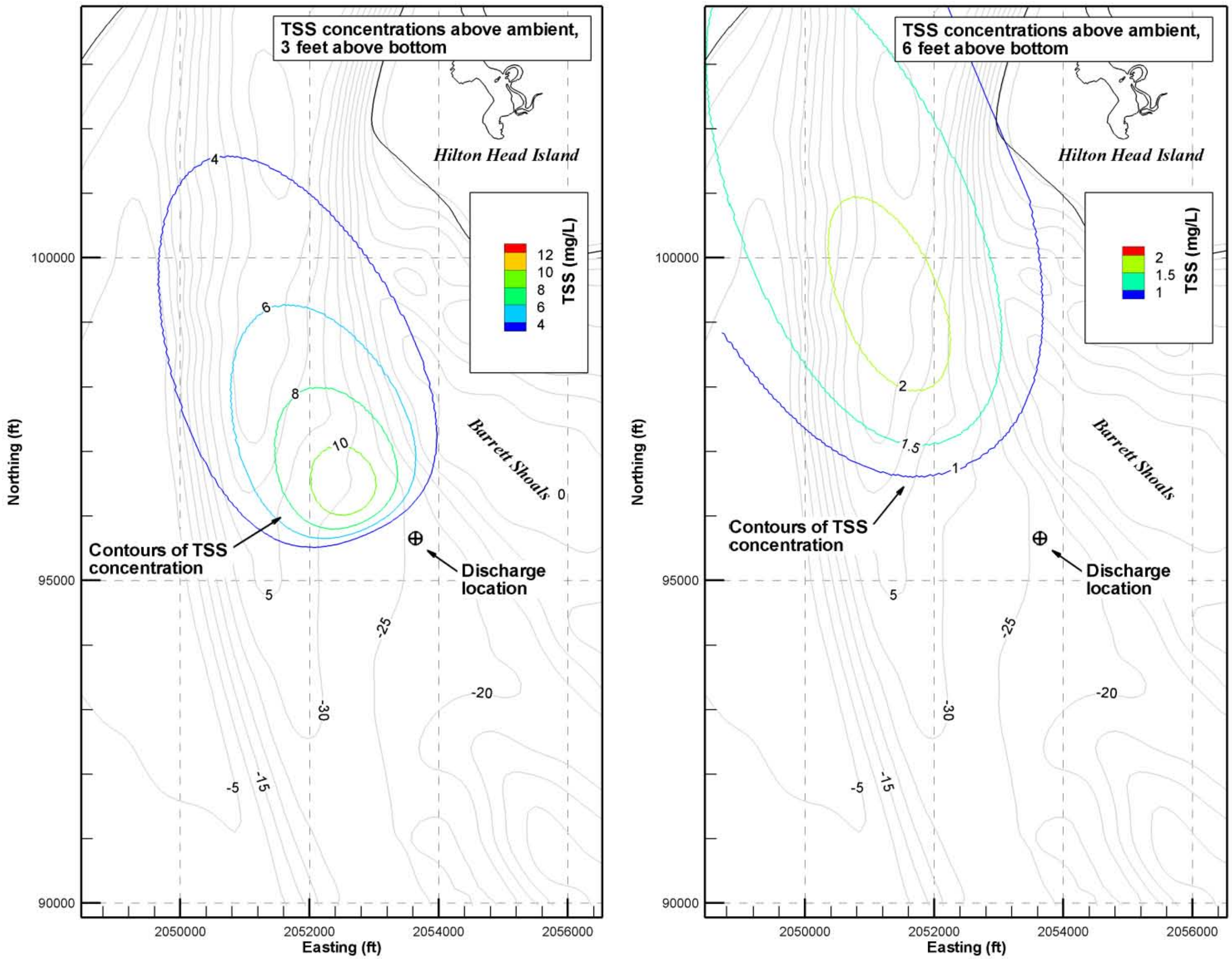

Figure 6-1 – Predicted TSS concentrations during peak flood current conditions, 3 and 6 feet above the bottom

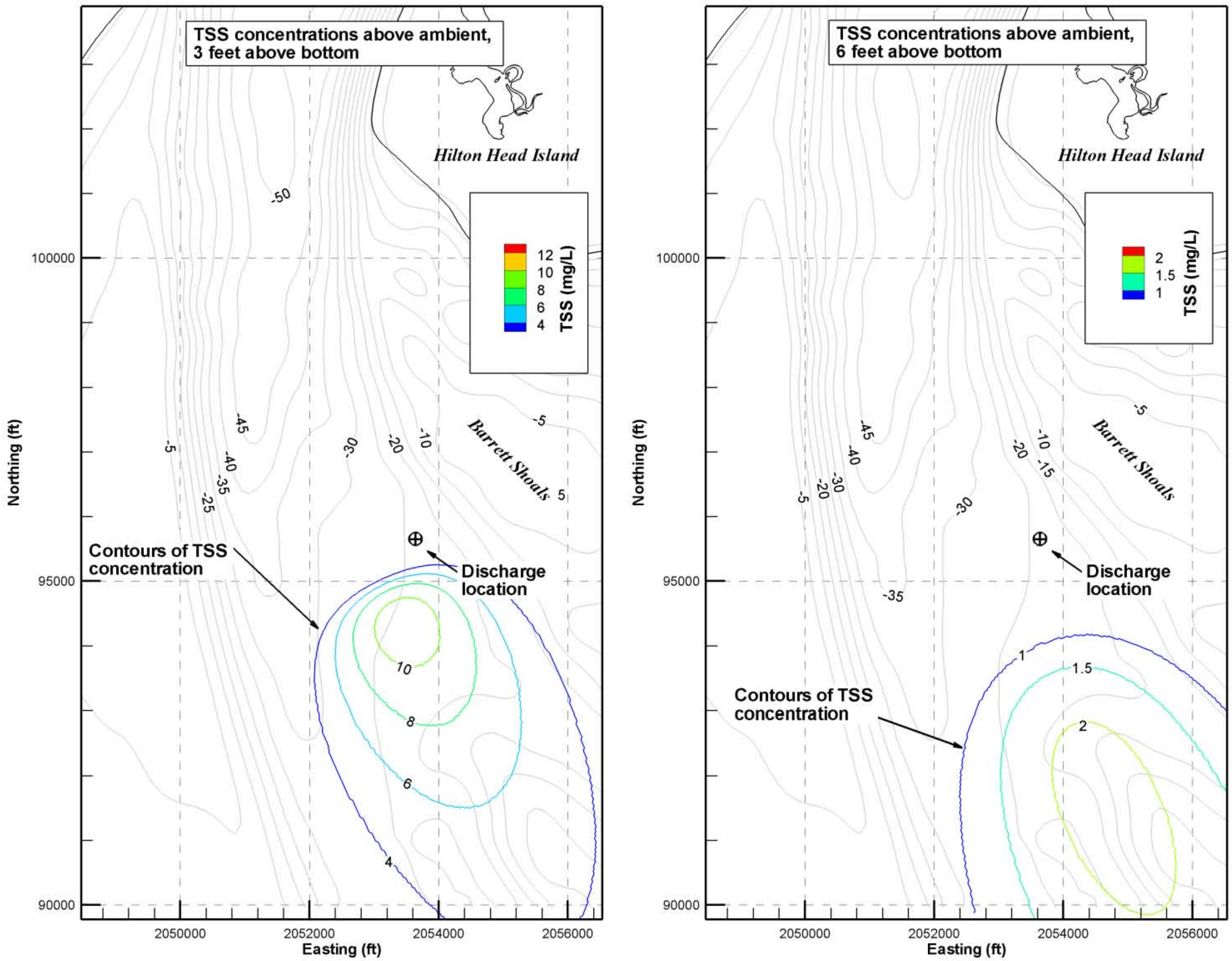

Figure 6-2 – Predicted TSS concentrations during peak ebb current conditions, 3 and 6 feet above the bottom

