Husky Energy

White Rose Extension Project

Dredging Assessment: Nearshore

June 2012

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Environmental Impact Assessment

White Rose Extension Project

Dredging Assessment: Nearshore

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Executive Summary

Husky Oil Operations Limited (Husky), on behalf of the White Rose Extension Project (WREP) proponents, Husky, Suncor Energy Inc. and Nalcor Energy – Oil and Gas Inc., is leading the development of the WREP. Under the wellhead platform development option, a concrete gravity structure (CGS) will be constructed in a purpose-built graving dock at Argentia, NL. After construction of the CGS is complete, the structure will be floated out of the graving dock and towed to a deep-water site in Placentia Bay for installation of the topsides.

A coastal dredger will be used to create an exit channel from the graving dock to a water depth of approximately 18 to 20 m to accommodate the draft of the CGS. It is anticipated that 200,278 m^3 of sediment will be dredged in the coastal area near the construction site. It is anticipated that dredging in two sections of the tow-out corridor, Corridor 1 and Corridor 2, will include dredging 25 m^3 of sediment in Corridor 1, and dredging 165,394 m^3 of sediment in Corridor 2.

The aim of the present study is to assess the potential for suspension of the fine sediments during dredging activities, and to predict the likely fate and dispersion of these sediments through the duration of the dredging program and beyond, without any mitigation for the dispersion of sediment. These results are therefore considered to represent a worst case scenario.

The sediment re-suspension and dispersion at the construction site were modelled using the ADDAMS-DREDGE model. The results show that for the backhoe dredge (BHD), the concentrations at the site would be relatively low (5.5 mg/L to 28.5 mg/L), and fall below 1 mg/L within approximately 230 m to 1 km of the site. The fine sediment plumes are expected to propagate mostly along the shoreline (southwest to northeast direction), as the tidal currents are expected to be aligned with the shore in this area.

The local effect of the cutter suction dredge (CSD) on suspended sediment levels would be higher than that of the BHD, with predicted suspended sediment concentrations within 10 m of the source ranging from 291.6 to 718.3 mg/L. A comparison of the far-field dispersion for the two dredging methods revealed that levels for the CSD are broadly comparable to those of the 20 m^3 and 25 m^3 BHD option at current speeds of 5 cm/s (440 to 1,650 m).

The modelling of the trailing suction hopper dredge (TSHD) operations showed that depending on the cruising speed of the TSHD, the end of the near-field mixing zone would be reached at distances of 30 to 95 m from the dredging location. The dilution factor reached within this initial zone is expected to range from 31.2 to 90.9, resulting in initial plume concentrations of 1,490 to 4,330 mg/L within the first 100 m.

Maximum concentrations of 5 to 10 mg/L occur for the first 6 to 10 hours after the dredging cycle, and are generally restricted within an area of 3 km^2 around Corridor 2. Overall, suspended sediment concentrations are expected to fall to approximately 1 mg/L within the first 30 hours of a dredging operation. The vast majority of the fine sediments are expected to be transported out of the bay by the combined tidal and wind-driven currents.

In order to assess the cumulative exposure to the suspended sediments associated with the unmitigated TSHD operations, the concentrations at all points in the model domain were averaged over sliding 24-hour and 30-day time windows over the duration of the program, and up to 30 days following the end of the dredging program. The results show that the mean exposure over 24-h would never reach higher than approximately 19 mg/L, and the highest mean exposure over 30 days is approximately 3.6 mg/L. These are the highest levels predicted to occur within the limits (200 m distance) of the actual dredging site (Corridor 2); however, within the first kilometre, the 24-hour exposures fall to approximately 10 mg/L or below. The highest exposure levels over 24 hours for most of the model domain in the vicinity of Argentia are predicted to be approximately 5 mg/L or less. The trends are similar for the 30-day exposure results, where the highest exposure levels outside the vicinity of the dredging site are expected to remain at approximately 1.5 mg/L or less.

The results presented here are well below the thresholds for Total Particulate Matter given in the Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME 2002).

Table of Contents

Executive Summary i

1.0 INTRODUCTION 1

- **1.1 Project Background** 1
- **1.2 Objectives** 3

2.0 Dredging Operations 4

- **2.1 Sediment Properties** 5
- **2.2 Dredging Methods for the Construction Site** 6
- **2.3 Dredging Method for Corridors 1 and 2** 8

3.0 Modelling Methods 11

- **3.1 Hydrodynamic Modelling** 11
- **3.2 Backhoe Dredger and Cutter Suction Dredger Models** 16
- **3.3 Trailing Suction Hopper Dredger Models** 18

4.0 Total Suspended Solids Dispersion Modelling Results 21

- **4.1 Dredging Total Suspended Solids Dispersion for the Construction Site** 21
- **4.2 Dredging Total Suspended Sediments Dispersion for Corridors 1 and 2** 23
- **4.3 Far-field Total Suspended Solids Dispersion Modelling at Corridors 1 and 2** 26

5.0 SUMMARY 33

6.0 REFERENCES 35

- **6.1 Personal Communications** 35
- **6.2 Literature Cited** 35

7.0 Acronyms 37

8.0 Glossary 38

List of Figures

Figure 1-1 Potential Graving Dock Construction Site on the Argentia Peninsula 2
Figure 1-2 Study Area for Dredging Operations Assessment 3
Figure 2-1 Dredging Areas along the Concrete Gravity Structure Tow-out Route 4
Figure 2-2 Layout of a Backhoe Dredger 6
Figure 2-3 Layout of a Cutter Suction Dredger 7
Figure 2-4 Working Method of a Cutter Suction Dredger 7
Figure 2-5 Sediment Suspension Processes Associated with the Operation of a Trailing Suction Hopper Dredger 9
Figure 2-6 Observed and Predicted Overflow Sediment Concentrations For a Typical TSHD During Dredging of Sediments Composed of 4 to 8 Percent Silt 9
Figure 3-1 Model Grid for the Delft3D Hydrodynamic Model near Argentia 12
Figure 3-2 Modelled Tidal Water Levels at the Tidal Gauge Station 13
Figure 3-3 Modelled M2 Tidal Currents at Corridor 2 14
Figure 3-4 Modelled Tidal Currents at Corridor 2, Using All Five Tidal Components 15
Figure 3-5 Modelled Tidal and Wind Driven Currents at Corridor 2 15
Figure 3-6 Modelled Tidal Currents at the Construction Site 16
Figure 3-7 Far-field Model Domain Used for Total Suspended Solids Dispersion for Corridors 1 and 2 20
Figure 4-1 Near-Field Plume Dispersion, Concentration and Dilution for Trailing Suction Hopper Dredger Cruising Speed of 0.5 m/s 24
Figure 4-2 Near-Field Plume Dispersion, Concentration and Dilution for Trailing Suction Hopper Dredger Cruising Speed of 1.5 m/s 25
Figure 4-3 Total Suspended Solids Concentrations at the Beginning of the 17^{th} (last) Dredging Operation in Corridor 2 27
Figure 4-4 Total Suspended Solids Concentrations 6h after the Last of 17 Dredging Operations in Corridor 2 27
Figure 4-5 Total Suspended Solids Concentrations 24h after the Last of 17 Dredging Operations in Corridor 2 28
Figure 4-6 Total Suspended Solids Concentrations 48h after the Last of 17 Dredging Operations in Corridor 2 28
Figure 4-7 Far-field Total Suspended Solids Dispersion Model Results for Typical (Westerly) Wind Conditions 29
Figure 4-8 Far-field Total Suspended Solids Dispersion Model Results for Southwesterly Wind Conditions 29
Figure 4-9 Far-field Total Suspended Solids Dispersion Model Results for Northwesterly Wind Conditions 29

Figure 4-10 Maximum of Composite TSS Mean Concentration Exposures Over 24 Hours (left) and 30 Days (right), for the Typical, Westerly Winds Scenario. 31

Figure 4-11 Maximum of Composite TSS Mean Concentration Exposures Over 24 Hours (left) and 30 Days (right), for the Southwesterly Winds Scenario. 31

Figure 4-12 Maximum of Composite TSS Mean Concentration Exposures Over 24 Hours (left) and 30 Days (right), for the Northwesterly Winds Scenario. 32

List of Tables

Table 2-1 Volumes of Dredged Sediment in the Dredging Areas 5

Table 2-2 Sediment Composition in the Dredging Areas 5

Table 3-1 Tidal Constituents Used for Hydrodynamic Modelling 12

Table 3-2 Backhoe Dredger Modelling Inputs for the graving dock 17

Table 3-3 Cutter Suction Dredger Modelling Inputs for Construction Site 18

Table 4-1 Backhoe Dredger Dredging Option (Current = 1 cm/s) 21

Table 4-2 Backhoe Dredger Dredging Option (Current = 5 cm/s) 21

Table 4-3 Cutter Suction Dredger Dredging Option 22

Table 4-4 Sediment Plume Concentration and Dilution by Near-Field Dispersion Processes as a Function of Trailing Suction Hopper Dredger Cruising Speed 23

Table 4-5 Sediment Plume Concentration at Source, Persistence and Extent for the Average TSHD Dredging Cycle 30

1.0 INTRODUCTION

1.1 Project Background

Husky Oil Operations Limited (Husky), on behalf of the White Rose Extension Project (WREP) proponents, Husky, Suncor Energy Inc. and Nalcor Energy – Oil and Gas Inc., is leading the development of the WREP.

The White Rose field and satellite extensions are located in the Jeanne d'Arc Basin, of the Grand Banks of Newfoundland, 350 km east of St. John's in approximately 120 m of water. The current focus of the WREP is on the development of West White Rose, delineated in 2006. Husky and its co-venturers are evaluating options for development of the WREP resources, including subsea tiebacks, a wellhead platform (WHP), or a combination of both. All development options will be tied back to the existing *SeaRose FPSO* (floating production, storage and offloading) vessel.

Under the WHP development option, a concrete gravity structure (CGS) will be constructed in a purpose-built graving dock at Argentia, NL, which is located in Placentia Bay, on the southern Avalon Peninsula, 130 km south west of St. John's, NL.

After construction of the CGS is complete, the structure will be floated out of the graving dock and towed to a deep-water site in Placentia Bay for installation of the topsides. Upon completion of the topsides mating, associated hook-up between the CGS and the topsides and establishing the WHP's designated towing draft, the WHP structure will be towed from Placentia Bay to the White Rose field (Husky 2012).

The graving dock for construction of the CGS will initially be flooded to equalize the hydrostatic pressure, then a combination of land-based excavation equipment and a coastal dredger will be used to remove the shoreline berm, after which the float-out will occur. The dredger will be used to create an exit channel from the graving dock to a water depth of approximately 18 to 20 m to accommodate the draft of the CGS. It is currently estimated that this excavation/dredging work will take between six and eight weeks to complete (Husky 2012). The potential graving dock construction site (Construction Site) is shown in Figure 1-1.

Shoreline dredging activities will include loosening of the soil by a choice of a backhoe dredge (BHD) or a cutter suction dredge (CSD); the soil will transported or pumped to into The Pond on the tip of the Argentia Peninsula (Husky 2012).

Husky has completed a bathymetric survey of the CGS tow-out route to ensure adequate water depth exists for the draft of the CGS. The survey identified that dredging will be required in two sections of the tow-out channel. It is anticipated the work could be completed in four to six weeks using a trailing suction hopper dredger (TSHD) (Husky 2012).

Additional details are presented in Section 2.0 (for a focus on dredging activities) and in the WREP Project Description (Husky 2012).

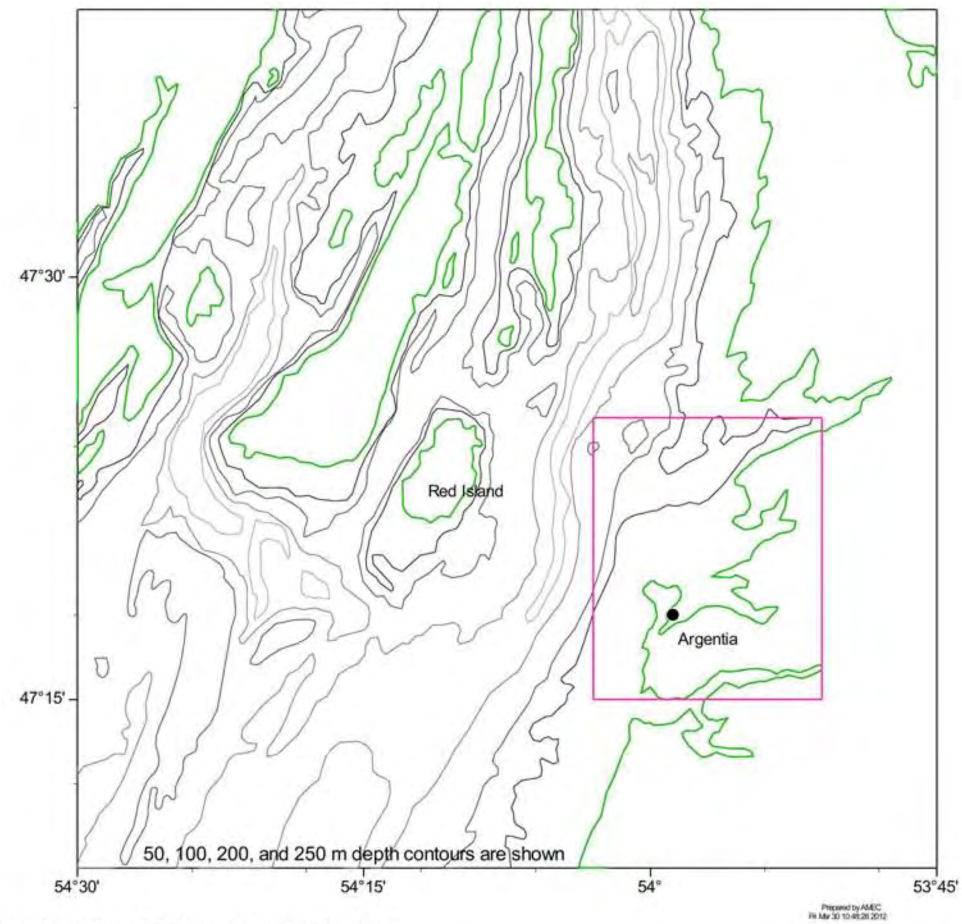
Source: Husky 2012

Figure 1-1 Potential Graving Dock Construction Site on the Argentia Peninsula

1.2 Objectives

This report presents the results of dredging modelling and associated assessment for the WREP. The Study Area for the dredging operations assessment is shown in Figure 1-2. The study objectives were:

