# Appendix G – Sediment Transport Analysis

# SEDIMENT TRANSPORT ANALYSIS FOR THE VIRGINIA OFFSHORE WIND TECHNOLOGY ADVANCEMENT PROJECT

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# EXECUTIVE SUMMARY

Woods Hole Group is pleased to provide this report presenting the sediment transport analysis related to the proposed Virginia Offshore Wind Technology Advancement Project (VOWTAP or Project) for Demonstration of an Innovative Offshore Wind System for Virginia Electric and Power Company, a wholly-owned subsidiary of Dominion Resources, Inc. (Dominion). The analysis was developed specifically for a planning level assessment of sediment transport potential associated with the installation of the Project's proposed submarine electric cable between the shoreline and the proposed VOWTAP Research Lease Area located approximately 43 km off the coast of Virginia near the Bureau of Ocean Energy Management (BOEM) commercial Wind Energy Area (WEA).

The work performed in this report was done in accordance with the September 11, 2013 Scope of Work. The sediment transport analysis is intended to support the environmental planning/approval process for the Project. The analytical modeling and analysis identifies potential environmental impacts associated with the proposed submarine cable installation activities, specifically related to the concentration of fine sediments in the water column and the footprint and thickness of sediments deposited on the seafloor..

Based on the results of the sediment transport modeling, the following general conclusions can be made:

- The concentration and settling thickness of the sediment plume is dependent on the strength of ambient tidal currents and the volume of fine material in the trench.
- The fine particles (<200 µm) will remain in suspension for approximately 6-7 minutes after initial release. Coarser particles will settle at a faster rate.
- For average peak running ebb and flood tides:
    - The concentration of fine sediment in the plume (Table 4) initially released from the trench varies between ~6,700 (core station 12) and 1.585x106 mg/L (core station 17). This plume is contained in a near-bottom water layer less than 2 m high. These initial conditions are conservatively high, and assume that all of the fine material (finer than 200 µm) in the plowed trench is mobilized instantly into the water column immediately above the plow footprint and within 2 m of the seafloor.

    - The initial fine suspended sediment concentration rapidly diminishes by several orders of magnitude within 5 to 10 m from the trench. The maximum zone of elevated suspended sediment on either side of trench is on the order of 150 m (Table 3) for stations VC-001 through VC-006.

    - While the suspended sediment concentrations are elevated even near the edge of the plume, the sediment is moving in a very thin layer, less than a tenth of a meter above the sea floor, at the edge of the plume.

- The fine sediment suspended in this plume settles into a thin layer on the ocean floor less generally than 1 mm. The maximum depositional thickness occurs roughly 10 to 25 m from the trench, and the maximum zone of influence on either side of the trench generally varies from between 50 m (e.g., offshore core stations V-12 through V-17) and 200 m (e.g., nearshore core stations V-1 through V-6), and is less than 250 m (Table 5). Deposition exceeded 1 mm within 100 m of the trench only at stations VC-007, VC-016, and VC-017, where the concentration of fines was high and the currents were weakest, resulting in a narrower, more concentrated plume.

- Settled sediment will be available for resuspension and dispersal into a more diffuse layer by the ambient currents (e.g., wave orbital velocities and higher currents during more energetic climatic events), not simulated by this model.

The sensitivity analysis revealed:

- The width of the plume is controlled by the settling velocity of the particle size, the height of discharge, and the current speed.
- Deepening the trench will increase the amount of sediment mobilized into the water column, which proportionally increases the suspended sediment concentration and settling thickness.
- Operating during periods of higher current velocity reduces the thickness of settled sediments over a larger footprint. Conversely, installation during stages of the tide with a lower velocity reduces the overall footprint of deposition, while increasing the thickness in a narrow zone adjacent to the route.
- Coarser sediments, even in larger quantities, settle faster into a narrower footprint, and vice-versa.

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# List of Acronyms

| | |
|---|---|
| AGTC | Algonquin Gas Transmission Company |
| ASA | Applied Science Associates |
| BOEM | Bureau of Ocean Energy Management |
| CEM | Coastal Engineering Manual |
| Dominion | Virginia Electric and Power Company, a wholly-owned subsidiary of Dominion Resources, Inc. |
| ESPreSSO | Experimental System for Predicting Shelf and Slope Optics |
| ETA | Engineering Technology Applications, Ltd. |
| KBR | Kellogg, Brown and Root |
| ROMS | Regional Ocean Modeling System |
| USACE | U.S. Army Corp of Engineers |
| VOWTAP | Virginia Offshore Wind Technology Advancement Project |
| WEA | Wind Energy Area |

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# 1.0 INTRODUCTION

Woods Hole Group, Inc. (Woods Hole Group) was contracted by Tetra Tech, Inc. (Tetra Tech) to perform a sediment transport assessment in support of the Virginia Offshore Wind Technology Advancement Project (VOWTAP or Project), a 12-megawatt (MW), two-turbine offshore wind demonstration project located approximately 24 nautical miles (27 statute miles, 43 kilometers) offshore of Virginia Beach, Virginia, and adjacent to the Bureau of Ocean Energy Management (BOEM) commercial wind energy area (WEA). A 34.5 kilovolt (kV) Inter-Array Cable will interconnect the two VOWTAP wind turbine generators (WTGs), and a 34.5 kV Export Cable will convey electricity from the WTGs to a landfall site located in the City of Virginia Beach, Virginia (Figure 1).

Both the Inter-Array Cable and Export Cable will be installed using a jet plow that will create a narrow, temporary trench up to 1 m wide. The jet plow will rest on skids or wheels with a width of approximately 5.6 m. Dominion plans to bury the Inter-Array Cable to a target depth of at least 1 m of sediment and the Export Cable to a target depth of 2 m. At certain high risk areas of the route, such as the military practice area (live fire danger zone) and dredge material placement area, Dominion may elect to increase the cable burial depth up to 4 m. For the purpose of this analysis, sediment transport associated with the installation of the Export Cable was assessed as the worst-case installation assumption by determining the concentration of suspended sediment, as well as the sedimentation footprint and thickness resulting from the cable installation process, to support the evaluation of potential Project effects on surrounding habitats and water quality.

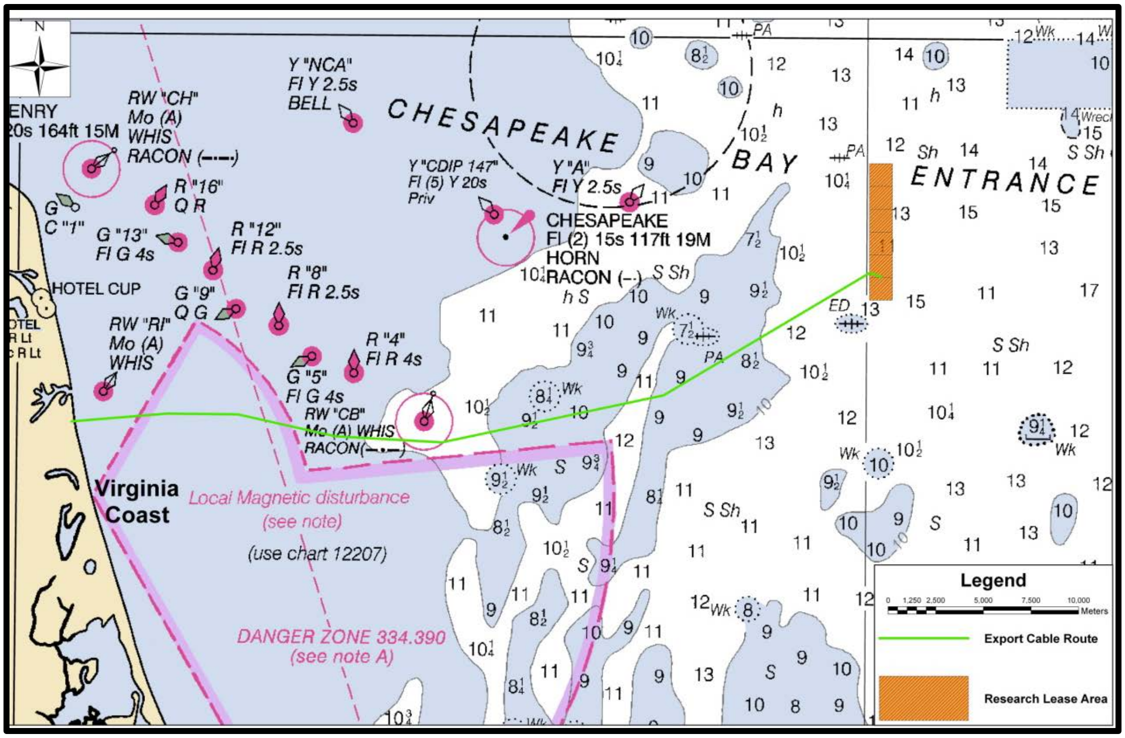

Figure 1. Proposed Export Cable Route.

# 2.0 INFORMATION SOURCES

## 2.1 CURRENT INFORMATION

To assess the variability of ocean currents along the proposed Export Cable route, Woods Hole Group reviewed available data sets from studies including the METOCEAN Criteria for Virginia Offshore Wind Technology Project (Fugro GEOS, 2012) and the Regional Ocean Modeling System (ROMS) ESPreSSO (Experimental System for Predicting Shelf and Slope Optics) model. The METOCEAN study provided wave climate data based on the Oceanweather hindcast data for extreme (storm) events; however, cable installation is not anticipated to take place during storm events and no information was available for daily tidal conditions. Therefore, the ESPreSSO data set was used for the model input as it includes hourly simulations covering the period from January 2006 through December 2012, for a total of seven years of model output. The model has been developed and run by the Rutgers Ocean Modeling Group (http://marine.rutgers.edu/po/). The ROMS ESPreSSO model covers the Mid-Atlantic Bight from the center of Cape Cod southward to Cape Hatteras. The prototype system is a 5-km horizontal, 36-level ROMS model with Incremental Strong Constraint 4DVAR data assimilation. The model is run using:

- Meteorological forcing from NCEP/NAM 12-km 3-hourly forecast data
- Boundary conditions from HYCOM forecast system
- Hudson River discharge from daily average observations
- Tide boundary conditions from the ADCIRC tidal model

The current velocity forecasts are computed starting from the initial conditions, which are obtained by minimizing the model-data misfit over the previous 3-day window. The current field is recomputed daily based on the new observations obtained in real-time. Measurements assimilated in the model are:

- Velocity data from high-frequency radars
- Satellite altimetry data
- Blended SST

The current information output from the model was taken from five current stations that the projected cable pathway intersected and labeled from inshore to offshore as 5-3, 4-4, 3-5, 2-6, and 2-7. The current profile was depth-averaged and analyzed for each location. The directional distribution of the depth averaged current speeds (cm/s) for the years 2006 to 2012 are presented in Figures 2-6. The current information is divided into 22.5 degree directional bins and color coded by current speed range. At the nearshore stations, the current direction was primarily oriented parallel to the coast (north-south) and the magnitude was higher than the offshore stations.

Modeled currents were then analyzed separately over the flood and ebb tides. The average maximum flood and ebb current magnitudes were calculated from the peak velocities corresponding to each running flood and ebb tide over the six-year period, along with a corresponding direction as shown in Table 1. The greatest magnitude flood and ebb currents occurred nearshore at the first node, 5-3, and the current magnitude gradually decreased with each successive offshore node. The current magnitudes ranged from 15 to 40 cm/s from the offshore to inshore stations. The flood and ebb velocities were of similar magnitudes at each current location. The current directions were oriented north-south and parallel to the coast inshore, but became increasingly northwest and southwest oriented further offshore. Note that in all cases, the dominant direction is oriented northward for the flood tide and southward for the ebb tide.