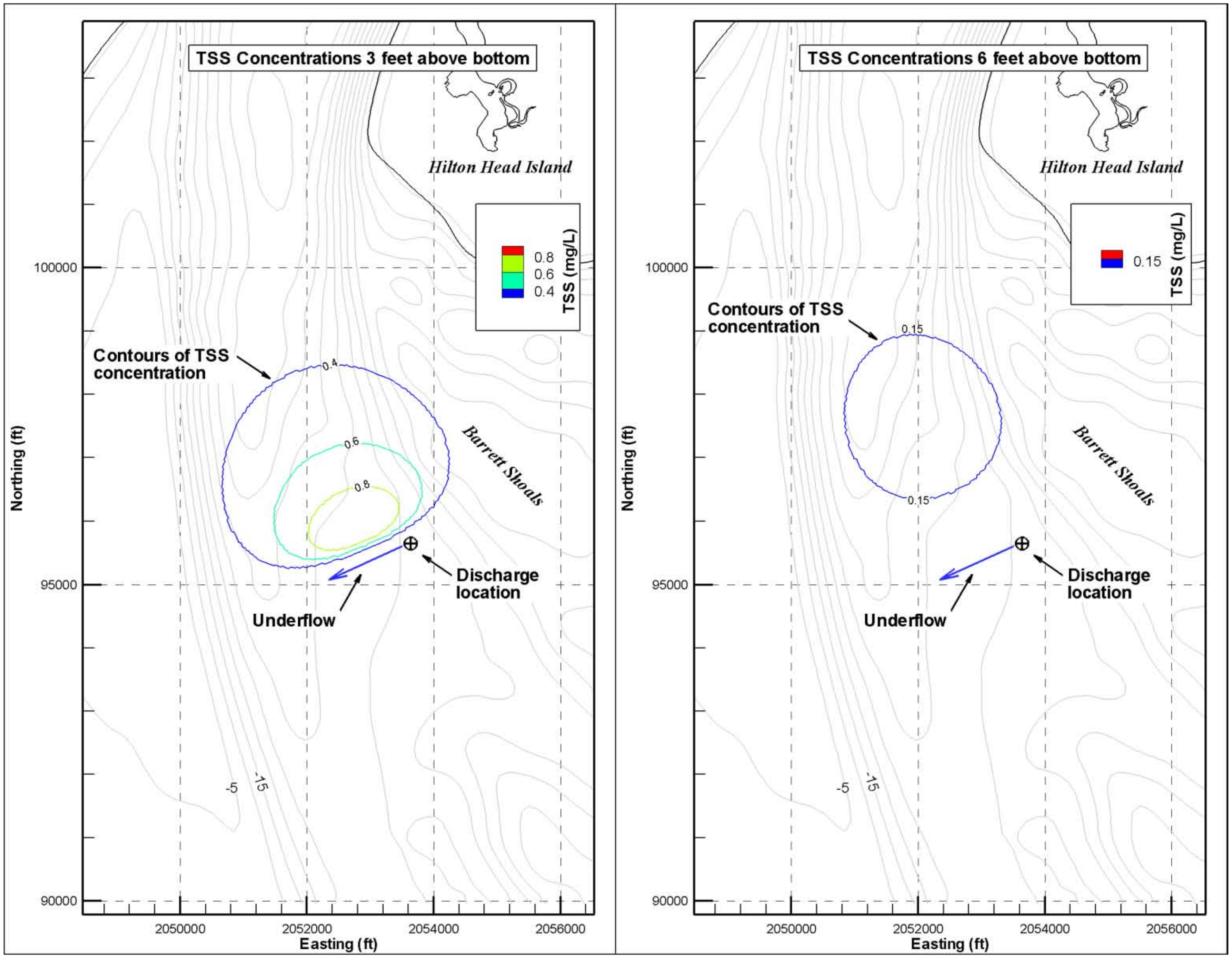

Figure 6-3 – Predicted TSS concentrations during mid-flood current conditions, 3 and 6 feet above the bottom