- To assess potential dredging activities
- To model the possible resulting sediment dispersion and deposition in the marine environment, without any mitigative measures, as a worst-case scenario



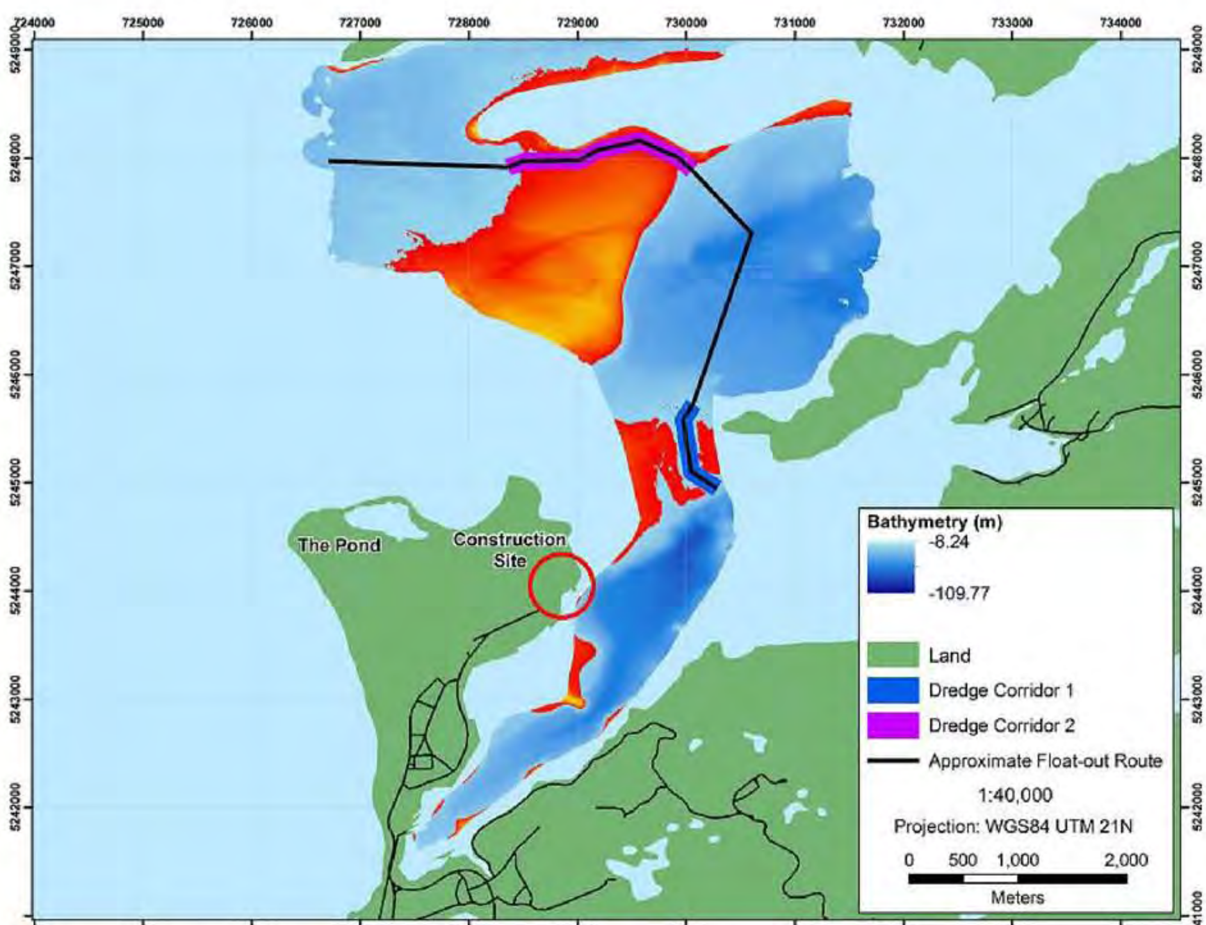
Source: based on ACON v. 10.5 (Black, 1991)

Figure 1-2 Study Area for Dredging Operations Assessment

2.0 Dredging Operations

Planned operations near Argentia will include dredging 200,278 m^3 of sediment in the coastal area near the graving dock construction site, associated with the removal of the berm; dredging 25 m^3 of sediment in the area designated as Corridor 1; and dredging 165,394 m^3 of sediment in Corridor 2, as shown in Figure 2-1.

Several dredging methods and equipment options are considered appropriate for the dredging operations, depending on the water depth, sediment types and sediment amounts to be dredged at each site. Dredging the area adjacent to the Construction Site would be done with either the backhoe dredger (BHD) or CSD, or their equivalents. A trailing suction hopper dredger (TSHD) will be used for dredging in Corridors 1 and 2. The following sections present the details of the sediment properties and dredging methods to be used in each area.



Source: C-CORE 2012

Note: Areas shallower than -16.5 m (Chart Datum) are shown in red/orange

Figure 2-1 Dredging Areas along the Concrete Gravity Structure Tow-out Route

2.1 Sediment Properties

The required volumes of sediment to be dredged have been calculated based on the optimal tow-out route for the WHP, and an analysis of the bathymetry dataset. It was considered that a 160 m-wide swatch is required to provide the necessary clearance for the CGS. The target depth within this swath was determined to be 16.5 m referenced to chart datum, resulting in a depth of approximately 18 m at high tide (C-CORE 2012). It is apparent from the volumes given in Table 2-1 that the dredging operations will be conducted mostly in the vicinity of the graving dock, and within Corridor 2, with only minor amounts to be dredged in Corridor 1.

Table 2-1 Volumes of Dredged Sediment in the Dredging Areas

Range (chart datum)	**Dredging Volumes (m^3)**		
	Construction Site	**Corridor 1**	**Corridor 2**
-16.5 m to seabed	200,278	25	165,394
Source: C-CORE 2012.			

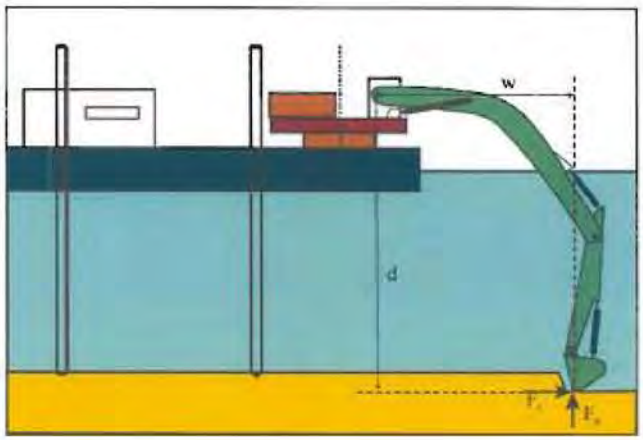
The composition of the sediment in each area has been inferred directly from samples taken during a field campaign (Stantec, pers. comm.), and indirectly from interpretations of acoustic backscatter return during the seabed survey (C-CORE 2012). Descriptive statistics for the sediment grains size distributions were derived for each area (see Table 2-2) and used as inputs in the dredging source models and suspended sediment transport models. It is apparent that there are substantial differences in sediment composition between the areas, with substantially larger amounts of fine sediments at the graving dock compared to the two corridors. These differences are attributable not only to the sediment sources in the area, but also to the intensity of the currents in each area.

Table 2-2 Sediment Composition in the Dredging Areas

Description	**Construction Site**	**Corridor 1**	**Corridor 2**
Gravel	1	2	1
Sand	44	81	96
Silt	38	12	1
Clay	17	5	2
D90 (µm)	246	450	260
D50 (µm)	54	111	166
D10 (µm)	3	41	91
Percent < 75 µm	61	27	7
Percent < 50 µm	48	14	2
Source: Stantec pers. comm.			

2.2 Dredging Methods for the Construction Site

The two methods considered suitable for dredging at the graving dock include dredging using a BHD, or a CSD. The BHD represents an excavator with a bucket mounted on a fabricated pedestal, located at one extremity of a spud-rigged pontoon (Figure 2-2). The BHD is stabilized by lowering the spuds 20 to 80 cm into the sea bottom, after which the bucket is lowered to the bottom to commence dredging. Three options for bucket sizes are considered for the BHD (15 m^3, 20 m^3 and 25 m^3), and it is assumed that one dredging cycle is completed within a period on the order of 60 seconds. For the purposes of the current study, it is assumed that 22 percent of the cycle time is spent during the bucket fall through the water column, 30 percent for the bucket rise and 48 percent of the time the bucket is above the water surface (ADDAMS DREDGE Modelling Manual). The dredged material would be placed in transport barges and further transported to The Pond.



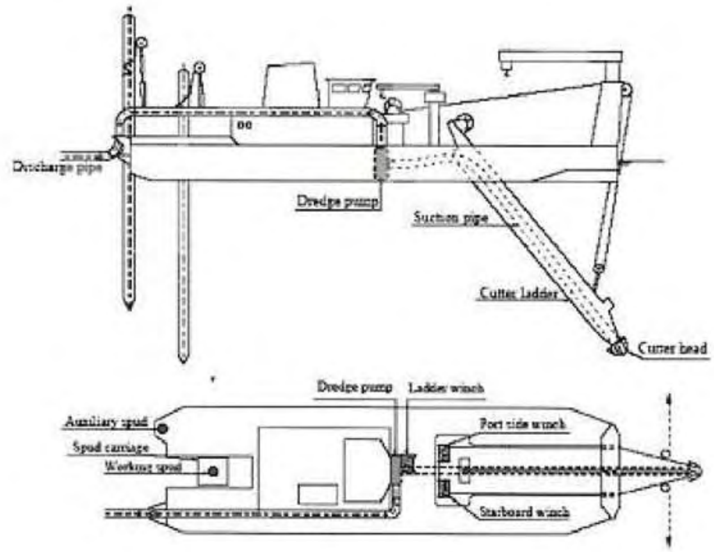
Source: Vlasblom 2007

Figure 2-2 Layout of a Backhoe Dredger

The CSD is a stationary dredger, consisting of a pontoon, which is positioned with a spud-pole at the back, and two anchors at the front. The dredging is conducted by a rotating cutting head, mounted at the extremity of a fabricated steel structure, called 'the ladder', which is able to rotate in the vertical plane (Figure 2-3). Using winches, the cutter is pulled in turns to the portside and starboard side anchor, therefore exhibiting a circular movement within a range of 4 to 6 m (Figure 2-4).

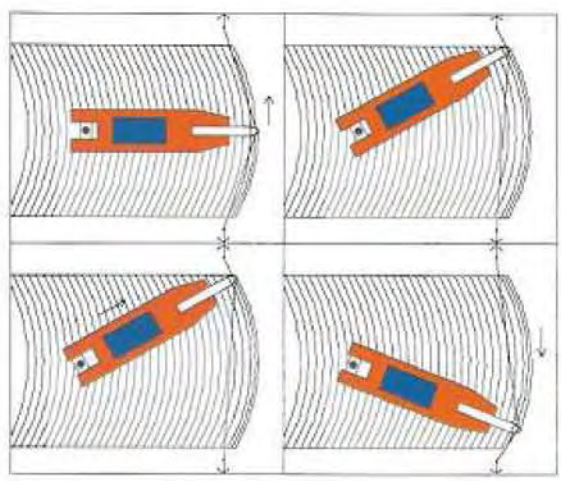
The CSD uses a suction pipe with a diameter of 1 m; therefore, for the purposes of the current study, it is assumed that the cutter head diameter is 2 m and the cutter head length is 3 m. The draught depth is 6.6 m, therefore, a minimum dredging depth of 7 m is considered. Upon loosening and suction of the soil, the water-sediment mixture will be pumped through a floating pipeline and land based pipeline into The Pond. The CSD operations would occur continuously 24 hours per day, and seven days a week over a period of six to eight weeks.

The choice of equipment for dredging at the graving dock will depend on further engineering analysis of the soil data and the development of detailed dredging plans.



Source: Vlasblom 2007

Figure 2-3 Layout of a Cutter Suction Dredger



Source: Vlasblom 2007

Figure 2-4 Working Method of a Cutter Suction Dredger

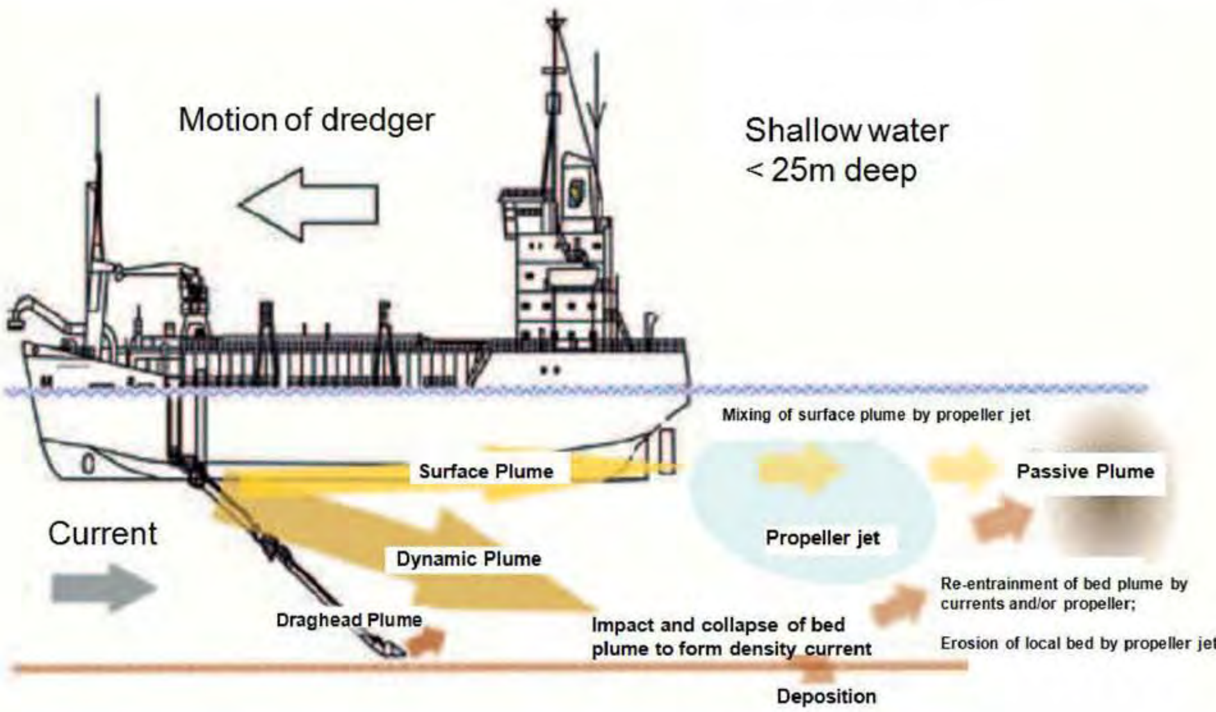
2.3 Dredging Method for Corridors 1 and 2

Dredging in the two corridors is expected to be conducted with a TSHD. The typical TSHD would be equipped with two suction pipes (1 m diameter each), a discharge pipe (0.8 m diameter) and a large hopper to contain the dredged materials for transport between the dredging location and the disposal area. The TSHD would have a typical hopper capacity of approximately 9,930 m^3; therefore, it is assumed that approximately 17 loading cycles will be necessary to complete the dredging of 165,419 m^3 of sediment in the two corridors.