**Table 1. Mean of the maximum flood and ebb current velocity and direction predicted by the Rutgers ESPreSSO model**

| | | | | Flood Tide | | Ebb Tide | |
|---|---|---|---|---|---|---|---|
| Node | Latitude [°N] | Longitude [°W] | Depth [m] | Mean Maximum Velocity [m/s] | Direction [°] | Mean Maximum Velocity [m/s] | Direction [°] |
| 5-3 | 34.0275 | -75.8931 | 12.11 | 0.269 | 345 | 0.395 | 180 |
| 4-4 | 34.0368 | -75.7837 | 16.43 | 0.196 | 345 | 0.231 | 165 |
| 3-5 | 34.0460 | -75.6744 | 19.47 | 0.172 | 330 | 0.160 | 180 |
| 2-6 | 34.0553 | -75.5650 | 21.47 | 0.152 | 300 | 0.152 | 195 |
| 2-7 | 34.1048 | -75.5019 | 24.17 | 0.155 | 285 | 0.150 | 195 |

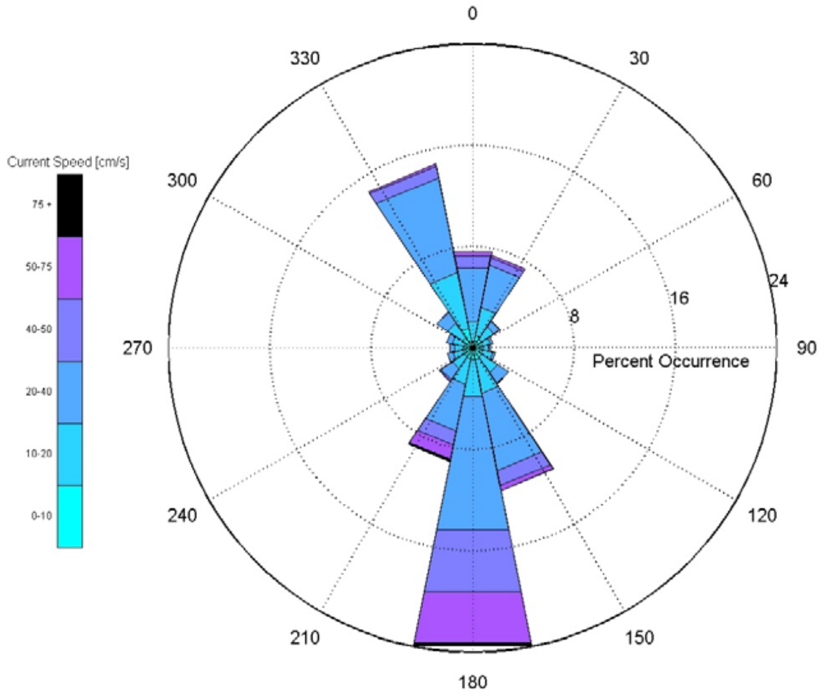

**Figure 2. Rose plot of current speeds (cm/s) observed at Station 5-3 from 2006 to 2012.**

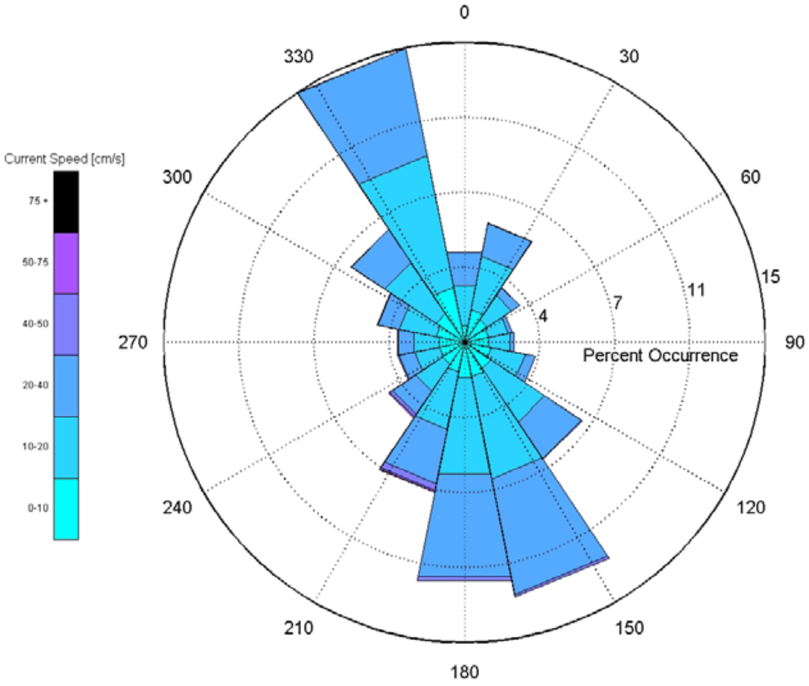

**Figure 3.** Rose plot of current speeds (cm/s) observed at Station 4-4 from 2006 to 2012.

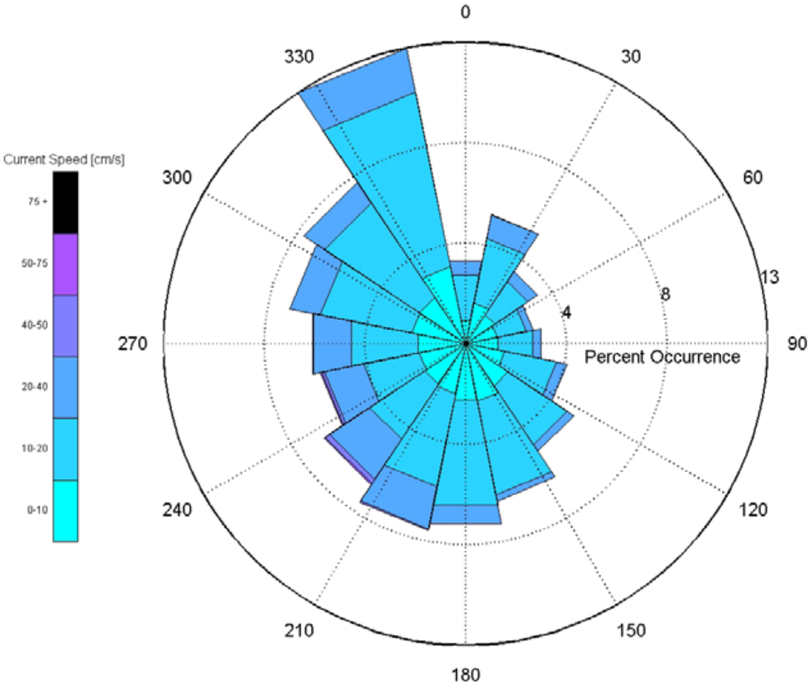

**Figure 4.** Rose plot of depth-averaged current speeds (cm/s) observed at Station 3-5 from 2006 to 2012.

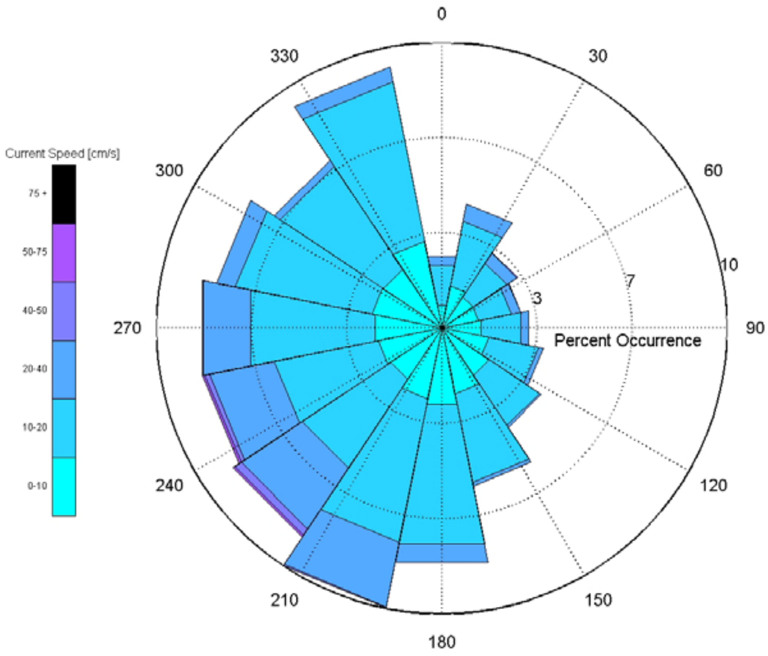

**Figure 5.** **Rose plot of depth-averaged current speeds (cm/s) observed at Station 2-6 from 2006 to 2012.**

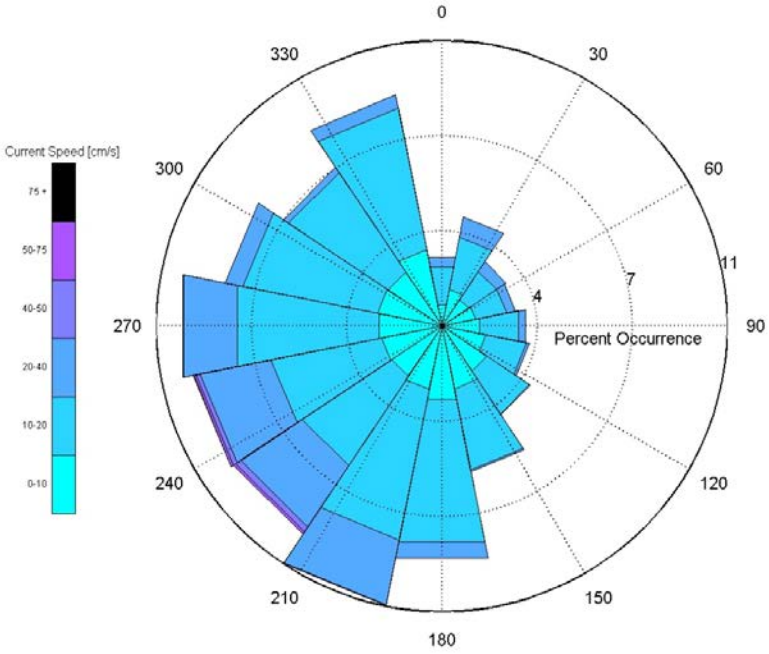

**Figure 6.** **Rose plot of depth-averaged current speeds (cm/s) observed at Station 2-7 from 2006 to 2012.**

## 2.2 SEDIMENT CHARACTERISTICS

Site-specific sediment characteristics play an important role for determining sediment transport. For instance, a threshold for sediment transport initiated by the jet plow is determined by computing where the sediment ejection velocity equals the critical velocity required to lift maintain suspension of sediments finer than 200 µm. The percentage of sediment in suspension and available for transport, therefore, is the fraction of the bottom sediments finer than 200 µm, including clays, silts and fine- to very-fine grained sands. For the purposes of this preliminary study, sediments were assumed to be comprised of unconsolidated clean sediments.

For this study, the Woods Hole Group used available sediment core data from the Marine Site Characterization Survey Report (Tetra Tech, 2013) to more accurately represent local site conditions. Past studies submitted for regulatory review of electrical cable burial projects, including the Applied Science Associate's *Sediment Transport Analysis of Cable Installation for Block Island Wind Farm and Block Island Transmission* System (ASA, 2012), assumed 25% of the excavated sediment is suspended in the water column due to a lack site specific sediment data. However, site-specific sediment core data were collected from nineteen (19) locations along the VOWTAP Export Cable route, and provided improved input data for the sediment transport analysis.