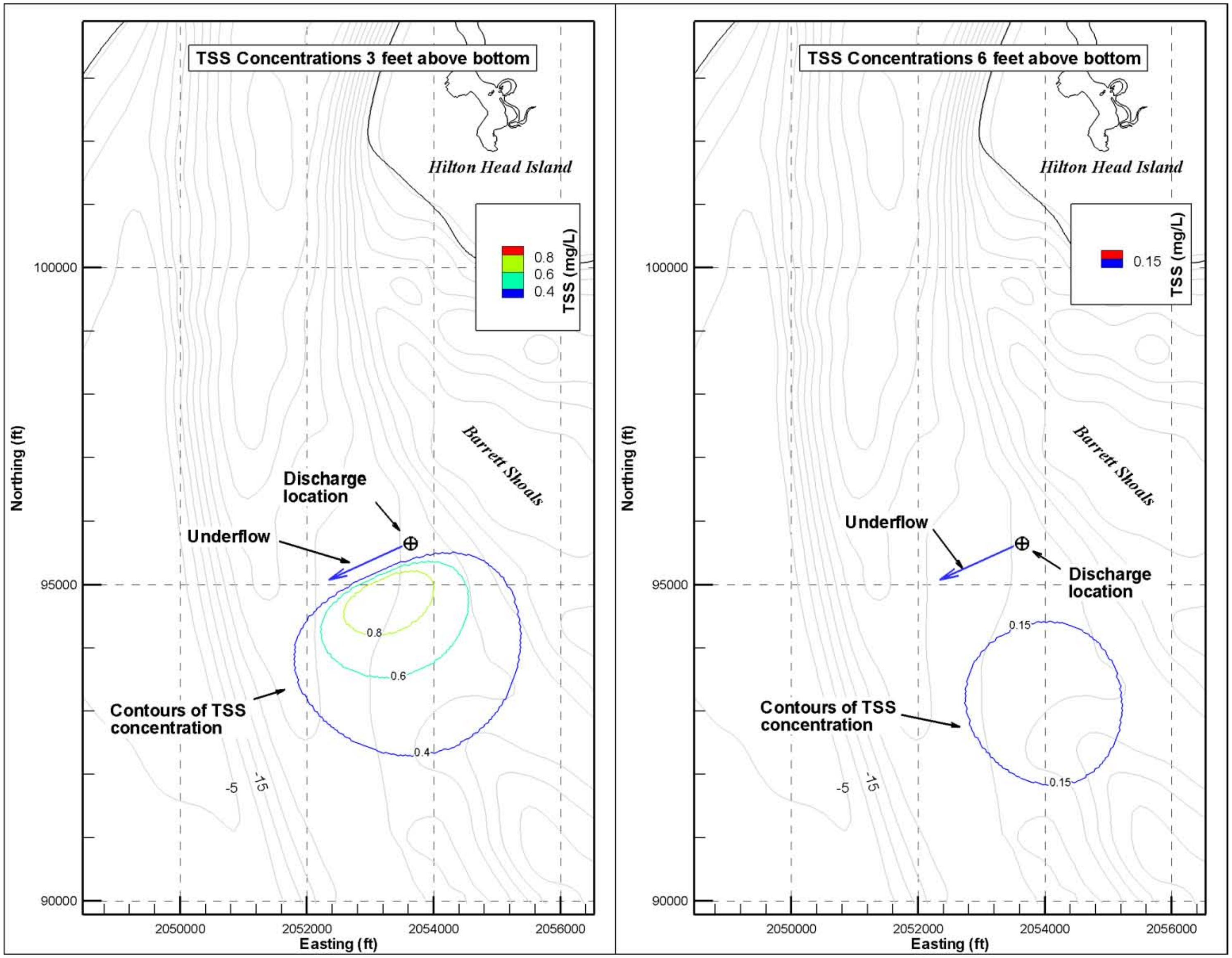

Figure 6-4 – Predicted TSS concentrations during mid-ebb current conditions, 3 and 6 feet above the bottom

7 Water Quality Impacts

This section discusses the potential for the proposed project to affect water quality variables of concern other than suspended sediments and turbidity (which are already discussed in detail in the previous section). Variables discussed include dissolved oxygen, salinity, temperature and pH. Sediment quality was evaluated by both ATM (2000b) and GEL (2008) and found to be acceptable for open water placement with no special management provisions.

The South Carolina Department of Health and Environmental Control (DHEC) classifies water bodies according to their intended uses, and determines the scientific water quality criteria to support these uses. Streams, lakes, and other waterbodies that do not meet the criteria are impaired and are required by the Clean Water Act to be listed as such.

DHEC classified Calibogue Sound as shellfish harvesting waters (SFH). The closest monitoring station to the project area that has been recently assessed (in 2010) is in Calibogue Sound at the mouth of the Cooper River (Waterbody ID: SCMD-175_E_06). For this water body, the 2010 water quality assessment lists the overall water quality status as “good” for its intended uses of aquatic life support and primary contact recreation. No impairments to water quality are listed for the project area.

7.1 Dissolved Oxygen

Oxygen is necessary for the survival of aquatic organisms. If the dissolved oxygen (DO) falls below the minimum requirements for survival, aquatic organisms or their eggs and larvae may die. In South Carolina, the dissolved oxygen standard for SFH to protect aquatic life is a minimum daily-averaged DO of 5.0 mg/l, and a minimum DO of 4 mg/l. The water body at the project site is not listed by DHEC as impaired for DO.

The effects of dredging on dissolved oxygen are varied, ranging from a small decrease to a small increase in DO concentrations. Mixing anoxic water from the sediment bed into the water column can reduce DO concentrations, and introduction of compounds that can oxidize (e.g., ferrous iron or sulfides) into the water column can also lower DO concentrations. At the same time, vertical mixing of the water column by the dredging process can raise DO levels near the bottom of the water column.

In Savannah Harbor (15 miles from the project site), attempts to establish the effects of dredging on DO concentrations have found limited effects that are difficult to distinguish from the natural variations in the ambient DO concentrations. Analysis of bottom sampling data upstream and downstream from a large hydraulic cutterhead dredge in Savannah Harbor found only a very weak relationship between decreasing DO and increasing turbidity (Clarke, 2011).

The effects of the proposed dredging project on DO concentrations in the dredge areas or at the placement site are expected to be only small increases or decreases in concentration. Furthermore, the project will occur between November and April, when water temperatures are cool and the DO saturation concentrations are high. Therefore, the proposed project will cause only minimal adverse impacts, if any, on DO and will not cause a violation of the water quality standard.

7.2 Salinity and Temperature

Salinity at the dredge sites is generally the same as at the placement site, except during rainfall events when stormwater runoff reduces salinity in the creeks. Water temperatures at the dredge sites are expected to vary from those at the placement site near the bottom given that the water depths in the creeks are much shallower than at the placement site. Although some differences in salinity and temperatures between the dredge discharge and the receiving water are expected, the mixing of the dredge discharge with the receiving water will cause these differences to be insignificant within a short distance of the end of the pipe. Therefore, the proposed project will have negligible effects on Calibogue Sound salinity and water temperature.

7.3 pH

The South Carolina water quality standard for SFH waters states that the pH shall not vary more than 3/10 of a pH unit above or below that of effluent-free waters in the same geological area having a similar total salinity, alkalinity and temperature, but not lower than 6.5 or above 8.5. The typical pH of seawater is 8.2. ATM (2000b) measured a pH of 8.09 in water sampled from Calibogue Sound. ATM (2000b) also measured pH values between 7.93 and 8.13 in sediment sample elutriate from the sediments to be dredged. Given that seawater has a high buffering capacity (the carbonate system in seawater tends to resist large changes to pH), and the fact that the pH in the dredged sediments will be similar to the ambient pH, the proposed project is expected to have a negligible effect on the receiving water pH.

8 Conclusions

This analysis evaluated the fate of dredged sediments to be placed at an inland open water site in the mouth of Calibogue Sound. Placement was by a tremie pipe and diffuser approximately 3 feet above the bottom. The analysis used several numerical models to estimate the initial mixing of the dredge discharge, the flow of a dense fluid mud underflow along the bottom, the deposition of sediments on the bottom, the subsequent erosion of the deposited sediments by tidal currents, and the entrainment and passive dispersion of suspended sediments in the overlying water column.

Approximately 99 percent of the discharged material will initially descend to the bottom as a fluid mud layer within the proposed boundaries of the placement area. This fluid mud will spread and flow along the bottom as an underflow. Based on the results of the CORMIX and PDFATE models, sediments will deposit from this underflow on the bottom within a radius extending 410 meters (1,350 feet) from the discharge location. The underflow is a density current that will flow in a down-slope direction, and the path of the flow will change over time as sediments are deposited on the bottom. Based on the model results, up to 52 percent of the material will be deposited on the bottom. The maximum bottom area potentially affected by the underflow is approximately 56 acres of existing sandy bottom. The area of 56 acres is based on conservative model inputs, and the actual area may be smaller. Regardless, it will not cover any of the identified hard bottom areas in Calibogue Sound.

Following deposition of the sediments on the bottom from the underflow, the tidal currents will begin to erode the sediments. Given the high tidal current velocities at the site and the low density of the sediments, the EFDC-SEDZLJ sediment transport model results indicate that the deposited sediments will erode quickly. Approximately 80 percent of the sediment will be eroded within two days of placement, and the remainder will erode within weeks. This erosion process will occur continuously throughout the 6-month project, and the sediments will be completely eroded from the placement site within weeks after the project is completed. Therefore, the proposed placement site is a dispersive site, and the project will not cause any permanent or long-term changes to the bottom.