The TSHD would cruise at a low speed, ranging from 0.5 to 1.5 m/s (1 to 3 knots) during dredging operations. Dredging begins when the drag head at the end of the suction pipe is lowered onto the seabed with a system of winches and gantries. A high-capacity dredge pump installed inside the TSHD creates a vacuum in the drag head, which, combined with the mechanical excavation, creates a sand-water mixture inside the drag head. The dredge pumps transfer the mixture to the hopper, where gravity causes the dredged material to settle in the hopper. As the dredging cycle progresses and the hopper fills up, it is necessary to drain the excess water via an overflow system (van Rhee 2002, Spearman et al. 2007).

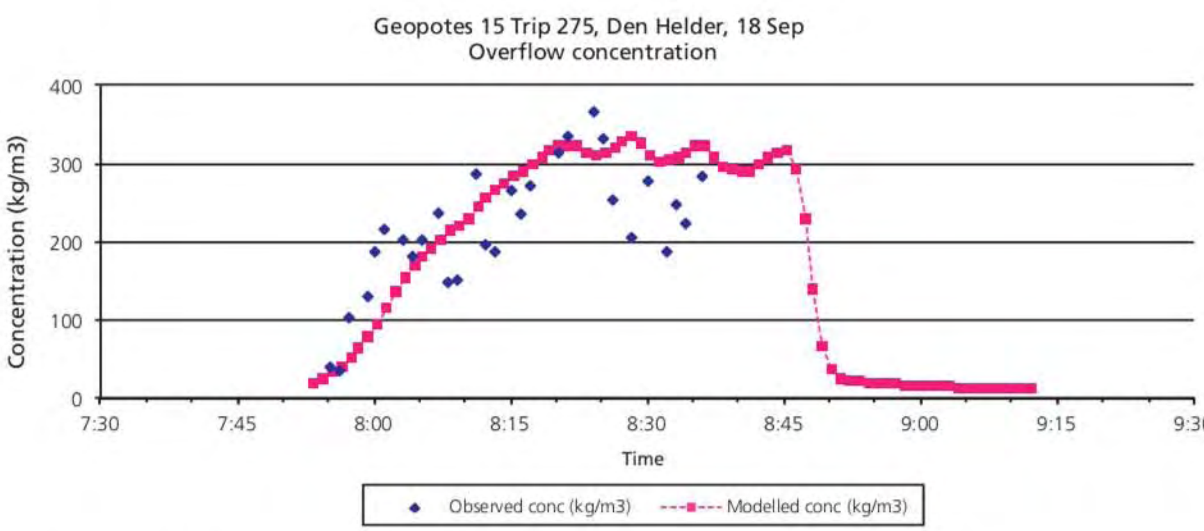
The operation of the overflow system is the most important aspect of the TSHD operation in terms of the effects of sediment suspension, as the flow patterns within the TSHD hopper are highly efficient at keeping any fine sediments in suspension. There are several other processes that contribute to the sediment disturbance associated with TSHD operations, associated with the draghead and the propeller jet, as shown in Figure 2-5 (Spearman et al. 2011). These contributions are considered at least an order of magnitude smaller than the dynamic plume released through the overflow, and are therefore not considered further in the present study.

As the loading cycle progresses, and the hopper eventually overflows, the fine sediments can be released in a concentrated overflow plume (van Rhee 2002). While the operating characteristics of the TSHD are expected to vary depending on site conditions, for the purposes of the study a representative overflow cycle was constructed based on the known properties of TSHD discharges, and the results of a field measurement campaign undertaken in 2007 off the Dutch coast at Den Helder (Spearman et al. 2011). Based on the results and discussion by Spearman et al. (2011), it is assumed that while the TSHD loading cycle may last several hours, the overflow occurs during a 75-minute period at the end of the cycle. The rate of overflow was assumed to be approximately 1 m^3/s, and the sediment concentrations within the overflow are reported to be approximately 100 kg/m^3, composed entirely of the silt and clay fractions. Based on these assumptions, the concentration curve in Figure 2-6 was integrated over the overflow period, indicating that approximately 77 percent of the fine materials from within the hopper are discharged through the overflow (based on fine sediment composition of 4 percent of the total). When the curve was proportionately downscaled for 3 percent fine sediment composition, representative of Corridor 2, an average overflow concentration of 135 kg/m^3 was computed for the 75-minute overflow event at the end of each dredging cycle.



Source: Spearman et al. 2011

Figure 2-5 Sediment Suspension Processes Associated with the Operation of a Trailing Suction Hopper Dredger



Source: Spearman et al. 2011

Figure 2-6 Observed and Predicted Overflow Sediment Concentrations For a Typical TSHD During Dredging of Sediments Composed of 4 to 8 Percent Silt

The dredging operations are expected to last for a period of four to six weeks. In the case of a four week program, a loading cycle would be completed once every 40 hours. A shorter dredging program duration is considered a conservative scenario in terms of the levels of suspended sediments in the environment, as there would be less available time for the plumes to dissipate between dredging cycles.

3.0 Modelling Methods

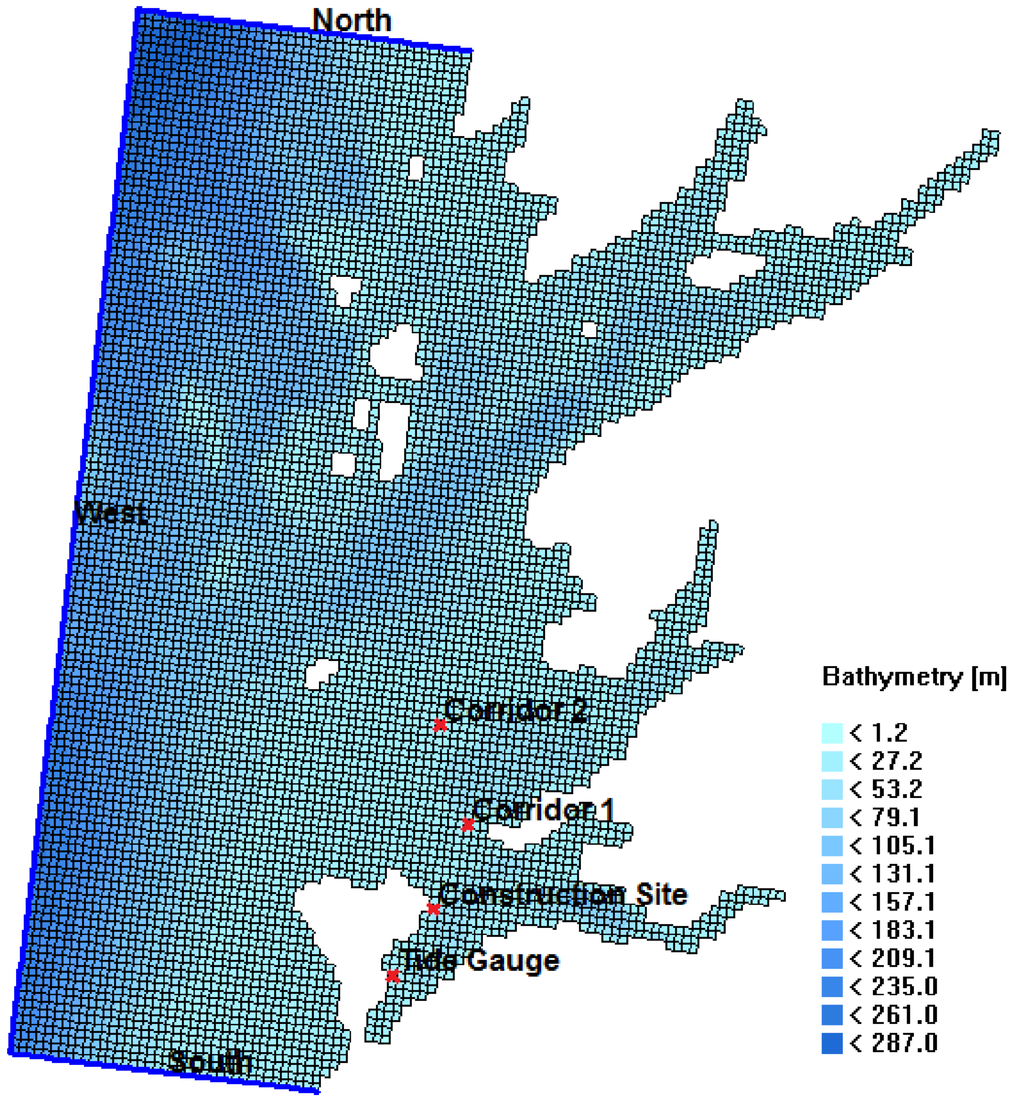
3.1 Hydrodynamic Modelling

The dispersion and deposition of the suspended sediments associated with the planned dredging operations are strongly dependent on the current speed and circulation patterns within Argentia Bay. Due to the unavailability of current measurements at the dredging sites, it was necessary to model the circulation in the bay by using the best available knowledge of the tidal circulation, as well as the mean wind-driven circulation near the shore. The dredging operations were anticipated to take place during the winter months; therefore, the average seasonal wind conditions were used to drive the mean circulation. Additionally, a conservative scenario was also modelled in which the model was driven only by the tides, resulting in the lowest anticipated dispersion rates.

To accomplish this goal, AMEC used the depth-averaged module of the Delft3D modelling system. The Delft3D suite consists of a highly-integrated set of modules to compute ocean currents by using the shallow water equations, as well as to employ the advection-diffusion equations for computations of sediment transport. The model domain extends approximately 5 to 7 km to the west of Argentia (Figure 3-1). A rectilinear model grid was used, with a uniform cell size of approximately 165 m. The model coastline and bathymetry were derived from depth data acquired from the Canadian Hydrographic Service, and the depth over the computational domain was generated by triangular interpolation of the bathymetric data. A time step of 15 seconds was chosen as the most efficient value to satisfy the Courant stability condition for the given depth distribution within the computational grid.

The tidal currents and water level variations were represented by prescribing harmonic water level variations along the western model boundary, and harmonic Neumann gradient-type boundary conditions at the lateral, north and south boundaries, consistent with the approach from previous successful modelling efforts of coastal tidal circulation conducted by Vitousek et al. (2007) and Roelvink and Walstra (2007). The harmonic gradient levels at the lateral boundaries were set with 90 degree phase lags relative to their corresponding water level boundary conditions, thus simulating tidal waves propagating along the western boundary, and allowing for a proper development of alongshore mean currents. The five most dominant tidal constituents were used, including three semidiurnal and two diurnal constituents (Table 3-1).

The tidal constituents used came from two sources: Han (pers. comm. 2012) supplied the tidal water level coefficients, as well as the current ellipses for the M2 and K1 constituents, derived from the FVCOM model. The N2, S2 and O1 constituents were derived from the WebTide model (DFO 2012). The available outputs from the FVCOM model were preferred to those from WebTide, due to the fact that the FVCOM model included a vastly superior representation of the bathymetry and circulation in Placentia Bay, including the coast near Argentia Bay.



Note the Markers for the Construction Site, Corridor 1, Corridor 2 and the Tide Gauge Monitoring Station

Figure 3-1 Model Grid for the Delft3D Hydrodynamic Model near Argentia

Table 3-1 Tidal Constituents Used for Hydrodynamic Modelling

Tidal Constituent	Frequency (degree/hour)	West Boundary Amplitude (m)
M2 (A)	28.984104	0.680
K1 (A)	15.041069	0.080
N2 (B)	28.439730	0.140
S2 (B)	30.000000	0.199
O1 (B)	13.943036	0.077
Sources: (A) Han 2012; (B) DFO WebTide		

Additionally, outputs of tidal constituents, tidal sea surface elevation amplitudes and phases and monthly-mean current profiles were obtained from the DFO FVCOM model (Ma et al. 2011) for validation at the three dredging locations in the study domain, from DFO (G. Han, pers. comm.).

DFO developed the FVCOM three-dimensional circulation model of Placentia Bay based on a finite-volume coastal ocean model to simulate temperature, currents and stratification. Simulated tides agree well with tide-gauge data, and non-tidal currents show reasonable agreement with moored measurements (Ma et al. 2011). Additional discussion of the model is provided in Section 4.1.2.4 of the Nearshore Physical Oceanography Setting of the environmental assessment.

The water levels produced by the hydrodynamic model (Figure 3-2) reliably reproduce the expected spring and neap cycles, and compare well to the measured mean tidal range of 1.6 m, and the large tidal range of 2.4 m at the Argentia tidal station (DFO 2012). Comprehensive validation of the current magnitudes was not possible due to unavailability of measurements; however, the tidal currents due to the M2 tidal component at the Corridor 2 location (Figure 3-3) was compared to the nearest available tidal ellipses from the FVCOM model. The modelled M2 current semimajor axis at Corridor 2 was approximately 5.5 cm/s, with an inclination of positive 15 degrees from East. In comparison, the nearest FVCOM ellipse had a semimajor axis of 3 cm/s, with an inclination of positive 27 degrees from East. The differences in current magnitudes between the two different models can be explained at least partly by the fact that the FVCOM is a regional model, and it represented the coastline, various inlets and the islands in Argentia Bay in a relatively looser manner than AMEC's Delft3D model.