Dominion has indicated that they plan to bury the Export Cable to a target depth of 2 m along the majority of the route. The percentage of fine sediments (<200 µm) and associated unit weight (lb/ft$^3$) was composited for the top 2 m at each core location for input the sediment transport calculation.

Table 2 summarizes the cores used for the sediment transport analysis, including the Core ID, location, and water depth. The last two columns illustrate the percent of sediments passing the 200 sieve and the unit wet weight of those fine sediments from each core based on a depth-weighted average of core sub-samples within the top 2 m of each core. Figure 7 presents the locations of the cores and respective fine sediment (<200 µm) concentrations. The average fine sediment concentration for all stations was 14%. Fine sediment concentrations along the cable route ranged from 10-22% for stations VC-001 through VC-004, then dropped to less than 10% for stations VC-005 through VC-015A, and finally increased to greater than 22% for VC-0016 and VC-017 with some notable exceptions. Stations VC-007, VC-009, and VC-017 have concentrations of fine sediments that are 46%, 22%, and 89%, respectively, and represent areas where greater amounts fine material may be released into the water column. At station VC-017, it was reported that fine clays were abundant, which are included in the 89% of the core composed of fine sediments.

## Table 2. Sediment Core Data

| Core ID | Easting [m] | Northing [m] | Latitude [°N] | Longitude [°W] | Depth (m MLLW) | % Finer < No. 200 | Unit Wet Weight (lb/ft^3) |
|---|---|---|---|---|---|---|---|
| VC-001 | 416227 | 4075017.6 | 36.81731 | -75.939269 | 10.49 | 19.7 | 127.2 |
| VC-001A | 416219 | 4075014.3 | 36.81728 | -75.939359 | 10.5 | 14 | 124.5 |
| VC-002B | 420159.6 | 4075204.5 | 36.81933 | -75.895201 | 12.05 | 1.3 | 125.3 |
| VC-003 | 421142 | 4075165.2 | 36.81906 | -75.884184 | 15.02 | 11.9 | 123.0 |
| VC-004 | 421866.6 | 4075183 | 36.81928 | -75.876062 | 16.5 | 18.9 | 124.9 |
| VC-005 | 422901.6 | 4075083.5 | 36.81847 | -75.864447 | 17.52 | 10.2 | 126.7 |
| VC-006 | 424022.1 | 4074823.6 | 36.81622 | -75.85186 | 18.22 | 5.8 | 121.1 |
| VC-007 | 426992.9 | 4074142.2 | 36.81031 | -75.81849 | 18.3 | 46.8 | 121.9 |
| VC-008 | 429943.6 | 4073888 | 36.80824 | -75.785388 | 21.26 | 7.0 | 126.4 |
| VC-009 | 433325.2 | 4073723.3 | 36.807 | -75.747467 | 22.02 | 22.1 | 132.8 |
| VC-010 | 435900.9 | 4074284.5 | 36.81224 | -75.71864 | 20.27 | 1.0 | 115.8 |
| VC-011 | 438826.5 | 4074926.1 | 36.81822 | -75.685894 | 21.74 | 4.5 | 131.8 |
| VC-012 | 441860 | 4075570.5 | 36.82421 | -75.651933 | 19.75 | 0.7 | 59.7 |
| VC-013 | 444774.4 | 4076206.8 | 36.83013 | -75.619302 | 20.2 | 1.7 | 114.7 |
| VC-014 | 447329.5 | 4077704.3 | 36.84377 | -75.590753 | 20.7 | 1.3 | 106.9 |
| VC-015 | 449917.3 | 4079241.9 | 36.85777 | -75.561831 | 20.35 | 1.2 | 122.7 |
| VC-015A | 449918.2 | 4079247.3 | 36.85782 | -75.561822 | 20.33 | 0.8 | 121.5 |
| VC-016 | 452537.3 | 4080795.8 | 36.87191 | -75.532539 | 26.95 | 14.5 | 127.4 |
| VC-017 | 455040.8 | 4082296.8 | 36.88557 | -75.504539 | 27.97 | 89.5 | 110.6 |

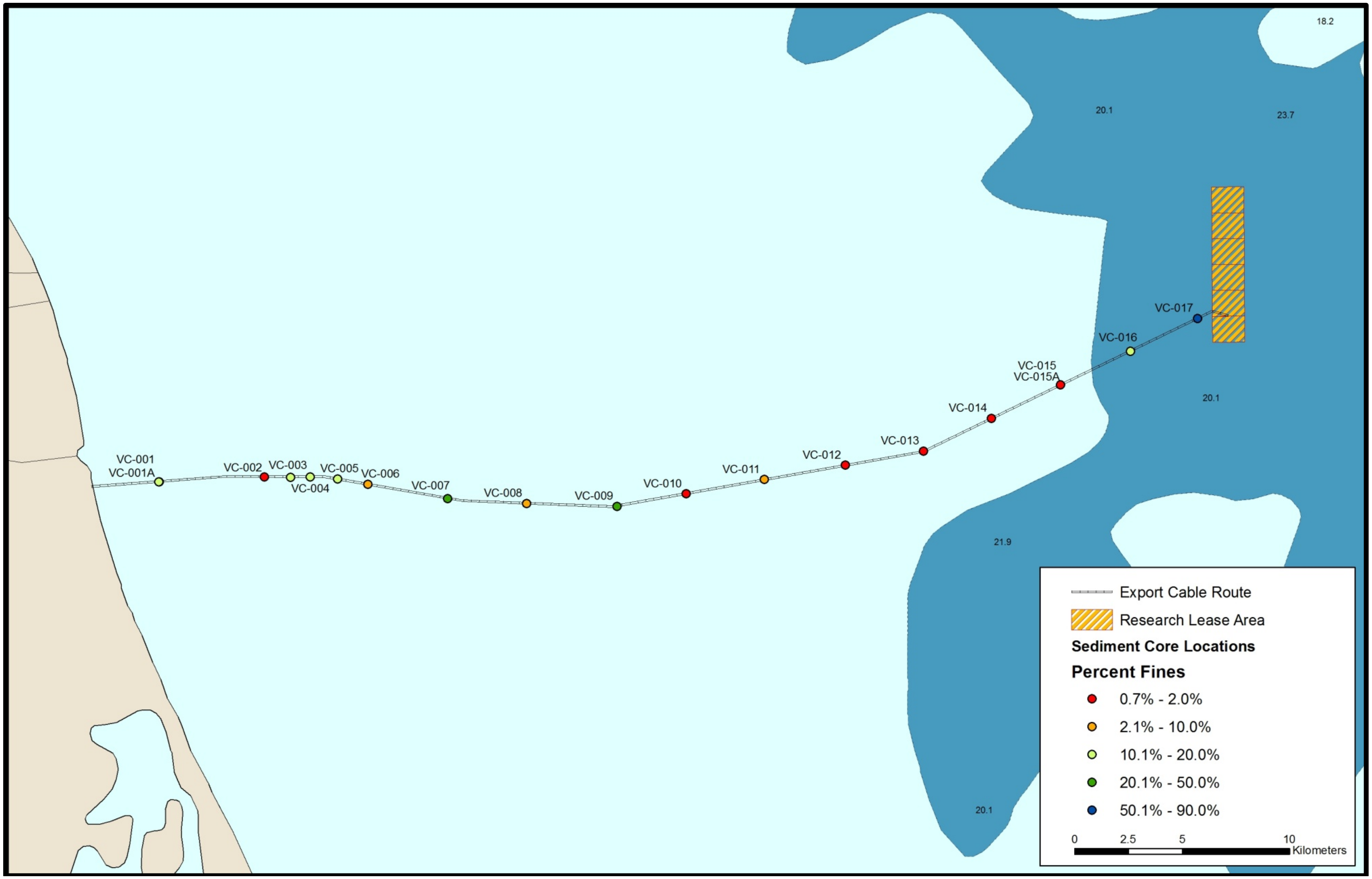

**Figure 7.** **Locations of sediment cores taken along proposed Export Cable Route**

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# 3.0 SEDIMENT TRANSPORT

This section describes the input information, methodology, and results for the analytical sediment transport modeling to determine the suspended sediment concentration, sedimentation rates, and deposition footprint and thickness anticipated from the jet plow construction process. The approach assumes application of an analytical approach to the sediment transport analysis, which is consistent with prior projects for environmental regulatory review purposes. The proposed approach does not incorporate a full hydrodynamic circulation model linked to a sediment transport/dispersion model, which would entail a greater level of effort and input data requirements.

## 3.1 MODEL SETUP AND PARAMETERS

The trenching will be performed utilizing a hydraulic jet plow that incorporates a series of high velocity water jets. For the purpose of this analysis Woods Hole Group has been directed to consider the Global Marine Systems Hi-Plough® as the VOWTAP's base-case assumption for cable installation. It should be noted, however, that the final selection of the installation equipment and associated vendors will be procured during the contracting phase of the Project following receipt of Project permits.

To achieve the required cable burial depth, high pressure water from vessel-mounted pumps will be injected into the sediments through nozzles distributed along the front of the jet plow. As the plow is towed by the vessel, the seafloor sediments are temporarily fluidize creating a narrow trench (approximately 1 m wide) as the cable is simultaneously guided into the trench by the plow. While the majority of fluidized sediment will settle back into the trench to provide cover for the cable, a portion of the fine sediments can remain in suspension under the influence of the ambient currents. Utilizing project-specific parameters of the jetting apparatus/operation, the zone of influence controlled by the jetting dynamics was determined based on assumptions about where the jet flow velocity equals or exceeds the critical velocity required to maintain suspension of sediments finer than 200 μm.

Sediment transport resulting from cable installation by jet plow was simulated for nineteen sediment core locations, shown in Figure 7, beginning at the first core station VC-001 (east) and ending at the last core station VC-0017 (west). The model simulated the burial of a single cable in a trench of 2-4 m deep and 1 m wide as a continuous process by moving the sled a rate of 0.2 km/h. The theoretical maximum volume of sediment that can be mobilized into the water column is the entire trench volume (i.e., 100% of sediment trench volume); however, this scenario is unrealistic since much of the coarser sediments settle in the immediate vicinity of the trench. Of the volume of material mobilized in the trench, only the fraction of fine sediments (% < 200 μm) was considered to be suspended and transported into the sediment plume. The amount of fine material mobilized is dependent on the concentration of fine material at each of the nineteen core locations.

The height of the sediment plume above the seafloor is a function of the local hydrodynamics and grain size as well as the jetting associated with the plow. Previous studies indicated the plume of sediment released during jet plowing reaches heights of roughly 2 m above the seafloor under small ambient currents (ETA, 2002), which is proportional to the typical depth of jetting. The suspended sediment plume is then dispersed by the local tidal currents. At each sediment core location where sediment transport was simulated, the tidal currents output from the nearest current station were used. Sediment transport at each location was simulated for both flood and ebb current scenarios, where currents velocities ranged between 15-39 cm/s (Table 1). The dominant current directions are oriented northward for the flood tide and southward for the ebb tide, which can transport fine sediment to either side of the cable route depending upon when installation occurs during the tidal cycle.