The sediments entrained into the water column and carried away by the currents will create a plume of suspended sediments. The contributions from three sources are included in estimates of the sediment plume concentrations: entrainment at the pipe outfall; entrainment along the underflow surface; and erosion of sediments recently deposited on the bottom. The resulting water column concentrations are relatively low because the underflow of fluid mud is spread along the bottom. Therefore, the source of entrained sediments is spread over an area on the bottom rather than a point source at the end of the dredge pipe.

The <u>peak</u> ebb and flood currents cause temporary total suspended sediment (TSS) concentrations up to 11 mg/L above ambient background concentrations within 3 feet above the bottom over a localized area downstream from the underflow. For reference, ATM measured a background concentration of 68 mg/L in 1999 (ATM, 2000a). There is no explicit South Carolina water quality standard for TSS. However, the South Carolina water quality standard for turbidity of 25 NTU is approximately equivalent to a TSS concentration of about 37 mg/L. Therefore, the natural ambient concentrations routinely exceed the water quality standard for turbidity at this location. The 11 mg/L TSS plume concentrations are equivalent to 16 percent of the observed background concentration, and approximately 30 percent of the concentration equivalent to the turbidity water quality standard.

Concentrations exceeding 10 mg/L above the background concentration would extend a maximum distance of 1,900 feet from the discharge point at 3 feet above the bottom. Because the sediment source is at the bottom, the highest concentrations occur at the bottom and concentrations gradually decrease as the sediments disperse vertically in the water column. Concentrations at elevations more than 6 feet above the bottom are minimal. No effects on suspended sediments would be detectable at the water surface.

Current speeds equal to half of the peak current speed show very low suspended sediment concentrations. The lower current speed causes much lower entrainment of sediment from the underflow into the overlying water column (5 percent of the peak value). Therefore, the project would cause only a very small increase in suspended sediment concentrations for some of the tidal cycle. Additionally, the predicted far-field suspended sediment concentrations from the proposed open water placement are within the range of concentrations experienced during typical conditions.

The net transport of sediments at the placement site is towards the ocean. In general, tidal inlets exhibit a net transport in the flood direction near the margins of the inlet (i.e., close to the shorelines), and a net ebb transport in the main channel. Because the placement site is located in the ebb channel of the inlet, it is expected that the net transport of sediments from the site will be in the ebb direction primarily towards the south-southeast. Therefore, most of the sediments placed at the site will ultimately be transported towards the ocean.

The bottom deposition of sediments from the proposed project is negligible in areas outside of the proposed placement site in the vicinity of the Calibogue Sound entrance. Sediments suspended into the water column will ultimately settle in quiescent areas with low current velocities. Dispersion of the sediments in areas beyond the immediate Calibogue Sound entrance area would be in very low concentrations, and as a result the deposition thickness of these sediments in quiescent areas would be indistinguishable from the deposition caused by ambient sediments in the environment. Based on these results, and given the distance between any inland areas of concern (such as the Cooper and May Rivers), there would be no appreciable increase in suspended sediment concentration or sedimentation in locations further inland, such as these rivers. Furthermore, these suspended sediments will not cause appreciable deposition in the vicinity of Calibogue Sound inlet or Barrett Shoals because the high current speeds in the area will keep these fine sediments in suspension.

One management technique considered to minimize potential project effects is to limit dredging to only the ebbing phase of the tide. However, given the negligible potential effects of the proposed project on areas north of the Calibogue Sound entrance, it is not recommended to restrict dredging placement activities to ebbing tides. The tidal restriction would extend the duration of the project by a factor of two in order to complete the same maintenance dredging volume. In return for this extended project duration, there would be negligible benefit by reducing effects on areas north of the Calibogue Sound entrance.

Potential project effects on other water quality variables were also evaluated, including dissolved oxygen, salinity, temperature and pH. The project will have minimal, if any, adverse effect on dissolved oxygen concentrations and will not cause a violation of the water quality standard. The project will have negligible effects on salinity, temperature and pH in Calibogue Sound.