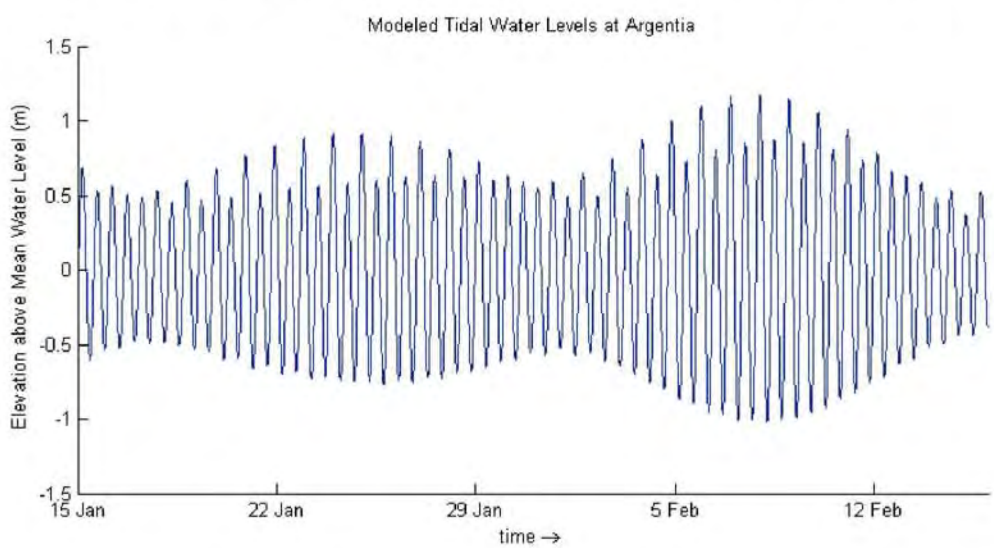


Figure 3-2 Modelled Tidal Water Levels at the Tidal Gauge Station

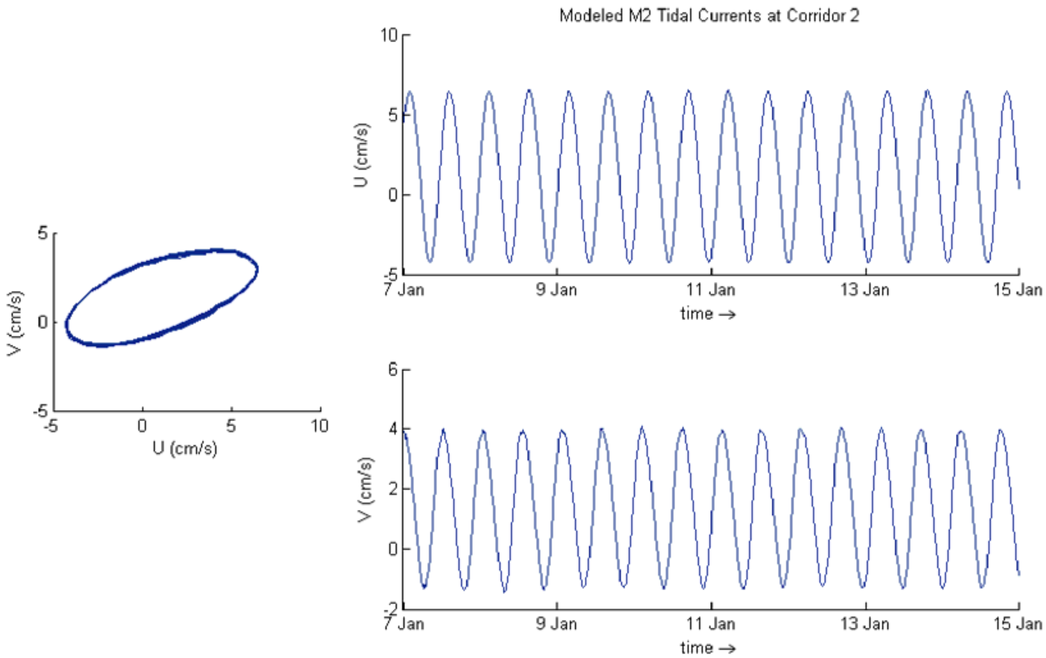


Figure 3-3 Modelled M2 Tidal Currents at Corridor 2

Including all five dominant tidal components produced a more realistic current pattern, in which a mean northward flow is established at Corridor 2 (Figure 3-4). Furthermore, in order to represent the mean wind-driven circulation in the bay, a model scenario was built in which the average seasonal winds were included in addition to the tides. Since it is anticipated that the dredging operations would occur during the winter months, the average winter westerly winds with a wind speed of 10 m/s were incorporated. The effect of the wind-driven circulation was to add a mean northward component (Figure 3-5) of approximately 5 to 7 cm/s, therefore contributing to an increased flushing rate of the Argentia Bay.

While the hydrodynamic model was primarily developed to model the far-field dispersion of TSHD overflow plumes, it was also used to provide an estimate of the expected range of current magnitudes near the Construction Site. The tidal currents plotted in Figure 3-6 show that the currents are much weaker there, with a peak tidal current amplitude of approximately 2 cm/s. The effect of the added wind-driven circulation is to introduce a mean northward component of 2 to 3 cm/s.

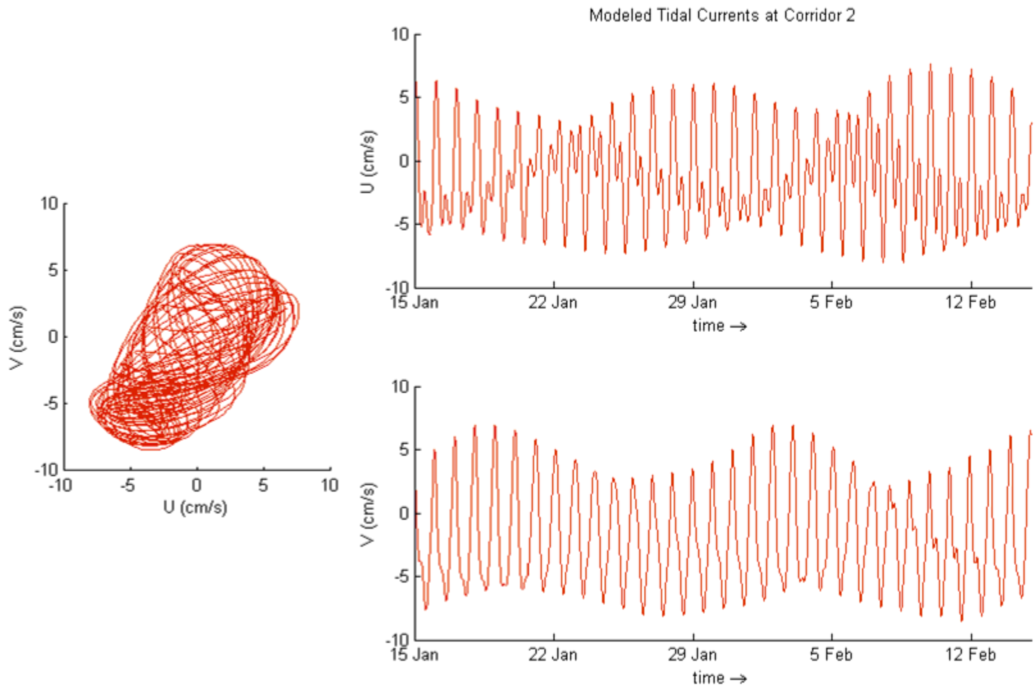


Figure 3-4 Modelled Tidal Currents at Corridor 2, Using All Five Tidal Components

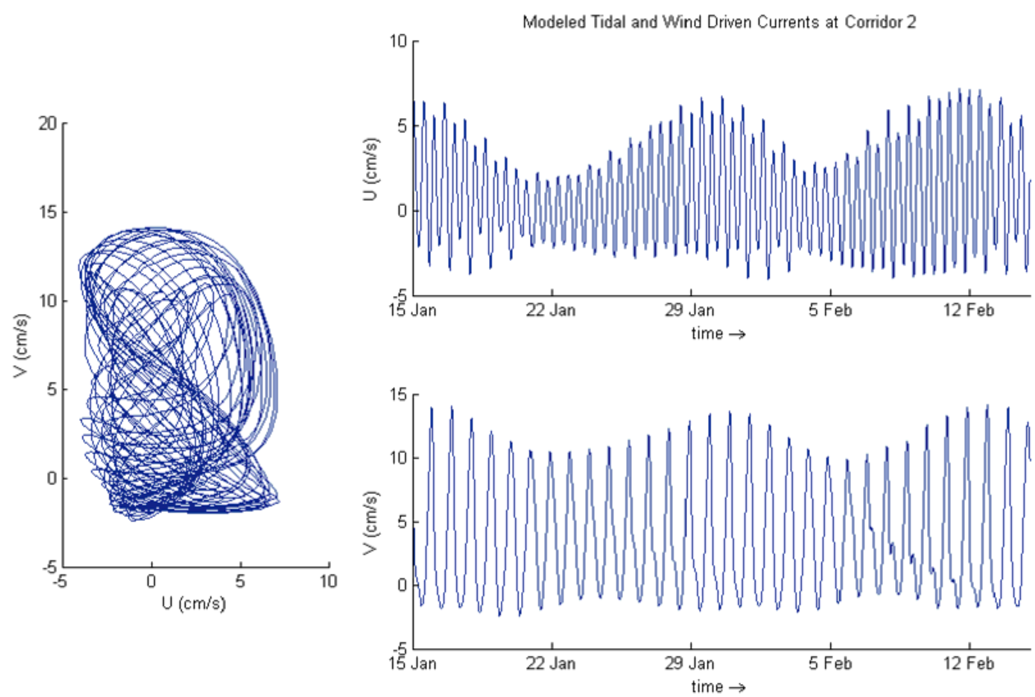


Figure 3-5 Modelled Tidal and Wind Driven Currents at Corridor 2

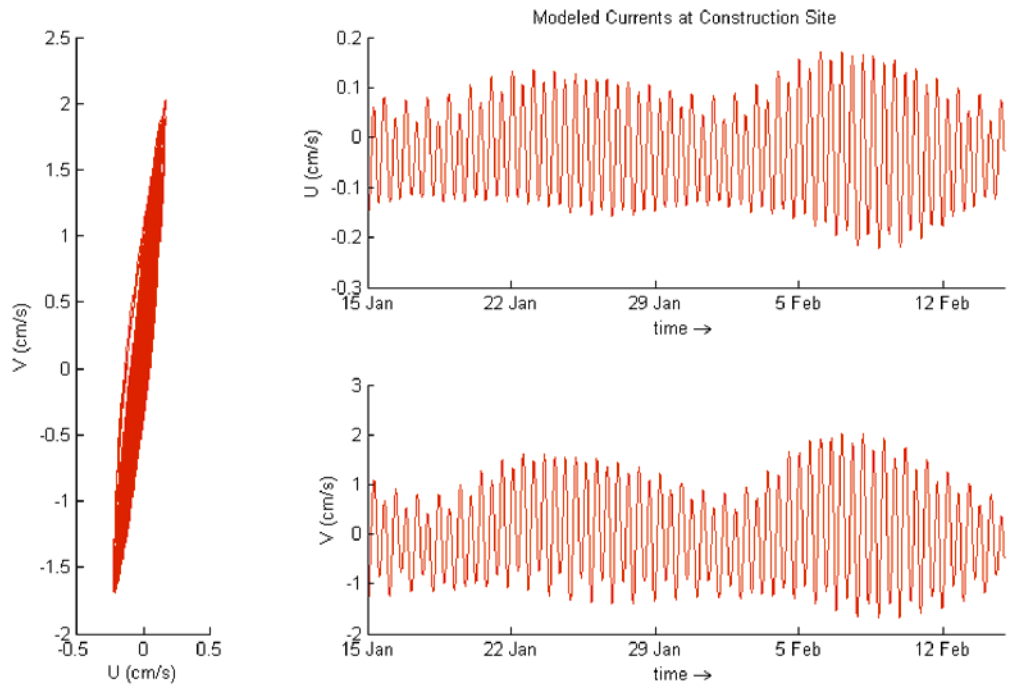


Figure 3-6 Modelled Tidal Currents at the Construction Site

3.2 Backhoe Dredger and Cutter Suction Dredger Models

Dredging operations commonly introduce bottom sediments into overlying waters because of imperfect entrainment and incomplete capture of sediments that are re-suspended during the process, as well as the spillage or leakage of sediments during subsequent transportation and disposal of the dredged sediment.

The mechanism of generating turbidity by dredging is different for each type of dredge. The diffusion of suspended material is influenced by the currents, grain sizes and other soil conditions, as well as the irregularities in the dredge action and bottom configuration.

Different methods have been described in order to estimate the sediment re-suspension and resulting concentration in surrounding waters of dredges operations (Nakai 1978; Collins 1995). These methods have been incorporated into a numerical model (DREDGE, Hayes and Je 2000), as a means to reliably estimate the sediment concentrations created by different types of dredging operations, including mechanical dredgers and hydraulic dredgers.

The DREDGE model estimates the mass rate at which bottom sediments become suspended into the water column as the result of hydraulic or mechanical dredging operations and the resulting suspended sediment concentrations. The sediment re-suspension mathematical schemes are based on the theory and empirical measurements of Collins (1995). The suspended sediment fluxes produced by the bucket dredge are dispersed and advected using a 2D laterally-averaged steady-state particle advection-diffusion model (Kuo and Hayes 1991), based on the local conditions currents and depth. The far-field dispersion of sediments re-suspended by CSDs is modelled using the formulations of Kuo et al. (1985).

The inputs for the DREDGE model (Table 3-2 and Table 3-3) were determined based on the known and assumed equipment specifications (Van Oord 2012), the sediment composition (Stantec, pers. comm.) and the current magnitude estimates from AMEC's hydrodynamic model at the graving dock. Hence, model runs were conducted with the mechanical dredge module for the three possible bucket sizes of BHD, two dredging depths representative of the beginning and the end of the dredging process, and two current speeds representing the range of currents expected at the site. The canonical value of 60 s was used for the cycle time, assuming a typical cycle time distribution of 30 percent for the bucket rising, 48 percent above the water surface and 22 percent for the bucket falling through the water column. The suspended sediments associated with the operation come from the disturbance of the sea bottom, as well as for the partial loss of fine materials when the bucket rises through the water column.