The time it takes for fine grain sediment to settle is dependent on the settling velocity of the particle, the depth of suspension, and the overlying tidal current speed and direction. For the fraction of sediments finer than a 200 μm sieve, a representative sediment grain diameter of 0.075 mm it was assumed, along with a resulting settling velocity of 0.5 cm/s calculated based upon Figure III-1-6 of the Coastal Engineering Manual (CEM) (USACE, 2002).

The fine sediments release rate, $Q_s$, resulting from the jet plow operations was calculated based on the volume of fine sediments within the 1 meter wide by 2 meter deep jetted trench, Vs, the travel rate of the sled, $T_r$, and the wet unit weight of the sediment, $\omega_s$, using the following methodology (AGTC, 2001):

$$Q_s = V_s * T_r * \omega_s \tag{1}$$

Where:

Vs = sediment volume released ($m^2$)
$T_r$ = travel rate of the sled (m/s)
$\omega_s$ = submerged weight of the sediment ($g/m^3$)

The sediment release rate along the proposed cable route varies from less 1 kg/s to over 176 kg/s depending on the local fraction of fine sediments with an average rate of 14 kg/s. The sediment release rate highlights potential fine sediment hotspots along the cable route, such as stations VC-007 and VC-0017 where $Q_s$ is greater than 100 g/s. By this method, the initial concentration is conservatively high, and represents a worst-case scenario since all the fine material is assumed to instantly be suspended into a 2 m high water column immediately above the plow.

## Table 3. Sediment Release Rate Qs (g/s)

| Core ID | % Finer < No. 200 | Unit Wet Weight (lb/ft^3) | Qs (kg/s) |
|---|---|---|---|
| VC-001 | 19.7 | 127.2 | 44.6 |
| VC-001A | 14.0 | 124.5 | 31.0 |
| VC-002B | 1.3 | 125.3 | 2.9 |
| VC-003 | 11.9 | 123.0 | 26.1 |
| VC-004 | 18.9 | 124.9 | 42.0 |
| VC-005 | 10.2 | 126.7 | 23.0 |
| VC-006 | 5.8 | 121.1 | 12.5 |
| VC-007 | 46.8 | 121.9 | 101.5 |
| VC-008 | 7.0 | 126.4 | 15.7 |
| VC-009 | 22.1 | 132.8 | 52.2 |
| VC-010 | 1.0 | 115.8 | 2.1 |
| VC-011 | 4.5 | 131.8 | 10.6 |
| VC-012 | 0.7 | 59.7 | 0.7 |
| VC-013 | 1.7 | 114.7 | 3.5 |
| VC-014 | 1.3 | 106.9 | 2.5 |
| VC-015 | 1.2 | 122.7 | 2.6 |
| VC-015A | 0.8 | 121.5 | 1.7 |
| VC-016 | 14.5 | 127.4 | 32.9 |
| VC-017 | 89.5 | 110.6 | 176.2 |

### 3.2 METHODOLOGY FOR DISPERSION OF FINE PARTICLES

This section describes the water-column sediment concentration resulting from continuous release of fine sediment from the jetted trench. The approach assumes the fine sediment fraction is released from a fixed height above the trench, which then is transported by local tidal currents, and settles at a fixed rate (i.e., settling velocity) in the presence of a depth-uniform current above a horizontal seafloor. The particles are assumed to settle under the influence of gravity while advected horizontally by the tidal current. The particles are assumed to fall into a bottom boundary layer of constant thickness, where vertical mixing and resuspension effectively cause the sediment concentration to be independent of height above bottom, and there is no sediment flux to the seafloor. The Eulerian velocity of the current is assumed to be stationary and ergodic (i.e., time average of one sequence of events is the same as the ensemble average) and to have Gaussian statistics.

The notation is as follows. The horizontal coordinates are $x$ and $y$ and the vertical coordinate is $z$, where $z = 0$ coincides with the seafloor. The location of the discharge is $(x, y, z) = (0,0,h)$, where $h$ is the height of the discharge above the seafloor. Time is $t$, with $t = 0$ corresponding to the time at which the sediment discharge begins. The velocity vector of the current in the $(x, y, z)$ coordinate system is $(u, v, 0)$. The auto-covariance functions $R_{uu}(\tau)$ and $R_{vv}(\tau)$ for the horizontal components of the current are defined by

$$R_{uu}(\tau) = \mathrm{cov}\left[u(t)u(t+\tau)\right] \text{ and } R_{vv}(\tau) = \mathrm{cov}\left[v(t)v(t+\tau)\right], \tag{2}$$

and the corresponding cross-covariance functions are

$$R_{uv}(\tau) = \mathrm{cov}\left[u(t)v(t+\tau)\right] \text{ and } R_{vu}(\tau) = \mathrm{cov}\left[v(t)u(t+\tau)\right]. \tag{3}$$

Overbars denote expected values. The volume flux of sediment at the discharge is $Q_s(t)$ and the volume of sediment discharged is $V_s(t) = \int_0^t Q_s(t')dt'$, where $t'$ is a dummy variable of integration. The fixed settling velocity of the particles is $w_s$. The volume concentration of sediment is $c(x,y,z,t)$ and the vertical flux of sediment is $q_s(x,y,z,t)$.

Let $\left[X(t), Y(t), Z(t)\right]$ be the position of a particle released at time $t = t_0$ at the discharge location $(x,y,z) = (0,0,h)$. For $0 \le t - t_0 \le h / w_s$, the vertical position of the particle is

$$Z(t) = h - w_s\left(t - t_0\right),$$

and the joint probability density function of the horizontal coordinates $X(t)$ and $Y(t)$ is the bivariate normal distribution:

$$f\left[X(t), Y(t)\right] = \frac{1}{2\pi\sigma_X\sigma_Y\sqrt{1-\rho^2}} \exp\left\{-\frac{1}{2\left(1-\rho^2\right)}\left[\frac{\left(X-\overline{X}\right)^2}{{\sigma_X}^2} + \frac{\left(Y-\overline{Y}\right)^2}{{\sigma_Y}^2} - \frac{2\rho\left(X-\overline{X}\right)\left(Y-\overline{Y}\right)}{\sigma_X\sigma_Y}\right]\right\}$$

(4).

Here $\overline{X}(t)$ and $\overline{Y}(t)$ are the expected values of $X(t)$ and $Y(t)$, given by

$$\overline{X}(t) = \overline{u}\left(t - t_0\right) \text{ and } \overline{Y}(t) = \overline{v}\left(t - t_0\right), \tag{5}$$

$\sigma_X(t)$ and $\sigma_Y(t)$ are the standard deviations of $X(t)$ and $Y(t)$, given according to Taylor's (1922) theory of diffusion by continuous movements by

$${\sigma_X}^2 = 2\int_0^{t-t_o}(t-\tau)R_{uu}(\tau)d\tau \text{ and } {\sigma_Y}^2 = 2\int_0^{t-t_0}(t-\tau)R_{vv}(\tau)d\tau, \tag{6}$$

and $\rho(t)$ is the correlation coefficient, defined by

$$\rho = \frac{\mathrm{cov}(X,Y)}{\sigma_X\sigma_Y}, \tag{7}$$

with $\mathrm{cov}(X,Y)$ given according to Taylor's (1922) theory by

$$\mathrm{cov}(X,Y) = \int_0^{t-t_0} (t-\tau)\left[R_{uv}(\tau) + R_{vu}(\tau)\right] d\tau \, . \tag{8}$$

It follows from the stated assumptions that the volumetric vertical sediment flux $q_s(x,y,z,t)$ in the water column above the bottom boundary layer is the sediment flux $Q_s$ at the discharge, evaluated at time $t-(h-z)/w_s$, times the probability density function $f$, evaluated at $(x,y)$:

$$q_s(x,y,z,t) = \frac{Q_s\left[t-(h-z)/w_s\right]}{2\pi\sigma_X\sigma_Y\sqrt{1-\rho^2}} \exp\left\{-\frac{1}{2\left(1-\rho^2\right)}\left[\frac{\left(x-\overline{X}\right)^2}{\sigma_X{}^2} + \frac{\left(y-\overline{Y}\right)^2}{\sigma_Y{}^2} - \frac{2\rho\left(x-\overline{X}\right)\left(y-\overline{Y}\right)}{\sigma_X\sigma_Y}\right]\right\}$$

(9),

with $\overline{X}$, $\overline{Y}$, $\sigma_X$, $\sigma_Y$ and $\rho$ evaluated at $t-t_0 = (h-z)/w_s$, which is the time required for a particle released at the discharge height to reach the elevation z. The corresponding volumetric concentration $c(x,y,z,t)$ is $q_s/w_s$. The vertically uniform sediment concentration in the bottom boundary layer is

$$c = \int_0^{t-(h-\delta)/w_s} \frac{Q_s(t_0)dt_0}{2\pi\sigma_X\sigma_Y\sqrt{1-\rho^2}\,\delta} \exp\left\{-\frac{1}{2\left(1-\rho^2\right)}\left[\frac{\left(x-\overline{X}\right)^2}{\sigma_X{}^2} + \frac{\left(y-\overline{Y}\right)^2}{\sigma_Y{}^2} - \frac{2\rho\left(x-\overline{X}\right)\left(y-\overline{Y}\right)}{\sigma_X\sigma_Y}\right]\right\}$$

(10),

with $\overline{X}$, $\overline{Y}$, $\sigma_X$, $\sigma_Y$ and $\rho$ evaluated at $t-t_0 = (h-\delta)/w_s$, which is the time required for a particle released at the discharge height to reach the bottom boundary layer. The concentration $c(x,y,z,t)$ is in a volumetric form (m3/m3), but can be converted to a mass based quantity by multiply it by the unit weight of the fine sediment particles. By this method, calculated concentrations are conservatively high, and represent a worst-case scenario along the centerline of the advected sediment plume.

### 3.3 METHODOLOGY FOR DEPOSITION OF FINE PARTICULATES

To determine the dispersion of fine sediments potentially released during jet plow activities, an analytical model was applied to determine the fate of construction derived fine particulates in the marine environment. At the point of initial discharge, dynamic plume processes dominate dispersion of the particulates, rapidly mixing and diluting the material. Lighter particulate matter remains in the water column, is advected by ambient currents, and subsequently deposited over a distance from the exit point as it settles to the seafloor. After deposition, long-term processes may resuspend the particulates and further disperse the sediments; however, these resuspended concentrations are independent from the jetting operation and were not analyzed herein. No resuspension of particulates has been considered in the present analysis. The model focuses on the initial dispersion of the particulates over jetted areas that may generate brief episodes of elevated fine particulate concentration and adjacent transport and deposition.

The analytical model is based on a trajectory approach that neglects oceanic turbulence and uses the current velocities from the ROMS output. This approach is reasonable for generating temporal and spatial patterns consistent with observations of particulate flux. In this approach, a volume (V) of fine particulates is released throughout the water column to a certain height (h) above the seafloor. A uniform current velocity u is assumed based on the ROMS output. The along-flow coordinate is x, the cross-flow coordinate is y, and the vertical coordinate is z, with z = 0 at the seafloor. Particulates are assumed to fall vertically at a settling velocity, $w_s$, of 0.5 cm/s and spread longitudinally and laterally in the x and y directions according to a diffusivity K. The objective of the model is to determine the thickness $\zeta(x, y)$ of the sediment deposited on the seafloor. Equation 11 illustrates the relationship between the principal parameters in the analytical model.