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APPENDIX A – SUSPENDED SEDIMENT PLUME PLOTS

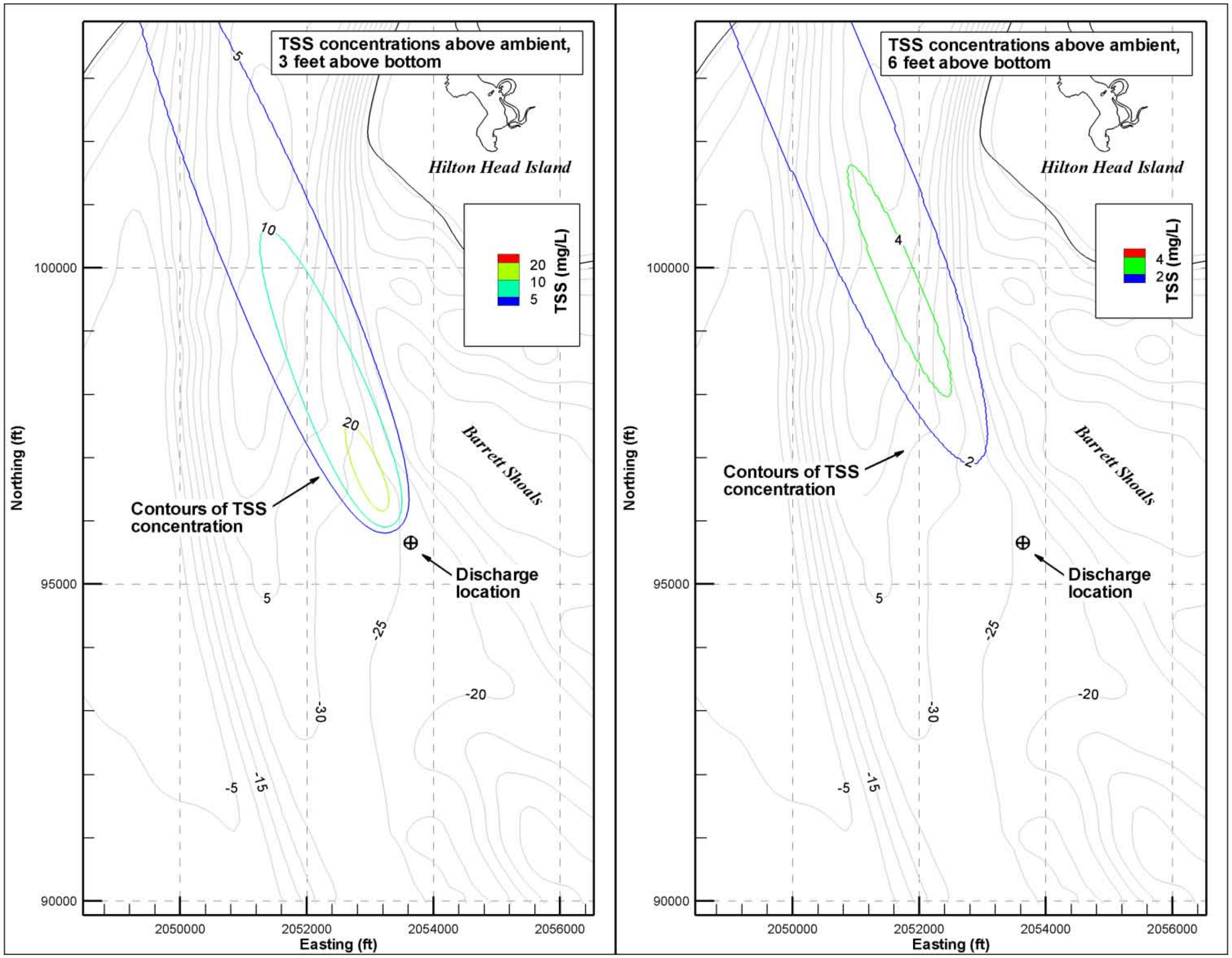

Figure A-1 – Predicted TSS for 100m underflow; Ky = 10^5 cm^3/s; Kz = 5 cm^3/s

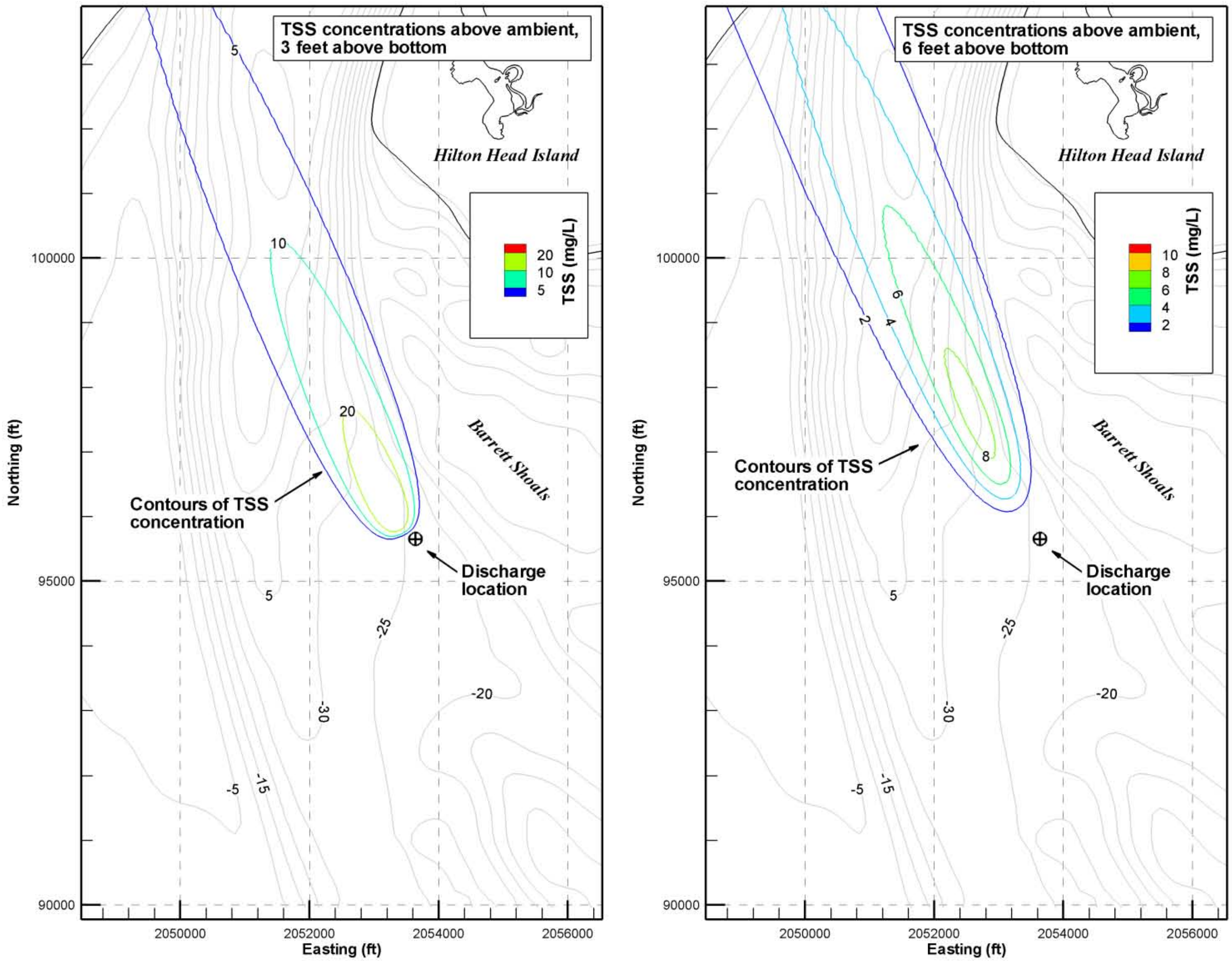