Table 3-2 Backhoe Dredger Modelling Inputs for the graving dock

Parameter	Values Used
Bucket Size (m^3)	15, 20, 25
Cycle Time (s)	60
Water Depth (m)	7, 20
Current Speed (m/s)	0.01, 0.05
Average Settling Velocity (m/s)	0.001
Fines Settling Velocity (m/s)	0.0003
In-situ Dry Density (kg/m^3)	1560
Mean Particle Size (µm)	54
Fraction of Particles <74 µm	0.61
Fraction of Particles <50 µm	0.48
Lateral Diffusion Coefficient (cm^2/s)	100,000
Vertical Diffusion Coefficient (cm^2/s)	5

Table 3-3 Cutter Suction Dredger Modelling Inputs for Construction Site

Parameter	Values Used
Cutterhead Diameter (m)	2
Cutterhead Length (m)	3
Thickness of Cut (m)	2
Ladder Length (m)	23
Cutterhead Rotation Speed (rpm)	2
Dredge Flowrate (m^3/s)	2
Water Depth (m)	7, 20
Current Speed (m/s)	0.01, 0.05
Average Settling Velocity (m/s)	0.001
Fines Settling Velocity (m/s)	0.0003
In-situ Dry Density (kg/m^3)	1560
Mean Particle Size (µm)	54
Fraction of Particles <74 µm	0.61
Fraction of Particles <50 µm	0.48
Lateral Diffusion Coefficient (cm^2/s)	100,000
Vertical Diffusion Coefficient (cm^2/s)	5

The values for the parameters describing the components of a CSD, such as the cutter head diameter, length, rotational speed and flow rate, were based on typical values for the specified suction pipe diameter of 1 m. Model runs were conducted for the two selected current speeds of 1 and 5 cm/s, and water depths of 7 and 20 m. The sediment re-suspension associated with CSD operations is due to the disturbance at the sea bottom, and the fact that the suction pipe would not capture all the sediment that the cutter head loosens during the cutting process.

3.3 Trailing Suction Hopper Dredger Models

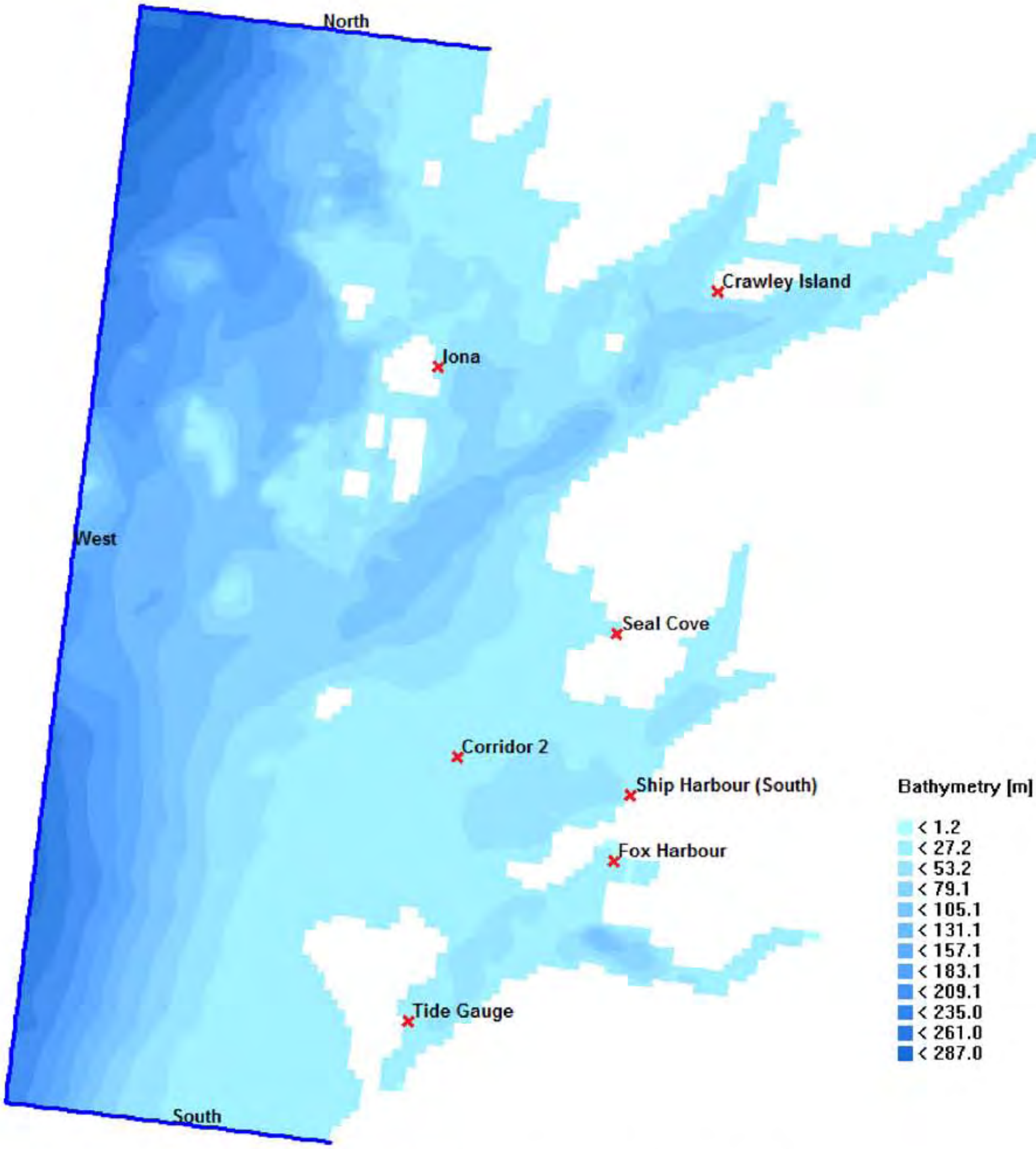
The TSHD operations can affect the environment in a noticeably different manner compared to the BHD and CSD used for the Construction Site. Due to the substantially lower concentration of fines in Corridors 1 and 2 (17 percent and 3 percent, respectively), the disturbances at the bottom are expected to be much lower than those observed at the graving dock. However, the TSHD is very efficient at keeping any fine sediment in suspension within the capacity of its hopper during most of the dredging cycle, and the majority of these fine sediments are usually discharged in a concentrated overflow plume at the end of each dredging cycle.

For these reasons, AMEC employed two different modelling strategies. First, modelling was conducted for the immediate, momentum-driven discharge (near-field model) using the CDFATE (continuous discharge fate) module of the ADDAMS modelling suite. Subsequently, modelling of the far-field dispersion of sediments over the duration of the whole operation was conducted using the Delft3D modelling suite. Given the capacity of the TSHD (9,930 m^3), it was assumed that approximately 17 dredging operations will be necessary, spread over a period of four to six weeks. Therefore, the current study considered 17 dredging cycles over the period of four weeks as a conservative, worst-case scenario, with 40 hours between each operation.

Each dredging cycle is assumed to conclude with the release of an overflow plume at 1 m^3/s, with a concentration of 135 kg/m^3 of fine sediment (silt and clay combined) over the course of 75 minutes, estimated from available operational data for a typical TSHD. The overflow plumes are expected to occur as the dredging operation progresses towards the end, after a substantial part of the hopper has been filled. Considering the fact that only a minor amount (25 m^3) of sediment is to be dredged in Corridor 1, it is highly unlikely that overflow of the TSHD hopper would occur there, or that the sediment composition in Corridor 1 would contribute toward the overflow plume concentrations. Therefore, the TSHD overflow plume releases have been modelled to occur only within Corridor 2, using the sediment composition in Corridor 2.

The near-field plume was modelled as a single port hopper dredge discharge, assuming a flow rate of 1 m^3/s through a port (assumed 0.7 m diameter) oriented vertically, at a nominal depth of 6 m. Sensitivity testing showed that the vessel cruising speed is a dominant factor determining the near-field dispersion process; therefore, two scenarios were considered, for ship speeds of 0.5 and 1.5 m/s, against ambient currents of 0.1 m/s.

The far-field dispersion of the TSHD overflow plumes was conducted using the hydrodynamic model described in Section 3.1. For the purpose of monitoring the suspended sediment concentrations through the four-week model run, monitoring points were set up through the model domain as shown in Figure 3-7. The discharges occurred in Corridor 2 every 40 hours for 75 minutes, starting arbitrarily at 6 am on January 15, and ending at 10 pm on February 10. The monitoring was continued for more than one month following the end of operations, in order to estimate the longer term rate of dissipation of the sediment concentrations.



Note: TSS Concentration Time Series were captured at the monitoring points marked in red

Figure 3-7 Far-field Model Domain Used for Total Suspended Solids Dispersion for Corridors 1 and 2

4.0 Total Suspended Solids Dispersion Modelling Results

4.1 Dredging Total Suspended Solids Dispersion for the Construction Site

The total suspended solids (TSS) dispersion modelling considered the three bucket sizes available for the BHD, as well as the assumed configuration of the CSD. Two depths were considered: the minimum dredging depth of 7 m, as well as the approximate final depth of 20 m.

The results (Table 4-1, Table 4-2 and Table 4-3) show that the concentrations are generally low, and fall below 1 mg/L within approximately 1 km of the site. The TSS plumes are expected to propagate mostly along the shoreline (southwest to northeast direction), as the tidal currents are expected to be aligned with the shore in this area. The estimated maximum concentrations of TSS within 10 m of the dredging area are also shown.

Table 4-1 Backhoe Dredger Dredging Option (Current = 1 cm/s)

Bucket Size (m^3)	15		20		25	
Depth (m)	Max TSS at site (mg/L)	Distance TSS < 1 mg/L (m)	Max TSS at site (mg/L)	Distance TSS < 1 mg/L (m)	Max TSS at site (mg/L)	Distance TSS <1 mg/L (m)
7	12.0	230	18.9	300	27.8	370
20	12.2	430	19.6	620	28.5	790

Table 4-2 Backhoe Dredger Dredging Option (Current = 5 cm/s)

Bucket Size (m^3)	15		20		25	
Depth (m)	Max TSS at site (mg/L)	Distance TSS <1 mg/L (m)	Max TSS at site (mg/L)	Distance TSS <1 mg/L (m)	Max TSS at site (mg/L)	Distance TSS <1 mg/L (m)
7	5.5	220	8.8	400	12.9	650
20	5.5	270	8.9	570	12.9	950

Table 4-3 Cutter Suction Dredger Dredging Option

Current speed (cm/s)	1		5	
Depth (m)	Max TSS at site (mg/L)	Distance TSS <1 mg/L (m)	Max TSS at site (mg/L)	Distance TSS <1 mg/L (m)
7	291.6	440	302.3	1120
20	692.9	570	718.3	1650

The results for the BHD dredging option indicate that the bucket size has a substantial difference on the predicted sediment concentrations, with maximum concentrations at the site being more than double for bucket sizes of 25 m^3 compared to those of 15 m^3. The effect of the increased current speeds was to diminish the maximum TSS levels at the site, but the distance at which the levels fell below 1 mg/L were extended further away from the site. The maximum concentrations at the source are expected to be similar for the two different water depths, but the distance required to reach dilution to below 1 mg/L is approximately doubled when the water depth is doubled. This is likely attributable to the fact that deeper water depths translate into a longer vertical path for the bucket, and consequently, a larger loss of sediment that is evenly distributed and dispersed through the water column.

The results for the CSD dredging option (Table 4-3) are notable for the fact that the predicted maximum TSS levels at the dredging site are much larger than those shown for the BHD. This wide discrepancy can be partly explained by the difference in formulations between the two source models, with the CSD being represented by a localized point-source at the sea floor, while the BHD is represented by a vertical line source spread through the whole water column. A more useful comparison would be that of the distances at which levels fall below 1 mg/L. Thus, the TSS levels for the CSD are broadly comparable to those of the 20 and 25 m^3 BHD option at current speeds of 5 cm/s.

Therefore, the overall effect of the CSD on suspended sediment levels would be higher than that of the BHD. However, it should be noted that the CSD dredging option has been indicated in the preliminary dredging plan as an alternative dredging method, to be employed only if coarse, hard material (rock) is encountered or anticipated at the dredging site. If the samples considered in the current study are representative of the full volume to be dredged, it is likely that the BHD would be the preferred option. For this reason, a CSD scenario including high percentages of fine sediments, such as the one presented in Table 4-3, is unlikely.

4.2 Dredging Total Suspended Sediments Dispersion for Corridors 1 and 2

The cruising speed of the TSHD during operations is expected to vary between 0.5 and 1.5 m/s. Since the ocean currents in the area of Corridors 1 and 2 are much lower (0.10 to 0.15 cm/s), the cruising speed is the controlling factor for the initial rate of water entrainment into the plume, and its subsequent dispersion until the momentum is dissipated and the plume becomes subject to spreading by the ambient currents. Depending on the initial discharge velocity and the ambient conditions, the plume is modelled through several stages: weakly deflected jet, strongly deflected jet, weakly deflected plume, strongly deflected plume and bottom boundary impingement.

In both modelled scenarios, the plumes would undergo rapid dilution while descending toward the sea bottom (Figure 4-1, Figure 4-2) in the wake of the ship. The two scenarios exhibit a substantial difference in dilution rates and distances required to reach the end of near-field dispersion. Namely, the end of the near-field mixing zone is reached at a distance of 95 m for the higher cruising speed, which is more than three times further than that for the lower cruising speed scenario. Consequently, the dilution factor achieved during this stage is approximately three times higher for the higher speed scenario, reaching a factor of 90.9 (Table 4-4). In either case, following the end of near-field spreading, the sediment plume would be further advected and dispersed by the ambient tidal and wind-driven currents. The far-field dispersion and longer term fate of the plumes are discussed in the following section.