Consider an infinitesimal volume of the fine particle release with height dz, settling velocity $w_s$, and volume $(V/h)dz$. With a constant settling velocity 0.5 cm/s. This infinitesimal element of the release produces an infinitesimal element $d\zeta(x, y)$ of the specific particulate type deposited on the seafloor. Therefore, $d\zeta(x, y)$ is given by

$$d\zeta(x, y) = \frac{Vdz}{2\pi\sigma^2 h}\exp\left[-\frac{(x - uz/w_s)^2 + y^2}{2\sigma^2}\right] \tag{11}$$

Where:

$$\sigma = \sqrt{2Kz/w_s} \tag{12}$$

is the lateral scale of the diffusive spreading that occurs as the particulate advects and falls. The total thickness of the deposit is then determined by summing all of the infinitesimal contributions:

$$\zeta(x, y) = \frac{V}{2\pi h}\int_{z_1}^{z_2}\frac{1}{\sigma^2}\exp\left[-\frac{(x - uz/w_s)^2 + y^2}{2\sigma^2}\right]dz \tag{13}$$

# 4.0 RESULTS

This section presents the sediment transport modeling results in terms of fine sediment plume concentrations, distance from the jet plow the sediment is deposited on the sea floor, and settling thicknesses.

## 4.1 SUSPENDED FINE SEDIMENT CONCENTRATION RESULTS

Figure 8 illustrates results from the analytical model for a conservative case at core location VC-001, where fine sediment on the order of $10^5$ mg/L is released into the marine waters from the trench. The figure shows the fine sediment concentration (mg/L) along the plume centerline normal to the trench direction, which represents the maximum amount of sediment introduced to the water column as a part of this conservative approach. The left side of the figure represents the flood current case and the right side represents the ebb current case. The horizontal axis shows distance from the trench in the direction of current flow, and the vertical axis shows the concentration of sediment in the direction of current flow. The color bar to the right of the figure delineates concentration (mg/L) of fine sediment in the water column on a $\log_{10}$ based scale; hotter colors (reds, orange, and yellow) indicate higher concentrations deposits, and cooler colors (blue, green, purple) indicate lower concentrations.

The highest concentrations of sediment occur in the immediate vicinity (<10 m) of the trench. These initial conditions are conservatively high, and assume that all of the fine material (finer than 200 μm) in the plowed trench is mobilized instantly into the water column immediately above the plow footprint and within 2 m of the seafloor. The initial concentration then rapidly decreases away from the source (jetted trench). Note that while concentrations remain elevated at a distance of 50 m from the trench, the plume is confined to a layer only 1 m off the seafloor. The zone of influence of the trenching activities is considered to be the limit of the plume, which would be 150 meters and 100 meters for the flood and ebb tide scenarios, respectively, for this case. The plume height is less than a tenth of a meter at the edge of the plume. The reported concentrations also are conservatively high in that they represent the maximum concentration along the centerline of the plume, as it is transported adjacent to the trench by tidal currents.

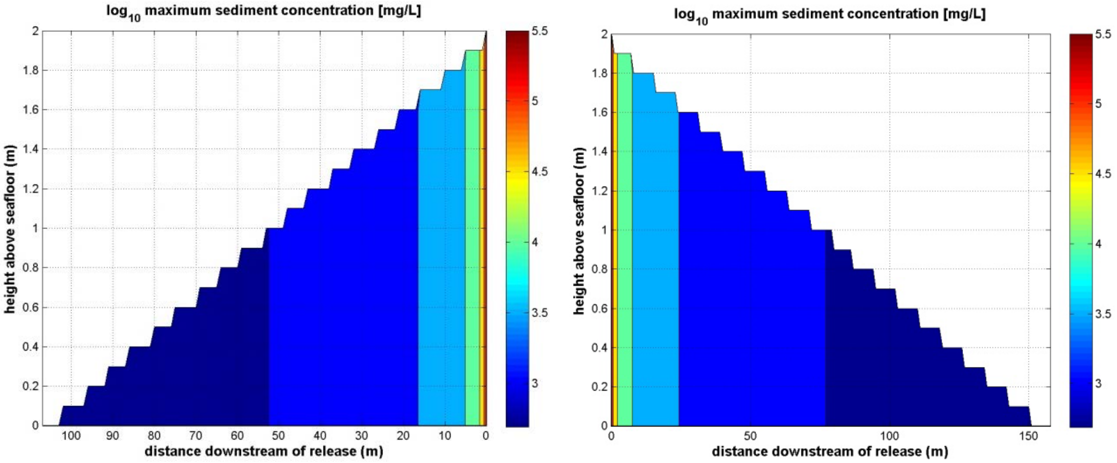

**Figure 8.** **Sediment concentration (mg/L) along plume centerline for the flood (left) and ebb (right) scenarios at Station VC-001.**

Figure 9 illustrates a similar case for core station VC-017. For this case a greater concentration of fine material, on the order of $10^6$ mg/L, is mobilized initially as compared to the concentration at VC-001 ($10^5$ mg/L), since the fraction of fine material is higher at this location; however, the zone of influence is greater for VC-001 (100 meters flood/150 ebb) than VC-017 (~60 meters flood/ebb) due to the higher magnitude of the tidal currents.

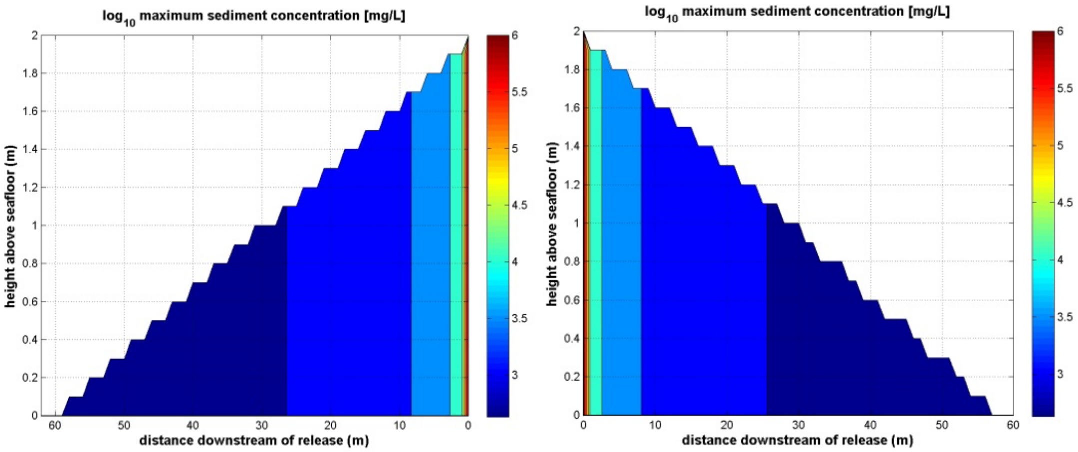

**Figure 9.** **Sediment concentration (mg/L) along plume centerline for the flood (left) and ebb (right) scenarios at Station VC-017.**

Table 4 summaries the fine sediment concentrations predicted by the model at distances along the centerline of the sediment plume (away from the jetted trench) for the nineteen core stations for both flood and ebb current scenarios. The zone of influence for the trenching activities are generally widest for the near shore stations (160 m) where the current velocities are highest, and are narrowest (50 m) at the offshore stations where the current velocities are less. The concentrations are initially very high but rapidly decrease as sediment settles from the plume to the ocean floor. The concentrations at the edge of the plume is elevated (>100 mg/l), but the plume is confined to a layer less than a tenth of a meter from the seafloor. Reported concentrations are conservatively high, representing transport of the entire volume of fine material from the trench, confined to the bottom 2 meters or less of the water column along the centerline of the plume.

Figure 10 shows the fine sediment plume (mg/l) generated by the jet plow in relation to the Virginia shoreline. The scale of the plume width (100-300 m) is narrow relative to the overall length of the Export Cable (43 km). Therefore, several insets are provided to illustrate representative sections of the plume. Concentrations range in the figure range from nearly 0 mg/l to more than 100,000 mg/l for localized initial conditions where the fraction of fine sediment is relatively high.

**Table 4.** **Potential suspended fine sediment concentrations (mg/l) at centerline of plume.**

| Station ID | Current Stage | Distance from Trench Centerline (m) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 5 | 10 | 25 | 50 | 75 | 100 | 125 | 160 |
| VC-001 | Flood | 401,089 | 10,231 | 5,193 | 2,097 | 1,051 | 702 | 527 | 0 | 0 |
| | Ebb | 401,089 | 14,813 | 7,572 | 3,070 | 1,542 | 1,029 | 773 | 618 | 0 |
| VC-001A | Flood | 278,987 | 9,892 | 5,052 | 2,047 | 1,028 | 686 | 515 | 0 | 0 |
| | Ebb | 278,987 | 14,242 | 7,345 | 2,994 | 1,506 | 1,006 | 756 | 605 | 0 |
| VC-002B | Flood | 26,072 | 6,905 | 4,178 | 1,898 | 992 | 672 | 508 | 0 | 0 |
| | Ebb | 26,072 | 8,665 | 5,593 | 2,675 | 1,427 | 972 | 737 | 594 | 0 |
| VC-003 | Flood | 234,282 | 9,700 | 4,972 | 2,019 | 1,015 | 678 | 509 | 0 | 0 |
| | Ebb | 234,282 | 13,920 | 7,216 | 2,951 | 1,486 | 993 | 746 | 597 | 0 |
| VC-004 | Flood | 377,843 | 10,033 | 5,096 | 2,058 | 1,032 | 689 | 517 | 0 | 0 |
| | Ebb | 377,843 | 14,518 | 7,428 | 3,013 | 1,514 | 1,011 | 759 | 607 | 0 |
| VC-005 | Flood | 206,854 | 9,910 | 5,101 | 2,076 | 1,044 | 698 | 524 | 0 | 0 |
| | Ebb | 206,854 | 14,169 | 7,388 | 3,032 | 1,529 | 1,022 | 768 | 615 | 0 |
| VC-006 | Flood | 112,424 | 9,074 | 4,769 | 1,967 | 994 | 665 | 499 | 0 | 0 |
| | Ebb | 112,424 | 12,733 | 6,840 | 2,861 | 1,452 | 973 | 732 | 586 | 0 |
| VC-007 | Flood | 913,138 | 7,296 | 3,665 | 1,470 | 736 | 491 | 0 | 0 | 0 |
| | Ebb | 913,138 | 8,584 | 4,316 | 1,732 | 867 | 578 | 0 | 0 | 0 |
| VC-008 | Flood | 141,622 | 7,178 | 3,701 | 1,508 | 759 | 507 | 0 | 0 | 0 |
| | Ebb | 141,622 | 8,369 | 4,338 | 1,774 | 893 | 597 | 0 | 0 | 0 |
| VC-009 | Flood | 469,761 | 7,866 | 3,972 | 1,598 | 801 | 534 | 0 | 0 | 0 |
| | Ebb | 469,761 | 9,238 | 4,673 | 1,882 | 943 | 629 | 0 | 0 | 0 |
| VC-010 | Flood | 18,535 | 4,339 | 2,556 | 1,138 | 591 | 0 | 0 | 0 | 0 |
| | Ebb | 18,535 | 4,126 | 2,407 | 1,064 | 551 | 0 | 0 | 0 | 0 |
| VC-011 | Flood | 94,932 | 6,425 | 3,349 | 1,374 | 693 | 0 | 0 | 0 | 0 |
| | Ebb | 94,932 | 6,011 | 3,124 | 1,280 | 645 | 0 | 0 | 0 | 0 |
| VC-012 | Flood | 6,689 | 1,827 | 1,114 | 509 | 267 | 0 | 0 | 0 | 0 |
| | Ebb | 6,689 | 1,827 | 1,114 | 509 | 267 | 0 | 0 | 0 | 0 |
| VC-013 | Flood | 31,210 | 4,444 | 2,437 | 1,033 | 527 | 0 | 0 | 0 | 0 |
| | Ebb | 31,210 | 4,444 | 2,437 | 1,033 | 527 | 0 | 0 | 0 | 0 |
| VC-014 | Flood | 22,244 | 3,923 | 2,206 | 951 | 488 | 0 | 0 | 0 | 0 |
| | Ebb | 22,244 | 3,923 | 2,206 | 951 | 488 | 0 | 0 | 0 | 0 |
| VC-015 | Flood | 23,567 | 4,420 | 2,507 | 1,087 | 559 | 0 | 0 | 0 | 0 |
| | Ebb | 23,567 | 4,420 | 2,507 | 1,087 | 559 | 0 | 0 | 0 | 0 |
| VC-015A | Flood | 15,558 | 3,897 | 2,328 | 1,047 | 546 | 0 | 0 | 0 | 0 |
| | Ebb | 15,558 | 3,897 | 2,328 | 1,047 | 546 | 0 | 0 | 0 | 0 |
| VC-016 | Flood | 295,682 | 5,943 | 3,007 | 1,212 | 607 | 0 | 0 | 0 | 0 |
| | Ebb | 295,682 | 5,756 | 2,911 | 1,173 | 588 | 0 | 0 | 0 | 0 |
| VC-017 | Flood | 1,584,401 | 5,264 | 2,637 | 1,056 | 528 | 0 | 0 | 0 | 0 |
| | Ebb | 1,584,401 | 5,095 | 2,552 | 1,022 | 511 | 0 | 0 | 0 | 0 |