Figure A-2 – Predicted TSS for 100m underflow; Ky = 10^5 cm^3/s; Kz = 10 cm^3/s

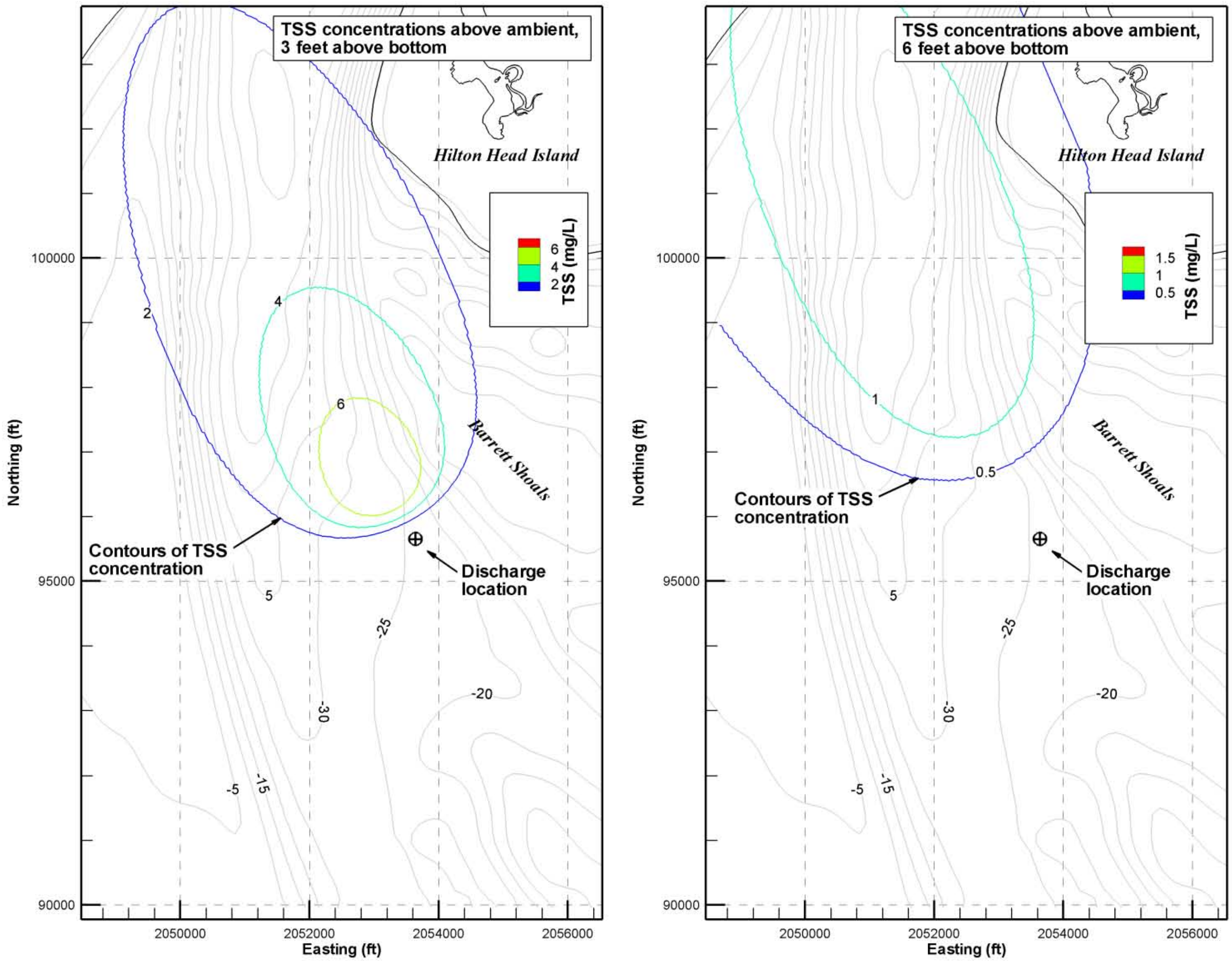

Figure A-3 – Predicted TSS for 100m underflow; Ky = 10^6 cm^3/s; Kz = 5 cm^3/s

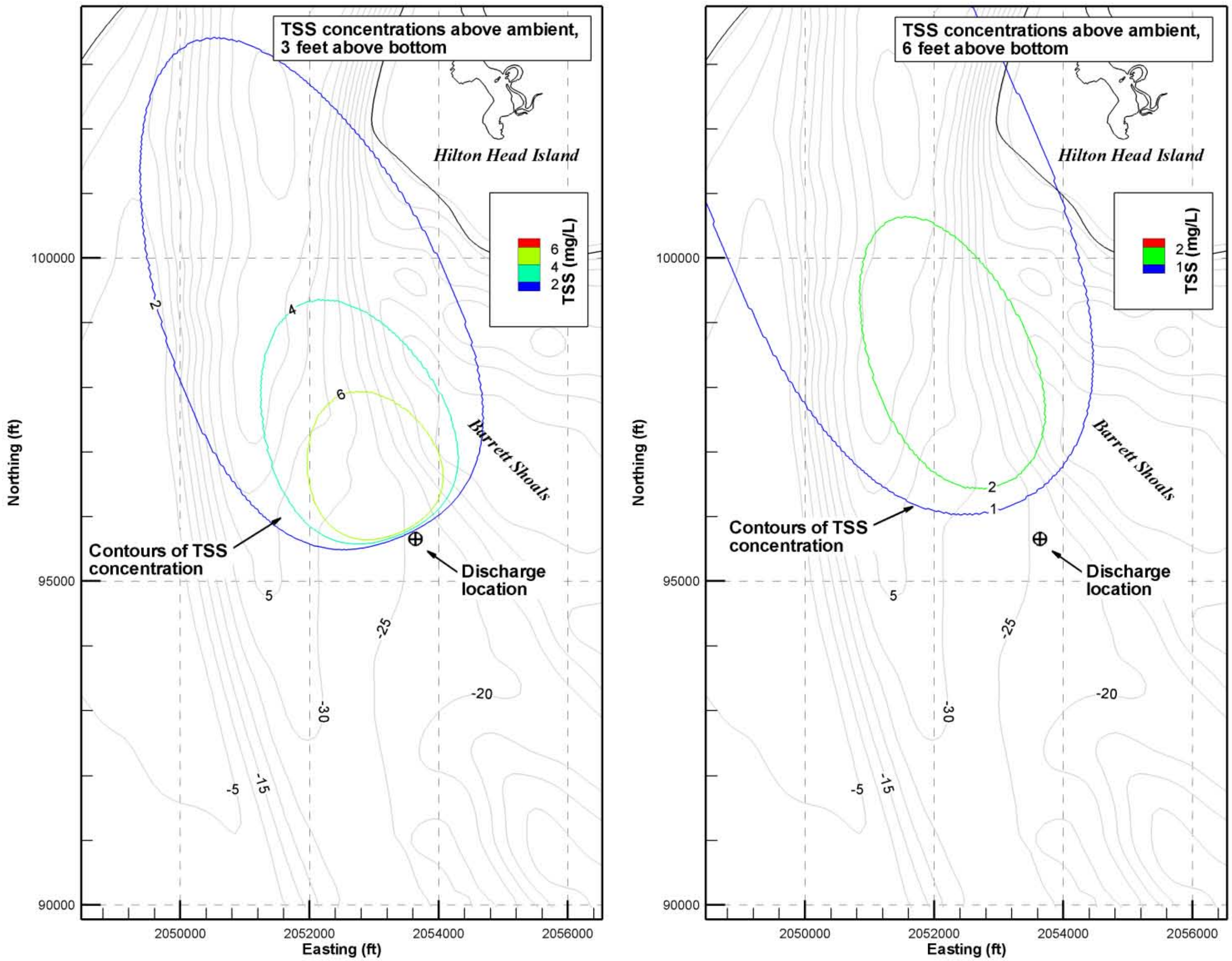