Table 4-4 Sediment Plume Concentration and Dilution by Near-Field Dispersion Processes as a Function of Trailing Suction Hopper Dredger Cruising Speed

TSHD Cruising Speed	0.5 m/s	1.5 m/s
End of Near-Field Distance (m)	30	95
Concentration at End of Near-Field Distance (mg/L)	4330	1490
Dilution Factor at End of Near-Field Distance	31.2	90.9

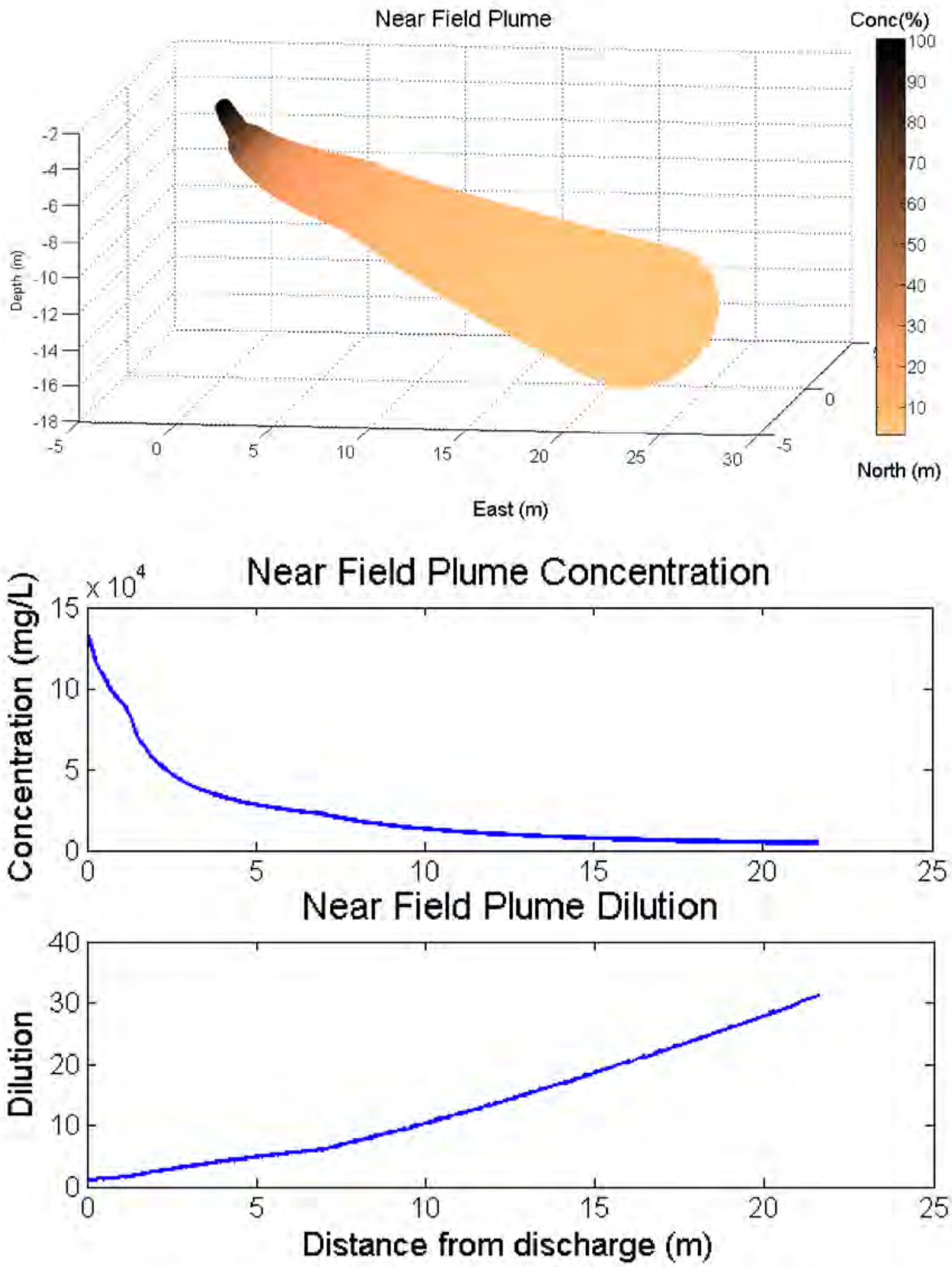


Figure 4-1 **Near-Field Plume Dispersion, Concentration and Dilution for Trailing Suction Hopper Dredger Cruising Speed of 0.5 m/s**

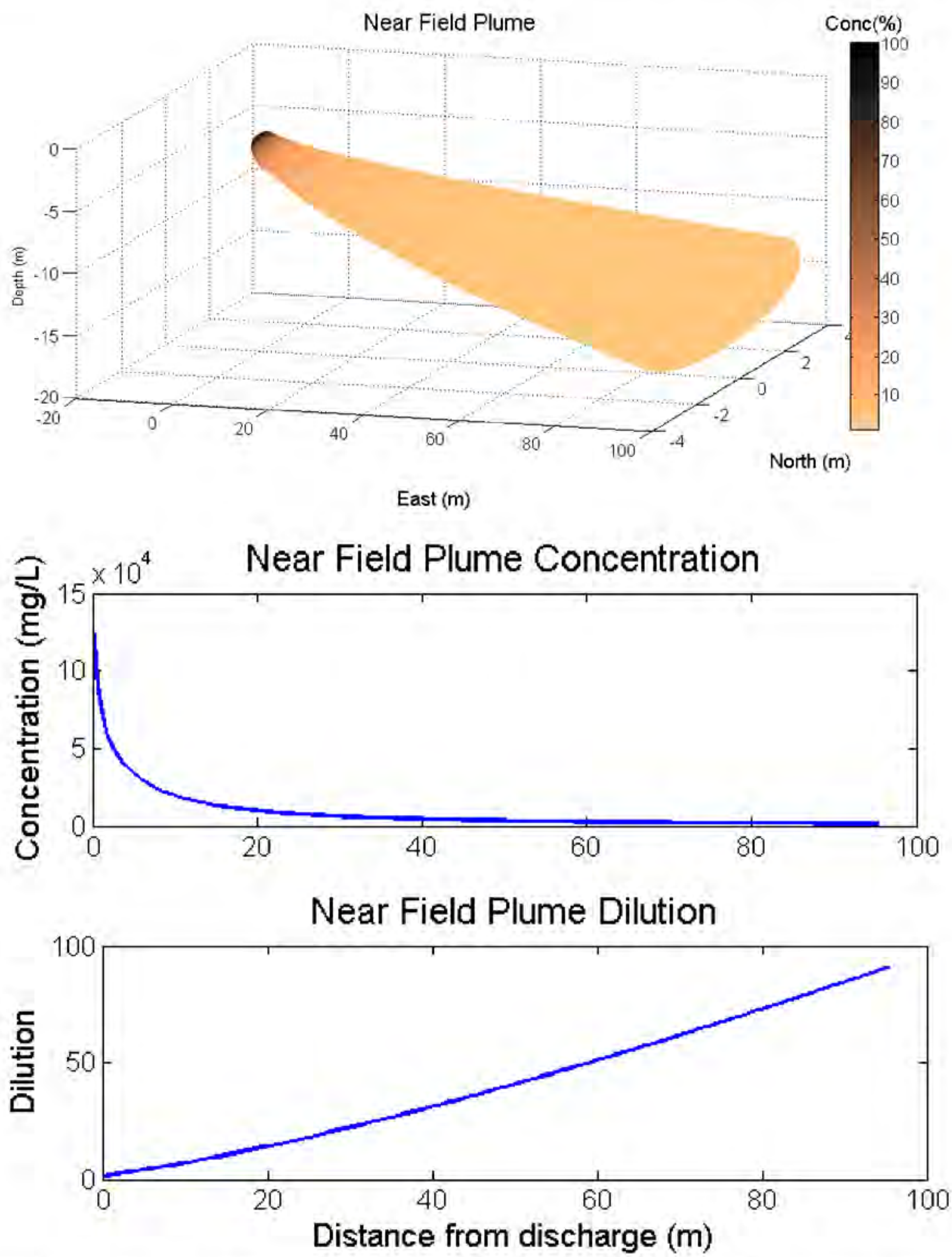


Figure 4-2 Near-Field Plume Dispersion, Concentration and Dilution for Trailing Suction Hopper Dredger Cruising Speed of 1.5 m/s

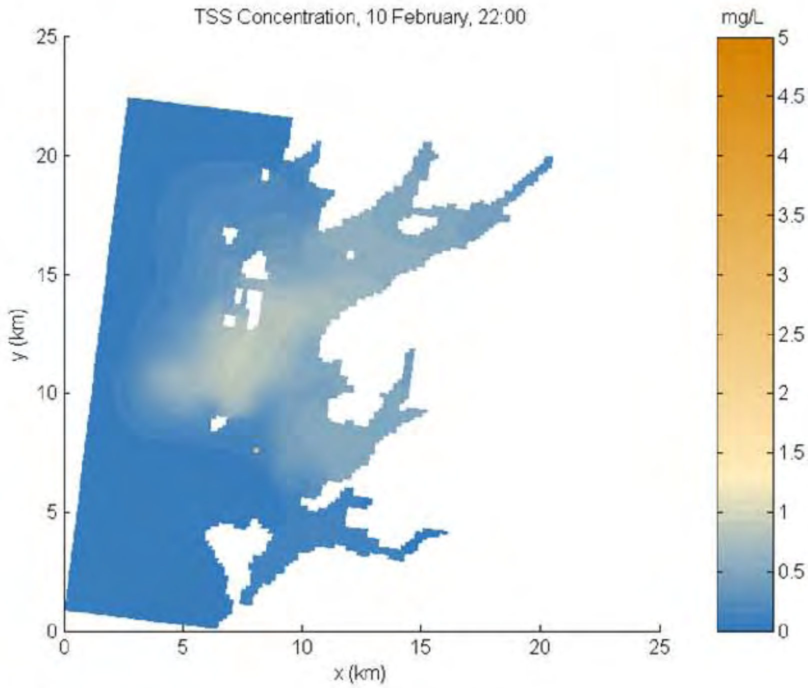
4.3 Far-field Total Suspended Solids Dispersion Modelling at Corridors 1 and 2

When an overflow sediment plume loses its initial momentum and becomes subject to ambient current spreading, it is necessary to consider and evaluate the wider circulation and depositional patterns. The far-field dispersion of the suspended sediments during a 4-week TSHD dredging program were evaluated by using average westerly winds at the average seasonal wind speed of 10 m/s. Additional sensitivity runs were conducted for the second and third most frequent wind directions, from the southwest and the northwest, using the same average wind speed. The models runs extended to more than 30 days following the end of the dredging program, and suspended sediment concentrations were captured throughout the model domain at hourly intervals. The model setup therefore allowed for the evaluation of the cumulative effects of TSHD operations as a worst case scenario, without mitigative measures in place.

The evolution of a typical sediment plume in the first 48 hours is shown in the series of plots in Figure 4-3 to Figure 4-6. Additionally, time series of TSS concentrations captured during the four-week run (15 January (first operation) to 10 February (last operation)) at the model monitoring points are plotted for the typical, as well as the sensitivity scenarios, in Figure 4-7 to Figure 4-9. These plots show that during typical conditions, there is a tendency for the plumes to be transported to the north of Corridor 2, with very limited transport to the south near the Tide Gauge and Fox Harbour monitoring points. Therefore, these two points would typically experience a miniscule increase of TSS levels (on the order of 0.1 mg/L) during the whole duration of dredging operations at Corridor 2, and most of the other stations generally see levels of less than 1 mg/L. The only exception is the Seal Cove location, where approximately half of the dredge cycles produce spikes in the TSS levels above 2 mg/L, and sometimes above 3 mg/L.

The northward sediment transport is further exaggerated when the winds come from the southwest, with Seal Cove levels reaching up to 4.5 mg/L, while the monitoring points to the south (Tide Gauge and Fox Harbour) experience almost no measurable increases in TSS levels. The trend is reversed for winds coming from the northwest, with the mean transport being to the south. The northwesterly winds scenario therefore results in much lower TSS levels north of Corridor 2, and the lowest overall levels (less than 1.5 mg/L) at all coastal monitoring points.

In order to further quantify the extent and persistence of the sediment plumes associated with TSHD operations, the surface areas with levels above certain thresholds (1 mg/L, 5 mg/L, 10 mg/L, 25 mg/L) were computed for all 17 dredging cycles throughout the program. The statistics describing the average plume characteristics for all wind scenarios are shown in Table 4-5.