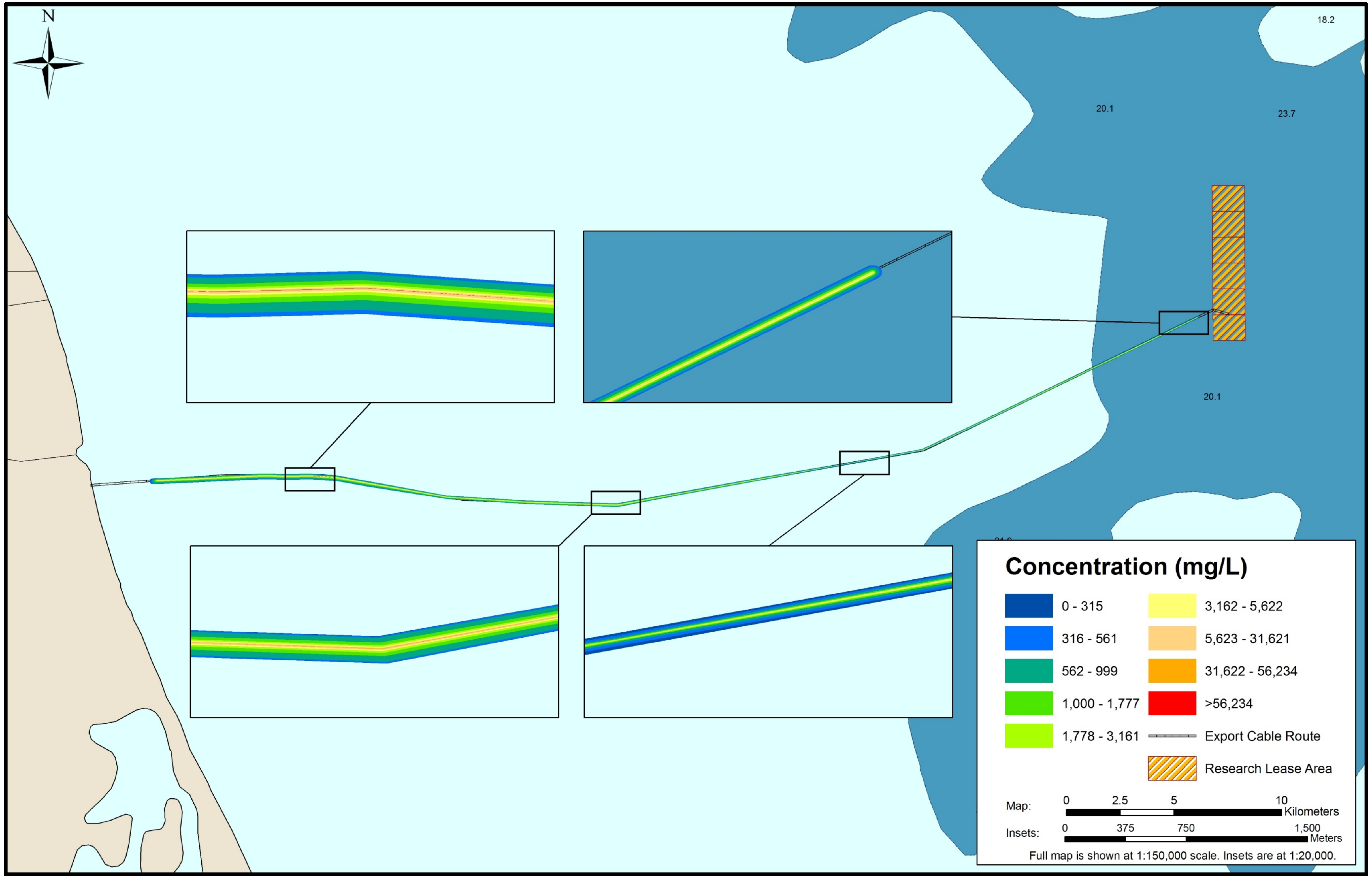

**Figure 10.** **Suspended fine sediment plume generated by jet plow activities along the proposed Export Cable route.**

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### 4.2 SEDIMENT DEPOSITION RESULTS

The model shows that the fine sediment suspended in the water column eventually settles into a thin layer along the seafloor. The fine sediment (<200 µm) will remain in suspension for approximately 6-7 minutes after the initial release before settling to the seafloor based upon a fall velocity of 0.5 cm/s and discharge height of 2 m. Figure 11 illustrates thickness of fine particulates settling on the seafloor along the centerline of the sediment plume normal to the trench direction, which represents the maximum settling thickness along the plume centerline as a part of this conservative approach. The horizontal axis presents distance from the trench in the direction of the dominant current, and the vertical axis shows total thickness of the particulates accumulated on the seafloor. The thickness is the total summation of all the fine particulates assumed to be released. The thickness of the total deposited material at the peak of the centerline is approximately 3.2 mm and 2.2 mm for the flood (left plot) and ebb (right plot) scenarios, respectively, at station VC-07. The reason for the difference is the magnitude of the ebb current is greater than the flood current and disperses the material over a wider distance resulting in a larger zone of influence with less thickness of cover. The thickness of the deposition is less than 1 mm at 100 m from the trench for both the flood and ebb current scenarios. The fine particle size, the conservative assumptions, and the energetic ocean processes in the vicinity of the trenching operations, combine to disperse the fine sediments up to 200 m from the trench in a relatively thin layer.

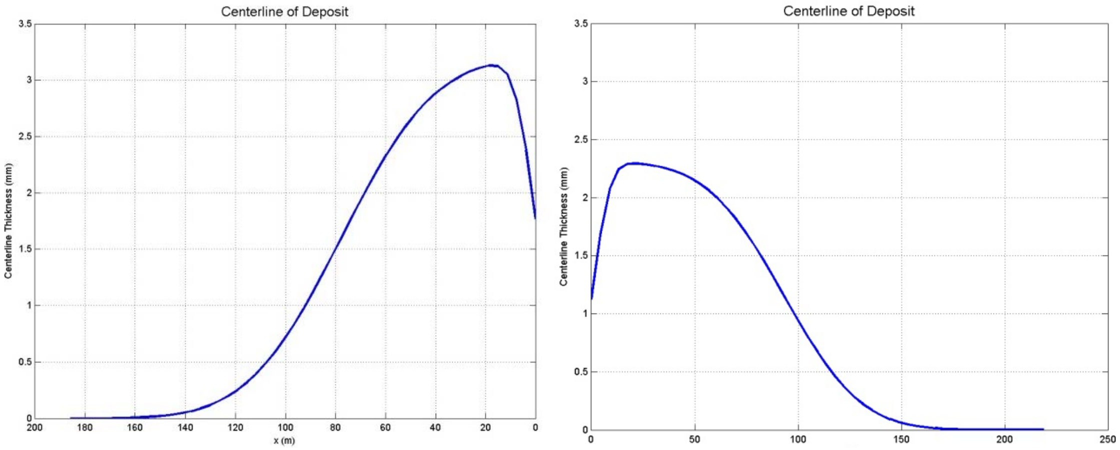

**Figure 11. Fine sediment settling thickness (mm) normal to cable route at VC-007 for the flood (left) and ebb (right) current scenarios.**

Table 5 summaries the settling distance away from the jetted trench and thickness of fine particulates deposited on the seafloor along the centerline of the sediment plume for the nineteen stations under average peak flood and ebb current scenarios. The zone of influence for the trenching activities is widest for the near shore stations (200 meters) where the current velocities are highest, and narrowest (50 meters) at the offshore stations where the current velocities are lower. Thickness of deposited sediment was less than 1 mm for the majority of locations simulated, with maximum deposition exceeding a few mm at isolated locations only at stations VC-007, VC-016, and VC-017, where the sediment had a high percentage of fine material and currents were weakest. Settled sediment is then available for resuspension and dispersal into a more diffuse layer by the ambient currents (e.g., wave orbital velocities and higher currents during more energetic climatic events), which are not simulated by this model.

Figure 12 shows the jet plow depositional plume in relation to the Virginia shoreline. The scale of the plume width (100-400 m) is narrow relative to the overall length of the Export Cable (44 km). Therefore, several inset images are provided to illustrate representative sections of the plume. Depositional thickness ranges from less 0.01 mm at the edge of the plume to more than 2 mm at the point of release. The greatest deposition occurred at stations VC-017 and VC-007, which had the highest concentrations of fine material.