Figure A-4 – Predicted TSS for 100m underflow; Ky = 10^6 cm^3/s; Kz = 10 cm^3/s

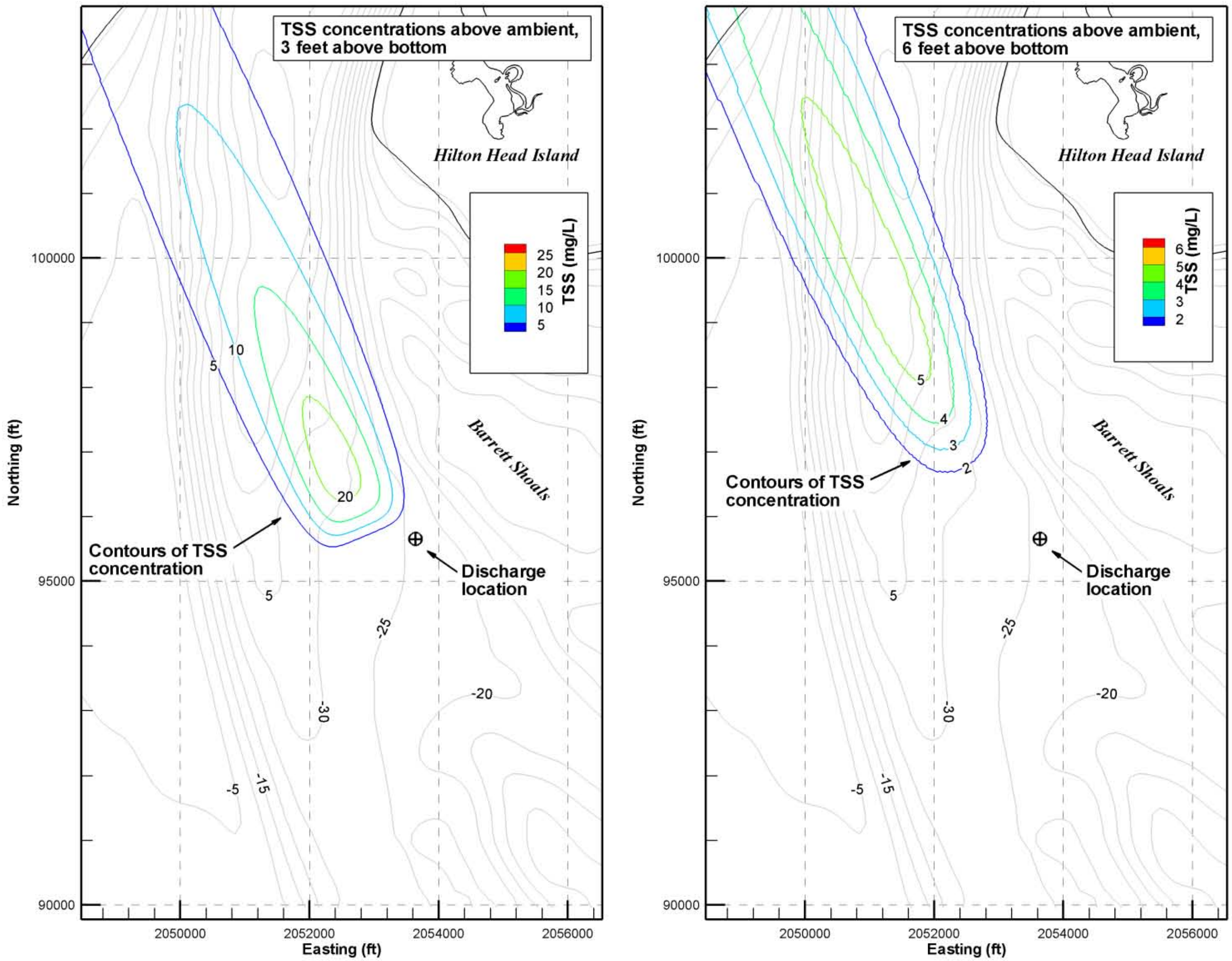

Figure A-5 – Predicted TSS for 410m underflow; Ky = 10^5 cm^3/s; Kz = 5 cm^3/s

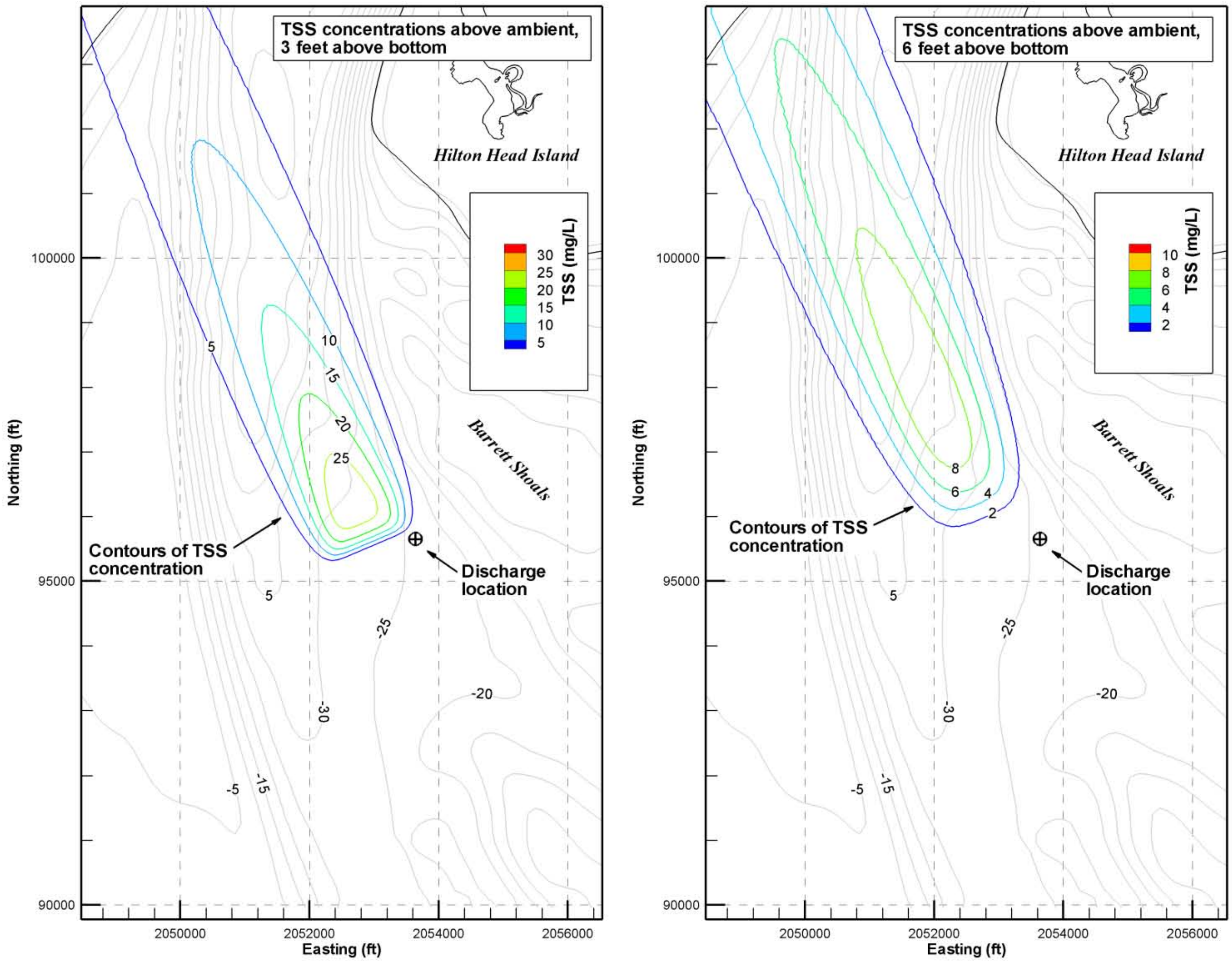

Figure A-6 – Predicted TSS for 410m underflow; Ky = 10^5 cm^3/s; Kz = 10 cm^3/s