Note the Pre-existing Sediment from the Previous 16 Operations

Figure 4-3 Total Suspended Solids Concentrations at the Beginning of the 17th (last) Dredging Operation in Corridor 2

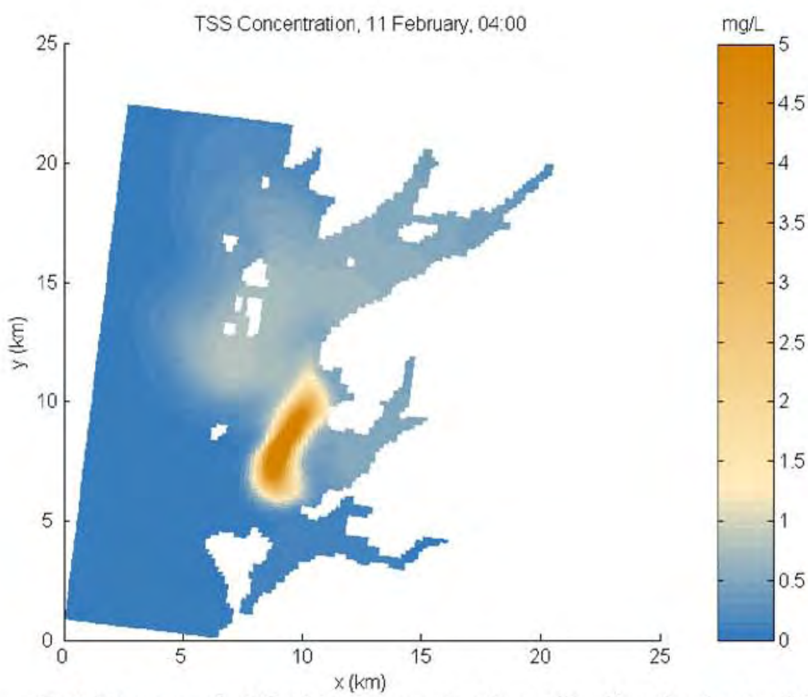


Figure 4-4 Total Suspended Solids Concentrations 6h after the Last of 17 Dredging Operations in Corridor 2

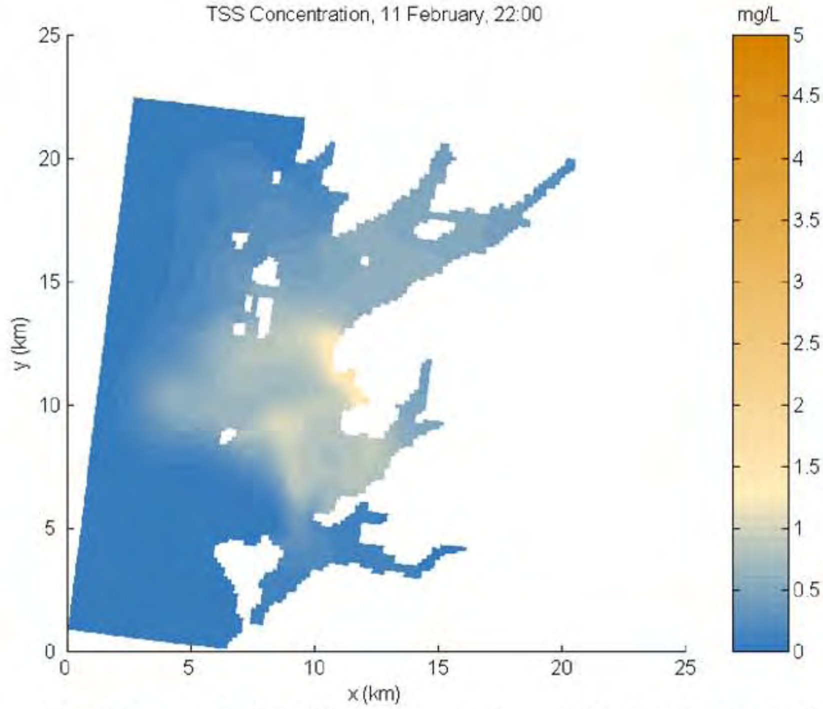


Figure 4-5 **Total Suspended Solids Concentrations 24h after the Last of 17 Dredging Operations in Corridor 2**

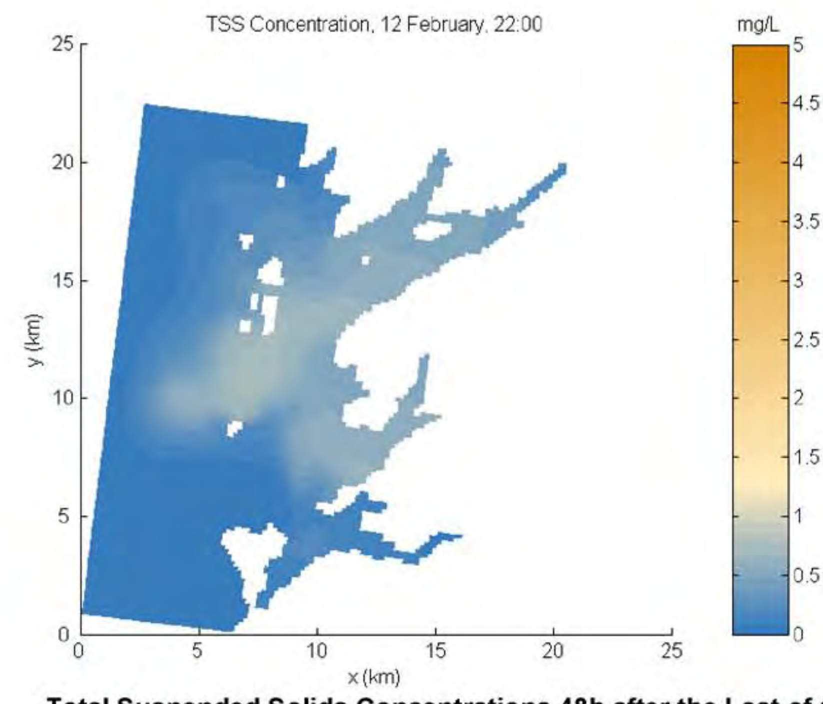


Figure 4-6 **Total Suspended Solids Concentrations 48h after the Last of 17 Dredging Operations in Corridor 2**

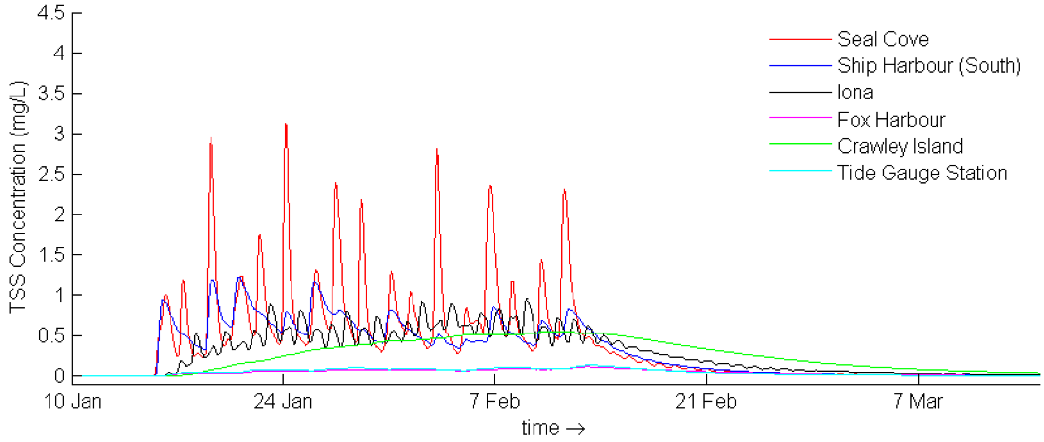


Figure 4-7 Far-field Total Suspended Solids Dispersion Model Results for Typical (Westerly) Wind Conditions

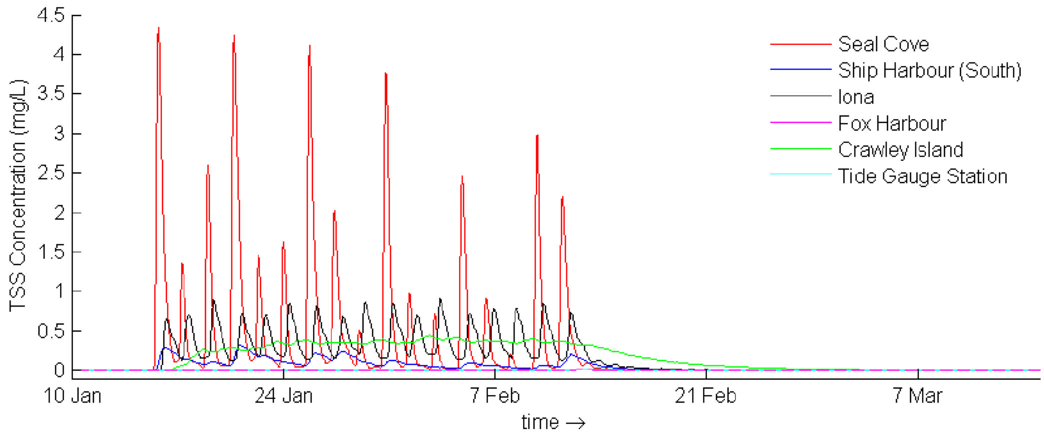


Figure 4-8 Far-field Total Suspended Solids Dispersion Model Results for Southwesterly Wind Conditions

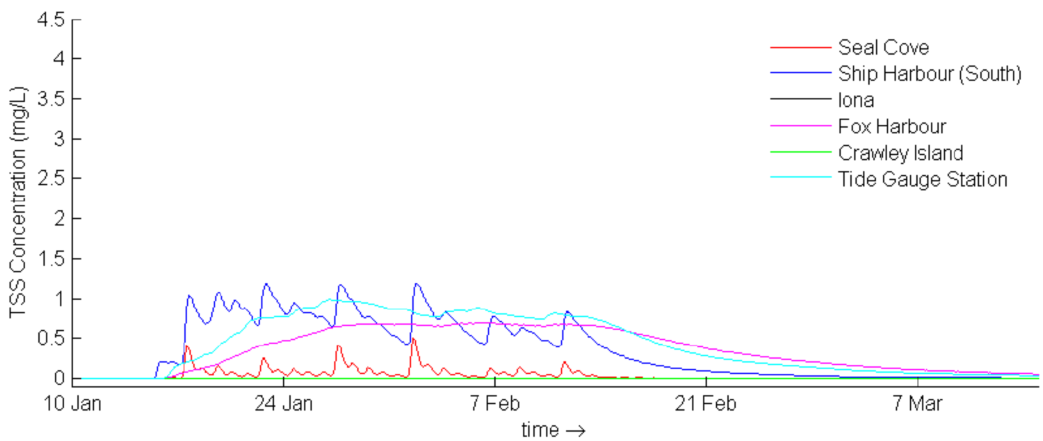


Figure 4-9 Far-field Total Suspended Solids Dispersion Model Results for Northwesterly Wind Conditions

Table 4-5 Sediment Plume Concentration at Source, Persistence and Extent for the Average TSHD Dredging Cycle

Wind Direction	Max TSS at source (mg/L)	Period TSS > 25 mg/L (h)	Period TSS > 10 mg/L (h)	Period TSS > 5 mg/L (h)	Period TSS > 1 mg/L (h))	Area TSS > 25 mg/L (km^2)	Area TSS > 10 mg/L (km^2)	Area TSS > 5 mg/L (km^2)	Area TSS > 1 mg/L (km^2)
West	274	3.8	6.1	9.3	32.6	0.7	1.7	3.1	16.6
Southwest	240	3.7	5.9	9.2	21.9	0.7	1.6	2.7	10.4
Northwest	269	3.7	6.4	10.0	37.8	0.6	1.6	3.0	22.6

Maximum plume concentrations above 25 mg/L are expected to persist for no more than 4 hours for an average dredging operation for all wind scenarios. Concentrations above 10 mg/L would persist for approximately 6 hours, and levels above 5 mg/L would last for about 10 hours for a single dredging operation. Plume concentrations above 25 mg/L are expected to occur within limited areas of approximately 0.7 km^2. The only significant difference between the wind scenarios is observed in the extent and persistence of plume concentrations above 1 mg/L (but below 5 mg/L), where the southwesterly winds are about twice as efficient at dispersing these low levels of suspended sediment (within 21.9 hours) compared to the northwesterly winds (37.8 hours), and the most frequent, westerly wind conditions. (32.6 hours).

Finally, in order to assess the cumulative exposure to the suspended sediments associated with the unmitigated TSHD operations, the concentrations at all points in the model domain were averaged over sliding 24-hour and 30-day time windows over the duration of the program, and up to 30 days following the end of the dredging program. The maximum exposure levels for both time windows were recorded over the model domain, and are plotted for the three different wind scenarios in Figure 4-10 to Figure 4-12. The results show that the mean exposure over 24-h would never reach higher than about 19 mg/L, and the highest mean exposure over 30 days is about 3.6 mg/L. These are the highest levels predicted to occur within the limits (200 m distance) of the actual dredging site (Corridor 2), however within the first kilometer the 24-hour exposures fall to about 10 mg/L or below. The highest exposure levels over 24 hours for most of the model domain in the vicinity of Argentia are predicted to be about 5 mg/L or less. The trends are similar for the 30-day exposure results, where the highest exposure levels outside the vicinity of the dredging site are expected to remain at about 1.5 mg/L or less.

The results presented here are well below the thresholds for Total Particulate Matter given in the Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME, 2002). The guidelines specify that during clear flow periods, anthropogenic activities should not increase suspended sediment concentrations by more than 25 mg/L over background levels during any short-term exposure period (24 hours), while for longer term exposure (30 days or more), average suspended sediment concentrations should not be increased by more than 5 mg/L over background levels.

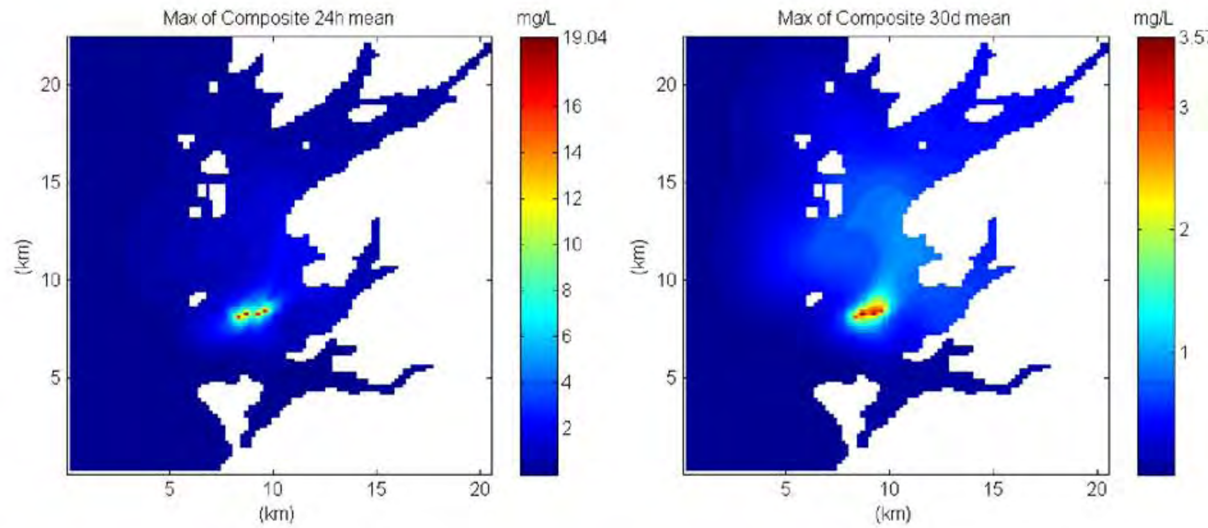


Figure 4-10 Maximum of Composite TSS Mean Concentration Exposures Over 24 Hours (left) and 30 Days (right), for the Typical, Westerly Winds Scenario.