**Table 5. Potential fine sediment deposition (mm) at centerline of plume for average peak running flood and ebb tides (maximum values in bold).**

| Station ID | Current Stage | Distance from Trench Centerline (m) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **0** | **5** | **10** | **25** | **50** | **100** | **150** | **200** | **250** |
| VC-001 | Flood | 0.301 | 0.505 | 0.647 | 0.716 | 0.703 | 0.453 | 0.062 | 0.001 | 0.000 |
| | Ebb | 0.079 | 0.175 | 0.255 | 0.333 | 0.334 | 0.329 | 0.229 | 0.037 | 0.001 |
| VC-001A | Flood | 0.214 | 0.359 | 0.460 | 0.509 | 0.500 | 0.322 | 0.044 | 0.001 | 0.000 |
| | Ebb | 0.056 | 0.125 | 0.181 | 0.237 | 0.237 | 0.234 | 0.163 | 0.026 | 0.000 |
| VC-002B | Flood | 0.020 | 0.033 | 0.043 | 0.047 | 0.046 | 0.030 | 0.004 | 0.000 | 0.000 |
| | Ebb | 0.005 | 0.012 | 0.017 | 0.022 | 0.022 | 0.022 | 0.015 | 0.002 | 0.000 |
| VC-003 | Flood | 0.182 | 0.305 | 0.391 | 0.433 | 0.425 | 0.274 | 0.037 | 0.001 | 0.000 |
| | Ebb | 0.048 | 0.106 | 0.154 | 0.201 | 0.202 | 0.199 | 0.138 | 0.022 | 0.000 |
| VC-004 | Flood | 0.289 | 0.484 | 0.621 | 0.687 | 0.674 | 0.435 | 0.059 | 0.001 | 0.000 |
| | Ebb | 0.075 | 0.168 | 0.244 | 0.320 | 0.320 | 0.316 | 0.220 | 0.036 | 0.001 |
| VC-005 | Flood | 0.156 | 0.261 | 0.335 | 0.371 | 0.364 | 0.235 | 0.032 | 0.000 | 0.000 |
| | Ebb | 0.041 | 0.091 | 0.132 | 0.173 | 0.173 | 0.170 | 0.119 | 0.019 | 0.000 |
| VC-006 | Flood | 0.089 | 0.149 | 0.190 | 0.211 | 0.207 | 0.133 | 0.018 | 0.000 | 0.000 |
| | Ebb | 0.023 | 0.052 | 0.075 | 0.098 | 0.098 | 0.097 | 0.067 | 0.011 | 0.000 |
| VC-007 | Flood | 1.771 | 2.532 | 2.978 | 3.088 | 2.648 | 0.719 | 0.022 | 0.000 | 0.000 |
| | Ebb | 1.127 | 1.734 | 2.120 | 2.288 | 2.147 | 0.944 | 0.061 | 0.000 | 0.000 |
| VC-008 | Flood | 0.265 | 0.379 | 0.446 | 0.462 | 0.396 | 0.108 | 0.003 | 0.000 | 0.000 |
| | Ebb | 0.169 | 0.259 | 0.317 | 0.342 | 0.321 | 0.141 | 0.009 | 0.000 | 0.000 |
| VC-009 | Flood | 0.836 | 1.196 | 1.406 | 1.458 | 1.250 | 0.340 | 0.011 | 0.000 | 0.000 |
| | Ebb | 0.532 | 0.819 | 1.001 | 1.081 | 1.014 | 0.446 | 0.029 | 0.000 | 0.000 |
| VC-010 | Flood | 0.053 | 0.072 | 0.082 | 0.082 | 0.064 | 0.012 | 0.000 | 0.000 | 0.000 |
| | Ebb | 0.063 | 0.084 | 0.094 | 0.092 | 0.067 | 0.010 | 0.000 | 0.000 | 0.000 |
| VC-011 | Flood | 0.237 | 0.323 | 0.371 | 0.368 | 0.286 | 0.052 | 0.001 | 0.000 | 0.000 |
| | Ebb | 0.284 | 0.378 | 0.425 | 0.412 | 0.301 | 0.044 | 0.001 | 0.000 | 0.000 |
| VC-012 | Flood | 0.050 | 0.065 | 0.072 | 0.069 | 0.048 | 0.006 | 0.000 | 0.000 | 0.000 |
| | Ebb | 0.050 | 0.065 | 0.072 | 0.069 | 0.048 | 0.006 | 0.000 | 0.000 | 0.000 |
| VC-013 | Flood | 0.121 | 0.158 | 0.176 | 0.167 | 0.116 | 0.015 | 0.000 | 0.000 | 0.000 |
| | Ebb | 0.121 | 0.158 | 0.176 | 0.167 | 0.116 | 0.015 | 0.000 | 0.000 | 0.000 |
| VC-014 | Flood | 0.092 | 0.121 | 0.134 | 0.128 | 0.089 | 0.011 | 0.000 | 0.000 | 0.000 |
| | Ebb | 0.092 | 0.121 | 0.134 | 0.128 | 0.089 | 0.011 | 0.000 | 0.000 | 0.000 |
| VC-015 | Flood | 0.085 | 0.112 | 0.124 | 0.118 | 0.082 | 0.010 | 0.000 | 0.000 | 0.000 |
| | Ebb | 0.085 | 0.112 | 0.124 | 0.118 | 0.082 | 0.010 | 0.000 | 0.000 | 0.000 |
| VC-015A | Flood | 0.057 | 0.074 | 0.083 | 0.079 | 0.055 | 0.007 | 0.000 | 0.000 | 0.000 |
| | Ebb | 0.057 | 0.074 | 0.083 | 0.079 | 0.055 | 0.007 | 0.000 | 0.000 | 0.000 |
| VC-016 | Flood | 0.982 | 1.296 | 1.446 | 1.387 | 0.983 | 0.132 | 0.000 | 0.000 | 0.000 |
| | Ebb | 1.056 | 1.381 | 1.529 | 1.449 | 0.996 | 0.122 | 0.000 | 0.000 | 0.000 |
| VC-017 | Flood | 6.061 | 7.997 | 8.926 | 8.562 | 6.068 | 0.814 | 0.000 | 0.000 | 0.000 |
| | Ebb | 6.520 | 8.522 | 9.440 | 8.944 | 6.147 | 0.751 | 0.000 | 0.000 | 0.000 |

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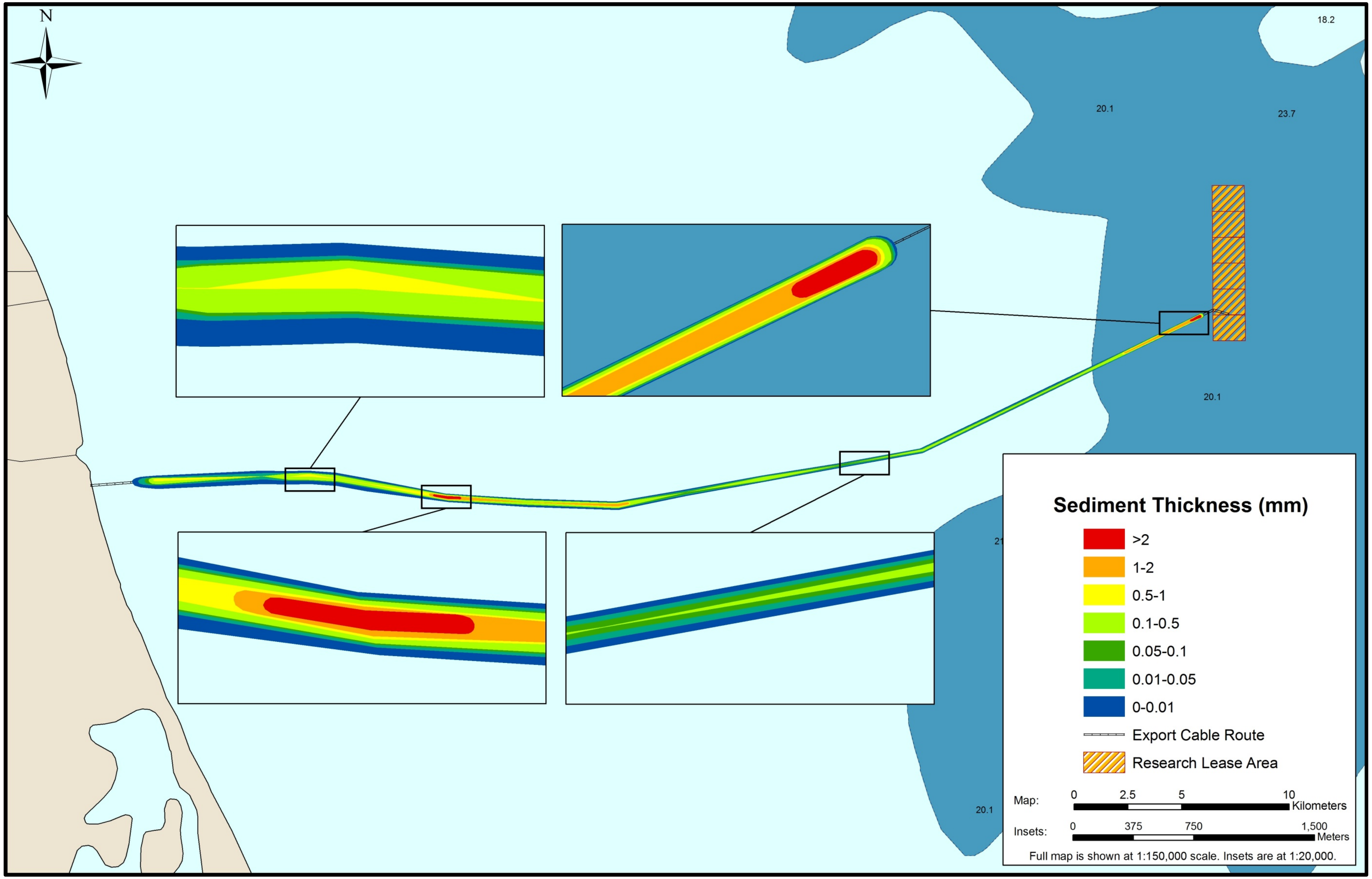

**Figure 12. Depositional plume generated by jet plow activities along the proposed Export Cable route.**

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### 4.3 SENSITIVITY OF THE SEDIMENT TRANSPORT ANALYSIS

The purpose of the sensitivity analysis was to investigate the potential variability of the results given the uncertainty in some of the input parameters and assumptions associated with the method. Tables 6 and 7 present the results of a model sensitivity analysis completed to gauge the variability in model results to the input conditions, including suspended sediment concentration and settling thickness. This analysis was performed for three (3) representative stations, VC-003, VC-010, and VC-017, which represent the beginning, middle, and end of the cable route. In addition, these stations vary in tidal currents and in the fraction of sediment finer than 200 µm. Each station was analyzed for five cases including:

1) Increasing the burial depth of the cable from 2 m to 4 m for ebb tidal conditions.
2) Increasing the height of sediment discharge from 2 m to 4 m for ebb tidal conditions.
3) Analyzing for maximum tidal velocity of 114 cm/s to simulate extreme conditions.
4) Analyzing a smaller tidal velocity of 5 cm/s to simulate a period of less current.
5) Mobilizing the entire volume of sediment for ebb tidal conditions.

The sensitivity analysis yielded the following results:

**Case 1**: The typical burial depth of the cable will be 2 m, but the cable will be buried up to 4 m in some locations. Increasing the burial depth from 2 m to 4 m doubles the amount of sediment in suspension, thereby doubling the concentration and settling thickness; however, the width of the plume does not change.

**Case 2**: Increasing the sediment discharge height from 2 m to 4 m effectively dilutes the suspended sediment concentration by a factor of 2 since the same sediment volume is distributed over twice the vertical distance. The suspended sediment concentration and settling thickness is reduced by half. The width of the plume is doubled since the sediment takes longer to settle from twice the height.

**Case 3**: The maximum current velocity from the ESPreSSO model data was 1.14 m/s, which is several times greater than the average maximum flood or ebb current velocities used to calculate sediment transport in the base cases. In addition, the maximum ESPreSSO current velocity is on the order of a 1-year return period storm event, which is 1 m/s based on the METOCEAN Report (FUGRO GEOS, 2010). Increasing the current velocity to 1.14 m/s generates the widest plume at more than twice the width during base case ebb tide conditions. Suspended sediment concentrations are higher farther from the plow since the plume is carried further from the point of release, while settling thickness is less as the same volume of sediment is spread over a larger distance.

**Case 4**: Reducing the current velocity to 5 cm/s to simulate installation during periods of less tidal current conditions reduces the concentration plume width to less than 50 m wide for all cases. The suspended sediment concentrations remain high while the settling thickness increases by an order of magnitude over ebb tide conditions with most of the material depositing locally within 25 m of the trench.