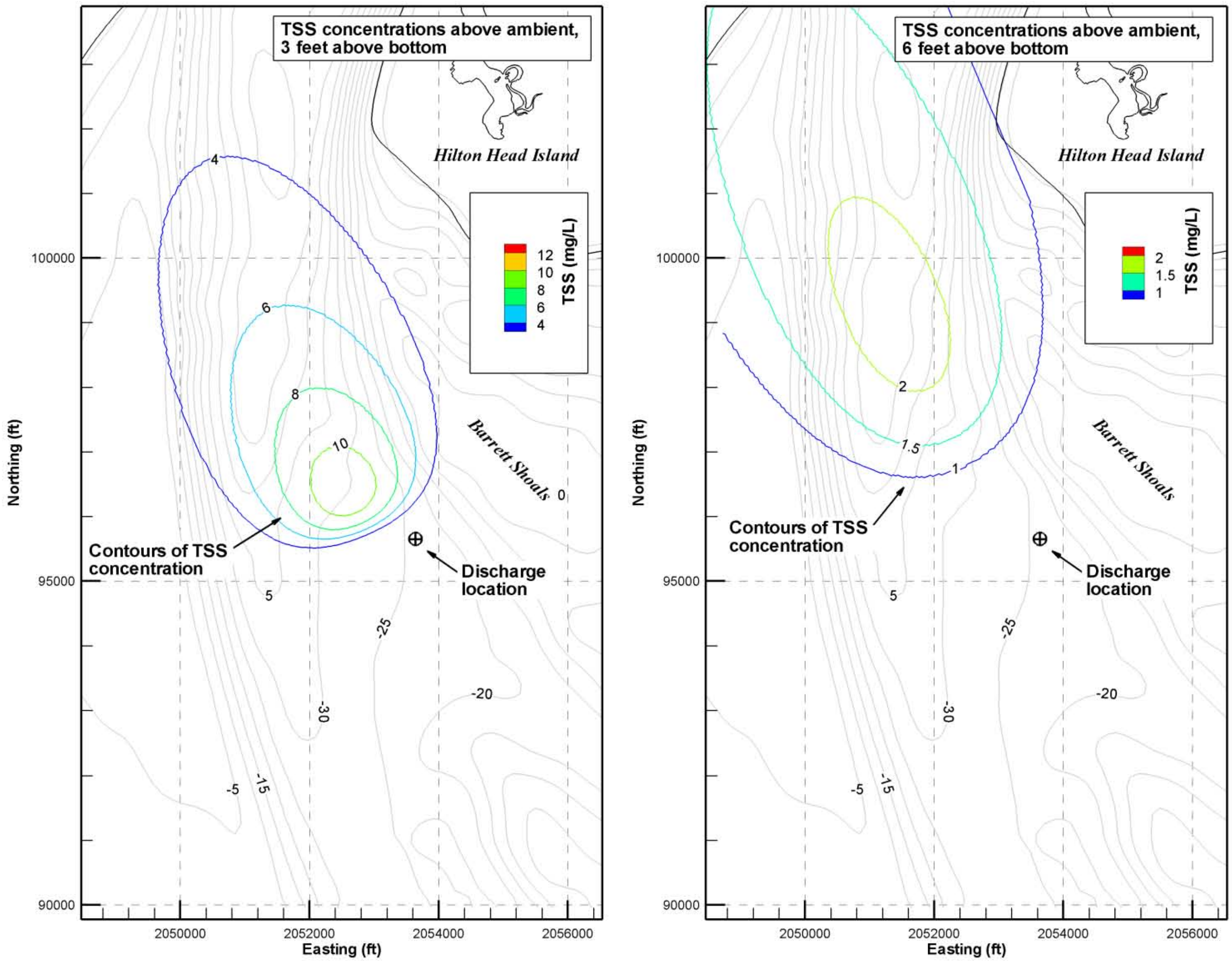

Figure A-7 – Predicted TSS for 410m underflow; Ky = 10^6 cm^3/s; Kz = 5 cm^3/s

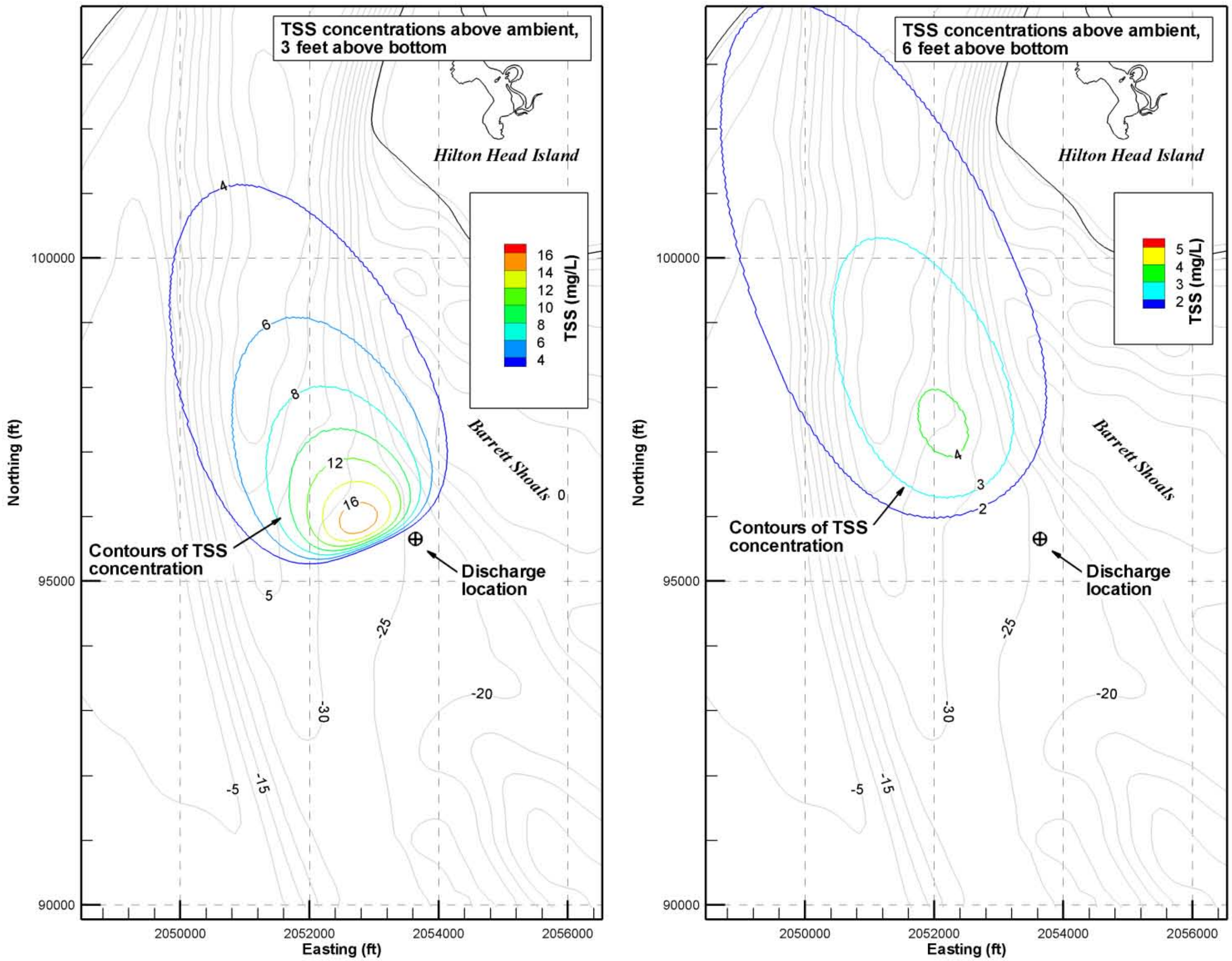

Figure A-8 – Predicted TSS for 410m underflow; Ky = 10^6 cm^3/s; Kz = 10 cm^3/s