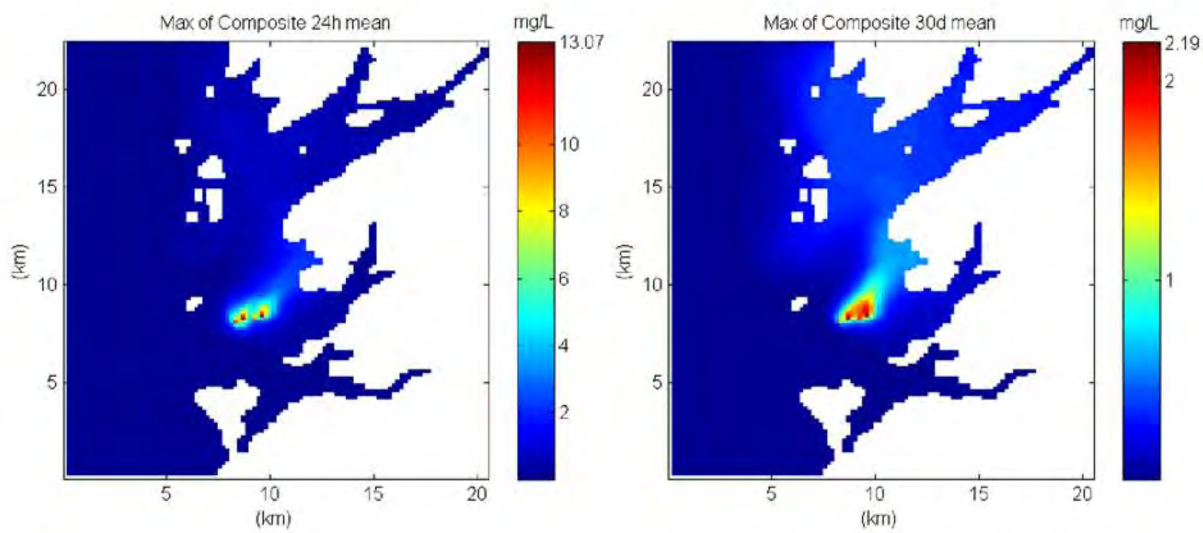


Figure 4-11 Maximum of Composite TSS Mean Concentration Exposures Over 24 Hours (left) and 30 Days (right), for the Southwesterly Winds Scenario.

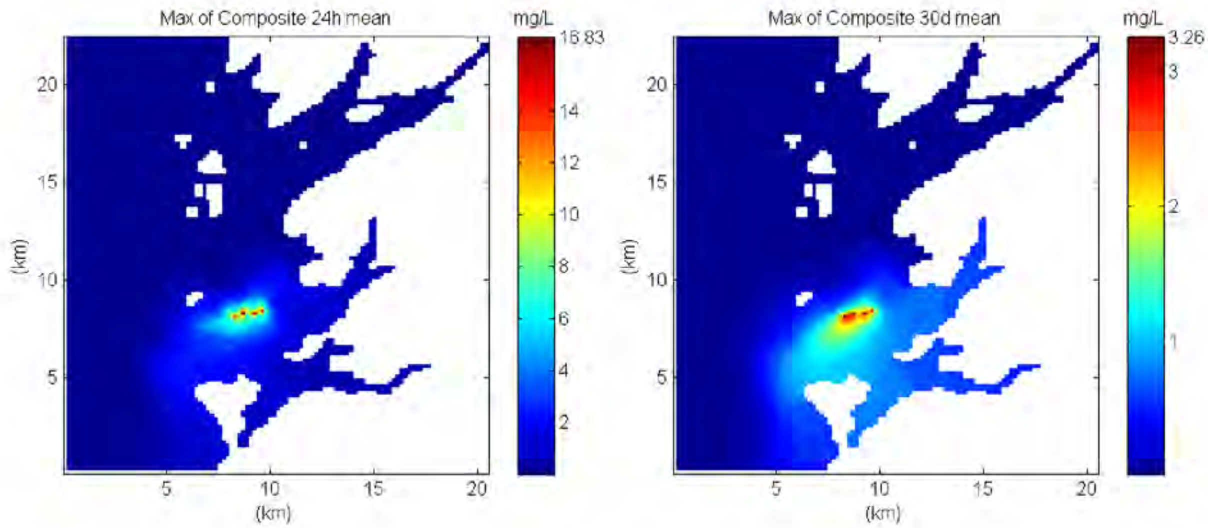


Figure 4-12 Maximum of Composite TSS Mean Concentration Exposures Over 24 Hours (left) and 30 Days (right), for the Northwesterly Winds Scenario.

5.0 SUMMARY

The aim of the present study was to assess the potential for suspension of the fine sediments during dredging activities, and to predict the likely fate and dispersion of these sediments through the duration of the dredging program and beyond. The assessment was based on ocean currents modelled by AMEC's implementation of the Delft3D modelling suite in the depth averaged mode, including tidal and wind-driven circulation in Argentia Bay. Current magnitudes were relatively low (5 cm/s or less) at the construction site, and higher (10 to 15 cm/s) within the dredging corridors. The composition of the sediment in each area was determined from samples taken during a field campaign (Stantec, pers. comm.). Fine sediments accounted for 55 percent of the material at the construction site, 17 percent in Corridor 1, and only 3 percent in Corridor 2.

The modeling results show that for the BHD option, the concentrations at the site would be relatively low (5.5 to 28.5 mg/L), and fall below 1 mg/L within approximately 230 m to 1 km of the site. The fine sediment plumes are expected to propagate mostly along the shoreline (southwest to northeast direction), as the tidal currents are expected to be aligned with the shore in this area.

The local effect of the CSD on suspended sediment levels would be higher than that of the BHD, with predicted suspended sediment concentrations within 10 m of the source ranging from 291.6 to 718.3 mg/L. The wide discrepancy between these levels and those of the BHD can be partly explained by the difference in formulations between the two source models, with the CSD being represented by a localized point-source at the sea floor, while the BHD is represented by a vertical line source spread through the whole water column. A comparison of the far-field dispersion for the two dredging methods revealed that levels for the CSD are broadly comparable to those of the 20 m^3 and 25 m^3 BHD option at current speeds of 5 cm/s.

It should be noted that the CSD dredging option has been indicated in the preliminary dredging plan as an alternative dredging method, to be employed only if coarse, hard material (rock) is encountered or anticipated at the dredging site. If the samples considered in the current study are representative of the full volume to be dredged, it is likely that the BHD would be the preferred option. For this reason, a CSD scenario including high percentages of fine sediments is relatively unlikely.

The near-field modeling results for the dredging operations in Corridors 1 and 2 show that depending on the cruising speed of the TSHD, the end of the near-field mixing zone would be reached at distances of 30 to 95 m from the dredging location. The dilution factor reached within this initial zone is expected to range from 31.2 to 90.9, resulting in initial plume concentrations of 1,490 to 4,330 mg/L within the first 100 m.

The far-field model results show that during typical conditions there is a tendency for the plumes to be transported to the north of Corridor 2, with very limited transport to the south near the Argentia Tide Gauge and Fox Harbour monitoring points. Therefore, these two points would experience a miniscule increase of total suspended solids (TSS) levels (on the order of 0.1 mg/L) during the whole duration of dredging operations at Corridor 2, and most of the coastal stations generally see levels of less than 1 mg/L. The only exception is the Seal Cove location, where approximately half of the dredge cycles produce spikes in the TSS levels above 2.5 mg/L, and sometimes above 3 mg/L.

However, the spikes in TSS levels are relatively short-lived, as the concentrations fall rapidly below 1 mg/L within a timescale of a day. The relatively high exposure of Seal Cove compared to the other monitoring points can be attributed not only to its relatively close proximity to Corridor 2, but also to the currents that are on average oriented toward the northeast of the dredging area.

Maximum concentrations of 5 to 10 mg/L occur for the first 6 to 10 hours after the dredging cycle, and are generally restricted within an area of 3 km^2 around Corridor 2. Overall, suspended sediment concentrations are expected to fall to approximately 1 mg/L within the first 30 hours of a dredging operation. The vast majority of the fine sediments are expected to be transported out of the bay by the combined tidal and wind-driven currents.

In order to assess the cumulative exposure to the suspended sediments associated with the unmitigated TSHD operations, the concentrations at all points in the model domain were averaged over sliding 24-hour and 30-day time windows over the duration of the program, and up to 30 days following the end of the dredging program. The results show that the mean exposure over 24-h would never reach higher than approximately 19 mg/L, and the highest mean exposure over 30 days is approximately 3.6 mg/L. These are the highest levels predicted to occur within the limits (200 m distance) of the actual dredging site (Corridor 2); however, within the first kilometre, the 24-hour exposures fall to approximately 10 mg/L or below. The highest exposure levels over 24 hours for most of the model domain in the vicinity of Argentia are predicted to be approximately 5 mg/L or less. The trends are similar for the 30-day exposure results, where the highest exposure levels outside the vicinity of the dredging site are expected to remain at approximately 1.5 mg/L or less.

The results presented here are well below the thresholds for Total Particulate Matter given in the Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME 2002). The guidelines specify that during clear flow periods, anthropogenic activities should not increase suspended sediment concentrations by more than 25 mg/L over background levels during any short-term exposure period (24 hours), while for longer term exposure (30 days or more), average suspended sediment concentrations should not be increased by more than 5 mg/L over background levels.

6.0 REFERENCES

6.1 Personal Communications

Han, G. Research Scientist, Fisheries and Oceans Canada, Northwest Atlantic Fisheries Centre, St. John's, NL. Emails: "Placentia Bay model circulation fields: tidal heights and current profiles, near Argentia, based on FVCOM model". May 15 and 18, 2012.

Stantec Consulting Ltd., 2012 Lab Results from Maxxam Analytics.

6.2 Literature Cited

Black, J. 1991. *ACON Data Visualization Software*. DFO, Maritimes Region, Dartmouth, NS. Available at: http://www.mar.dfo-mpo.gc.ca/science/acon/

CCME 2002. *Canadian Water Quality Guidlines for the Protection of Aquatic Life, Total Particular Matter.*

C-CORE 2012. *Technical Memorandum, Re: Argentia Acoustic Seabed Survey.*

Collins, M.A. 1995. *Dredging-Induced Near-Field Resuspended Sediment Concentrations and Source Strengths.* Miscellaneous Paper D-95-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hayes, D.F., T.R. Crockett, and T.J. Ward, 2000. Near-Field Sediment Resuspension During Cutterhead Dredging Operations. *ASCE Journal of Coastal, Ports, and Waterways*, 126(3).

Hayes, D.F., and C.H. Je, 2000. *DREDGE Module User's Guide.* Department of Civil Environmental Engineering, University of Utah.

Husky Energy, 2012. *White Rose Extension Project. Project Description*. May 2012.

Kuo, A., C. Welch, and R. Lukens 1985. *Dredge Induced Turbidity Plume Model. ASCE Journal of Waterway, Port, Coastal, and Ocean Engineering*, 111(3).

Ma Z., G. Han and B. de Young. 2011. Modelling temperature, currents and stratification in Placentia Bay. *Atmosphere-Ocean*, accepted.

Nakai, O. 1978. *Turbidity Generated by Dredging Projects*. Proceedings of the 3rd U.S./ Japan Experts Meeting, US Army Engineer Water Resources Support Center, Ft. Belvoir, VA.

Roelvink, D. And D.J. Walstra. 2007. Keeping it simple by using complex models. *Advances in Hydro-Science and Engineering*, 6.

Spearman J., Bray, R.N., Land, J., Burt, T.N., Mead, C.T., and D. Scott 2007. Plume Dispersion Modelling Using Dynamic Representation of Trailer Dredger Source Terms. *Proceedings in Marine Science*, 8: 417-448.

Spearman, J., Heer, A., Aarninkhof, S., and M.V. Koningsveld 2011. *Validation of the TASS system for predicting the environmental effects of Trailing Suction Hopper Dredgers.* Terra et Aqua, No. 125.

van Rhee, C. 2002. *Modelling the Sedimentation Process in a Trailing Suction Hopper Dredger.* Terra et Aqua, No. 86.

Vitousek, S., Fletcher, C.H., Merrifield, M.A., Pawlak, G., and C.D. Storlazzi. 2007. *Model scenarios of shoreline change at Kaanapali Beach, Maui, Hawaii: seasonal and extreme events.* Proceedings of the Sixth International Symposium on Coastal Engineering and Science of Coastal Sediment Processes. ASCE Conference Proceedings. doi:http://dx.doi.org/10.1061/40926(239)95.

Vlasblom, W. 2007. *Dredging Equipment and Technology*. Delft University of Technology Lecture Notes. Published by the Central Dredging Association (CEDA) at: www.dredging.org/content.asp?page=105.

7.0 Acronyms

Term	Description
BHD	Backhoe dredger
CCME	Canadian Council of Ministers of the Environment
CGS	Concrete gravity structure
CSD	Cutter suction dredger
FPSO	Floating production, storage and offloading vessel
h	hour
m/s	metres per second
s	seconds
TSHD	Trailing suction hopper dredger
TSS	Total suspended solids
WHP	Wellhead Platform
WREP	White Rose Extension Project

8.0 Glossary

Word	Definition
Bathymetry	The measurement of depths of water in oceans, seas and lakes; also the information derived from such measurements
Clay	Minerals or solid chemical substances; common in fine grained sedimentary rocks like shale, mudstone, and siltstone.
Hydrodynamic	The study of fluids in motion; here it pertains to the ocean
Sediment	Solid material, both mineral and organic, that is being or has been transported from its site of origin by air, water or ice, and has come to rest on the Earth's surface either above or below sea level
Silt	A detrital particle smaller than a very fine sand grain and larger than coarse clay, having a diameter in the range of 0.004 to 0.0625 mm
Stratification	Division of the water column into layers, or strata, because of differences in water density, structure or temperature
Surficial	Characteristic of, pertaining to, formed on, situated at, or occurring on the Earth's surface; especially, consisting of unconsolidated residual, alluvial or glacial deposits lying on the bedrock
Thermocline	A temperature gradient as in a layer of sea water, in which the temperature decrease with depth is greater than that of the overlying and underlying water
Topside Facilities	All the oil and gas separation and treatment equipment and related equipment such as compressors, flares and accommodations located on top of an offshore facility
Water Column	The vertical dimension of a body of water (i.e., the water between a reference point or area on the surface and one located directly below it on the bottom)
Wellhead	The equipment installed at the top of the wellbore used to support the casing strings and upon which the tree is installed; it controls the rate of flow of liquid and gas from the well

Note: Bolded **words within a definition are themselves defined**