**<u>Case 5</u>**: For the majority of the cases, it was assumed that only the fine fraction of sediment would be available for transport. While is it highly unlikely that the entire sediment volume could be mobilized into the water column, this scenario was analyzed as part of the sensitivity analysis to understand a truly worst-case scenario. Since the trench volume is not entirely composed of fine material, the fall velocity was adjusted based upon the median grain size, or $D_{50}$, of the characteristic grain size to account for the coarser grains present. The resulting fall velocities are 1.5 m/s (greater than the base case model settling velocity of 0.5 m/s), 4 cm/s (much greater than the base case), and 0.01 cm/s (much less than the base case) for stations VC-003, VC-010, and VC-017, respectively. Mobilizing the entire volume of the trench into the water column significantly increased the initial suspended sediment concentrations. For stations VC-003 and VC-010 where the fall velocity was greater than the base case (0.5 cm/s), the width of the plume was reduced by an order or magnitude with the majority of the material settling within 25 m from the trench. The settling thickness increased up to several millimeters for VC-003 and over ten centimeters for VC-010 within 10 m of the trench. For station VC-017, an extremely low settling velocity (0.01 cm/s), the plume width increased four times over the ebb tide simulation. Even though a significant amount of material was mobilized, it was spread over a greater distance (width) resulting in a shallower settling thickness on the order of tenths of a millimeter.

**Table 6. Sensitivity analysis for concentration (mg/l) for stations VC-003 (top), VC-010 (middle), and VC-017 (bottom).**

| **VC-003** | **Distance from Trench Centerline (m)** | | | | | | | | | Extent |
|---|---|---|---|---|---|---|---|---|---|---|
| **Case** | **0** | **5** | **10** | **25** | **50** | **75** | **100** | **125** | **160** | (m) |
| Flood | 234,282 | 9,700 | 4,972 | 2,019 | 1,015 | 678 | 509 | 0 | 0 | 109 |
| Ebb | 234,282 | 13,920 | 7,216 | 2,951 | 1,486 | 993 | 746 | 597 | 0 | 159 |
| Case 1 | 234,282 | 25,957 | 13,920 | 5,816 | 2,951 | 1,977 | 1,486 | 1,191 | 0 | 159 |
| Case 2 | 234,282 | 7,216 | 3,675 | 1,486 | 746 | 498 | 374 | 299 | 234 | 318 |
| Case 3 | 234,282 | 35,290 | 19,466 | 8,284 | 4,231 | 2,841 | 2,138 | 1,714 | 1,342 | 457 |
| Case 4 | 234,282 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| Case 5 | 1,968,757 | 14,844 | 7,455 | 2,990 | 1,496 | 0 | 0 | 0 | 0 | 54 |

| **VC-010** | **Distance from Trench Centerline (m)** | | | | | | | | | Extent |
|---|---|---|---|---|---|---|---|---|---|---|
| **Case** | **0** | **5** | **10** | **25** | **50** | **75** | **100** | **125** | **160** | (m) |
| Flood | 18,535 | 4,339 | 2,556 | 1,138 | 591 | 0 | 0 | 0 | 0 | 69 |
| Ebb | 18,535 | 4,126 | 2,407 | 1,064 | 551 | 0 | 0 | 0 | 0 | 65 |
| Case 1 | 18,535 | 6,331 | 4,126 | 1,990 | 1,064 | 0 | 0 | 0 | 0 | 65 |
| Case 2 | 18,535 | 2,407 | 1,308 | 551 | 280 | 188 | 142 | 113 | 0 | 129 |
| Case 3 | 18,535 | 9,860 | 8,151 | 5,219 | 3,206 | 2,305 | 1,798 | 1,473 | 1,176 | 435 |
| Case 4 | 18,535 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| Case 5 | 1,853,512 | 5,691 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |

| **VC-017** | **Distance from Trench Centerline (m)** | | | | | | | | | Extent |
|---|---|---|---|---|---|---|---|---|---|---|
| **Case** | **0** | **5** | **10** | **25** | **50** | **75** | **100** | **125** | **160** | (m) |
| Flood | 1,584,401 | 5,264 | 2,637 | 1,056 | 528 | 0 | 0 | 0 | 0 | 64 |
| Ebb | 1,584,401 | 5,095 | 2,552 | 1,022 | 511 | 0 | 0 | 0 | 0 | 61 |
| Case 1 | 1,584,401 | 10,151 | 5,095 | 2,042 | 1,022 | 0 | 0 | 0 | 0 | 61 |
| Case 2 | 1,584,401 | 2,552 | 1,277 | 511 | 256 | 170 | 128 | 0 | 0 | 122 |
| Case 3 | 1,584,401 | 37,775 | 19,157 | 7,729 | 3,875 | 2,586 | 1,940 | 1,553 | 1,213 | 457 |
| Case 4 | 1,584,400 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| Case 5 | 1,770,280 | 5,097 | 2,553 | 1,022 | 511 | 341 | 256 | 205 | 160 | 302 |

**Table 7. Sensitivity analysis for settling thickness (mm) for stations VC-003 (top), VC-010 (middle), and VC-017 (bottom).**

| **VC-003** | **Distance from Trench Centerline (m)** | | | | | | | | | **Extent** (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Case** | **0** | **5** | **10** | **25** | **50** | **100** | **150** | **200** | **250** | |
| Flood | 0.182 | 0.305 | 0.391 | 0.433 | 0.425 | 0.274 | 0.037 | 0.001 | 0.000 | 214 |
| Ebb | 0.048 | 0.106 | 0.154 | 0.201 | 0.202 | 0.199 | 0.138 | 0.022 | 0.000 | 269 |
| Case 1 | 0.095 | 0.212 | 0.308 | 0.403 | 0.403 | 0.397 | 0.277 | 0.045 | 0.001 | 273 |
| Case 2 | 0.003 | 0.007 | 0.011 | 0.023 | 0.026 | 0.025 | 0.025 | 0.025 | 0.024 | 478 |
| Case 3 | 0.000 | 0.003 | 0.006 | 0.014 | 0.023 | 0.016 | 0.014 | 0.013 | 0.012 | 604 |
| Case 4 | 5.021 | 5.282 | 4.925 | 3 | 0 | 0 | 0 | 0 | 0 | 48 |
| Case 5 | 7.513 | 13.63 | 15.10 | 14.50 | 8.713 | 0.043 | 0 | 0 | 0 | 126 |

| **VC-010** | **Distance from Trench Centerline (m)** | | | | | | | | | **Extent** (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Case** | **0** | **5** | **10** | **25** | **50** | **100** | **150** | **200** | **250** | |
| Flood | 0.053 | 0.072 | 0.082 | 0.082 | 0.064 | 0.012 | 0.000 | 0.000 | 0.000 | 164 |
| Ebb | 0.063 | 0.084 | 0.094 | 0.092 | 0.067 | 0.010 | 0.000 | 0.000 | 0.000 | 152 |
| Case 1 | 0.126 | 0.168 | 0.189 | 0.183 | 0.134 | 0.020 | 0.000 | 0 | 0 | 152 |
| Case 2 | 0.013 | 0.018 | 0.022 | 0.026 | 0.025 | 0.020 | 0.008 | 0.001 | 0 | 303 |
| Case 3 | 0.000 | 0.000 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 540 |
| Case 4 | 0.422 | 0.444 | 0.414 | 0.251 | 0 | 0 | 0 | 0 | 0 | 48 |
| Case 5 | 256.8 | 226.4 | 132.4 | 5.402 | 0.002 | 0 | 0 | 0 | 0 | 20 |

| **VC-017** | **Distance from Trench Centerline (m)** | | | | | | | | | **Extent** (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Cases** | **0** | **5** | **10** | **25** | **50** | **100** | **150** | **200** | **250** | |
| Flood | 6.061 | 7.997 | 8.926 | 8.562 | 6.068 | 0.814 | 0 | 0 | 0 | 147 |
| Ebb | 6.520 | 8.522 | 9.440 | 8.944 | 6.147 | 0.751 | 0 | 0 | 0 | 143 |
| Case 1 | 9.785 | 12.730 | 14.132 | 13.431 | 9.253 | 1.139 | 0.013 | 0 | 0 | 190 |
| Case 2 | 1.374 | 1.865 | 2.237 | 2.589 | 2.507 | 1.800 | 0.620 | 0.072 | 0.002 | 283 |
| Case 3 | 0.000 | 0.034 | 0.068 | 0.154 | 0.194 | 0.182 | 0.182 | 0.182 | 0.182 | 582 |
| Case 4 | 37.76 | 39.72 | 37.04 | 22.49 | 0 | 0 | 0 | 0 | 0 | 48 |
| Case 5 | 0.147 | 0.209 | 0.270 | 0.410 | 0.468 | 0.470 | 0.466 | 0.448 | 0.385 | 710 |

# 5.0 CONCLUSIONS

The sediment transport study was performed to evaluate sediment transport potential related to installation of an electric cable from shore to the primary site in water depths up to 27 meters approximately 43 km offshore Virginia. The analytical modeling and analysis evaluates the concentration of fine sediments in the water column, and the footprint and thickness of sediments deposited on the seafloor associated with the proposed cable installation.

Based on the results of the sediment transport modeling, the following general conclusions can be made:

- The concentration and settling thickness of the sediment plume is dependent on the strength of ambient tidal currents and the volume of fine material in the trench.
- The fine particles (<200 µm) will remain in suspension for approximately 6-7 minutes after initial release. Coarser particles will settle at a faster rate.
- For average peak running ebb and flood tides:

    - The concentration of fine sediment in the plume (Table 4) initially released from the trench varies between ~6,700 (core station 12) and $1.585 \times 10^6$ mg/L (core station 17). This plume is contained in a near-bottom water layer less than 2 m high. These initial conditions are conservatively high, and assume that all of the fine material (finer than 200 µm) in the plowed trench is mobilized instantly into the water column immediately above the plow footprint and within 2 m of the seafloor.

    - The initial fine suspended sediment concentration rapidly diminishes by several orders of magnitude within 5 to 10 m from the trench. The maximum zone of elevated suspended sediment on either side of trench is on the order of 150 m (Table 3) for stations VC-001 through VC-006.

    - While the suspended sediment concentrations are elevated even near the edge of the plume, the sediment is moving in a very thin layer, less than a tenth of a meter, at the edge of the plume.

    - The fine sediment suspended in this plume settles into a thin layer on the ocean floor less generally than 1 mm. The maximum depositional thickness occurs roughly 10 to 25 m from the trench and the maximum zone of influence on either side of trench generally varies from between 50 m (e.g., offshore core stations V-12 through V-17) and 200 m (e.g., nearshore core stations V-1 through V-6), and is less than 250 m (Table 5). Deposition exceeded 1 mm within 100 m of the trench only at stations VC-007, VC-016, and VC-017, where the concentration of fines was high and the currents were weakest resulting in a narrower, more concentrated plume.

  - Settled sediment is then available for resuspension and dispersal into a more diffuse layer by the ambient currents (e.g., wave orbital velocities and higher currents during more energetic climatic events), not simulated by this model.

The sensitivity analysis revealed:

- The width of the plume is controlled by the settling velocity of the particle size, the height of discharge, and the current speed.
- Deepening the trench will increase the amount of sediment mobilized into the water column, which proportionally increases the suspended sediment concentration and settling thickness.
- Operating during periods of higher current velocity reduces the thickness of settled sediments over a larger footprint. Conversely, installation during stages of tide with a lower velocity reduces the overall footprint of deposition, while increasing the thickness in a narrow zone adjacent to the route.
- Coarser sediments, even in larger quantities, settle faster into a narrower footprint, and vice-versa.

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