Modeling Sediment Dispersion from Cable Burial for Seacoast Reliability Project, Little Bay, New Hampshire

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Executive Summary

Public Service of New Hampshire d/b/a Eversource Energy (PSNH) has proposed the construction of an electrical cable system to increase the reliability of the electrical transmission grid in southern New Hampshire. This cable, known as the Seacoast Reliability Project, would cross the Little Bay portion of the Great Bay Estuarine System. The crossing would entail burial of three separate but parallel cable bundles by jet plowing, which is a technique that liquefies the sediment with high pressure water jets and simultaneously allows the cable to be buried at a predetermined depth. The cable sections in the shallow areas near the western and eastern landfalls will be buried by diver. The environmental consultant for the Project, Normandeau Associates, Inc., contracted with RPS ASA to supply its modeling capabilities to simulate the jet plowing and diver burial processes along the cable route to determine both the likely suspended sediment concentrations generated in the water column above the cable route and the resulting re-deposition of the sediments in and along the route.

Two computer models were used in the analysis: BELLAMY, a hydrodynamic model used for predicting the currents in Little Bay, and SSFATE, a sediment dispersion model used for predicting the fate and transport of sediment resuspended by the jet plowing operation. BELLAMY, a finite element, two-dimensional, vertically averaged, time stepping circulation model developed at Dartmouth College and previously applied to the Great Bay Estuarine System (GBES) (McLaughlin et al. 2003; Swanson et al. 2014) was used in this analysis. The model can calculate the time varying surface elevation and currents under the influence of tides, winds and river flow on a model domain discretized by a large number of finite element triangles. Due to the fact that Great Bay is tidally dominated (currents up to 2 m/s [6.6 ft/s] and much of it consists of narrow channels in which the tidal currents mostly flow in flood and ebb directions, the effect of wind is expected to show only in areas with relatively larger surface areas such as Great Bay proper and not Little Bay where the cable burial will occur. The model includes simulation of wetting and drying of tidal flats. All simulation parameters were set to be consistent with previously published work. The reader is referred to Swanson et al., (2014), Bilgili et al. (2005) and McLaughlin et al. (2003) for more detailed information.

The SSFATE (Suspended Sediment FATE) model was utilized to predict the excess suspended sediment concentration and the dispersion of suspended sediment resulting from jetting and diver activities. Since ambient suspended sediment concentrations are variable and generally unpredictable, the model predicts excess concentration, which is defined as the concentration above ambient suspended sediment concentration generated by the jetting activities. In addition SSFATE calculates the resulting deposition thickness of resuspended sediments that have resettled back on the bottom. The sediment grain size information necessary to characterize the sediment was extracted from vibracore data logs taken in April 2014. Some of the cores exhibited high (70 to 90%) fractions of fines (clays and silts) while others exhibited equally high (70 to 90%) of sands. A single representative cable route among the three cable bundles crossing Little Bay was chosen for modeling since the cables will be installed in sequence and are proposed to be separated by only about 9.4 m (30 ft) and all were parallel except when they approached the landfalls.

The cables in the offshore areas are to be buried by jet plowing to minimum depths of 1.07 m (42 in) deep in the shallows on the western but offshore section of Little Bay and 2.7 m (8 ft) in the center and east sections. For ease of discussion, this report refers to the jet plow disturbance as a trench although while the jet plow will be occupying a three-dimensional space, the “trench” is very temporary as it will

fill in immediately behind the jet plow. The total depth of the trench was 1.42 m (96 in) for the western section and 2.79 m (110 in) for the central and eastern sections. Based on Caldwell's specification the trench width was defined as 0.32 m (12.75 in) resulting in a vertical-walled trench cross sectional area of 0.46 m^2 (4.96 ft^2) in the shallow western portion and an area of 0.90 m^2 (9.69 ft^2) in the deeper central and eastern portions. The lengths of the trenches were defined by Caldwell to be 559 m (1,835 ft) for the shallow burial and 741 m (2,431 ft) for the deeper burial. The jet plow rate of advance was provided by the cable installer, Caldwell Marine International, LLC to be 100 m/hr (330 ft/hr). The model run was started on the west side of Little Bay at slack high water which is the beginning of the ebb tide. It was also conservatively assumed, based on past experience, that 25% of the material in the trench would be resuspended into the water column by the jetting activity.

The cables in the nearshore areas are to be buried by divers in trenches with a minimum depth of 1.07 m (42 in) deep in the shallows on both the western and eastern portions of Little Bay with lengths of 90 m (296 ft) in the western portion and 178 m (584 ft) in the eastern portion. The total depth of the trench was 1.22 m (48 in). Based on Caldwell's specification the trench width was defined as 1.22 m (48 in) resulting in a trench cross sectional area of 1.49 m^2 (16 ft^2). The diver rate of advance was much slower than the jet plowing at 2.3 m/hr (7.5 ft/hr) with an operational time restriction of 4 hr/dy. It was also conservatively assumed, based on past experience, that 50% of the material in the trench would be resuspended into the water column by the diver activity. The model run was started around two hours before high slack water and continued for four hours due to diver requirements of lower currents and deeper water. An option to use silt curtains for the diver burial operations in the western and eastern portions was also examined.

Jet Plowing

The size of the resulting excess suspended sediment (SS) concentration plume in the lower water column is defined as a series of areas enclosed by different concentration levels. The water column concentration contours shown, which are defined by a single concentration level, totally surround an enclosed area where concentrations are at or above the specified concentration, i.e., the area is cumulative. The entire area encompassed by the plume (as defined by the 10 mg/L excess SS concentration contour) averaged over time was 14.8 ha (36.58 ac) ranging from a low of 5.91 ha (14.61 ac) at 1 hr to a high of 22.36 ha (55.25 ac) at 10 hrs. These total enclosed areas dropped dramatically for the higher concentrations, averaging 1.94 ha (4.79 ac) at 100 mg/L, 0.28 ha (0.68 ac) at 1,000 mg/L and 0.02 ha (0.05 ac) at 5,000 mg/L. indicating that the extent of the plume is limited for higher concentrations. In the shallows, suspended sediments from the jet plow activity are likely to reach nearly to the water surface. In the channel, excess suspended sediments will be restricted to the lower half of the water column.

An important metric defining the plume is its duration for different concentrations, which could have biological significance if exposure (duration multiplied by concentration) is sufficiently elevated. The maximum plume size and duration at 10 mg/L excess SS concentration in the area that is totally enclosed by the contour is 90.20 ha (222.89 ac) but lasts for only 1 hr. This short duration continues for all the concentration contour thresholds through 1,000 mg/L. The enclosed areas quickly drop in time for a given concentrations so by 2 hrs the 10 mg/L area has dropped to 32.20 ha (79.57 ac) and the plume has completely dissipated within 6 hrs. The area coverages drop dramatically for the higher concentrations near the jet plow indicating that the duration and extent of the plume is relatively

limited. Once the jet plow reaches the eastern terminus and shuts down no additional sediment will be suspended and the residual plume will quickly dissipate.

The bottom deposition was calculated based on all three cable routes being jet plowed and assuming that any sediment deposited on the bottom remained in place. The bottom deposition thickness is defined for the area exclusively between the range of thicknesses described, i.e., the area is not cumulative. As with the water column concentrations of suspended sediment the sizes of the deposition thickness patterns generally drop in size, but not always. At the range of 0.1 to 0.5 mm (0.004 to 0.02 in) thickness the area is 35.6 ha (87.9 ac) due to jet plowing the three cable routes. These areas drop overall for the high deposition thicknesses (e.g., 2.4 ha [5.9 ac] for the 5 to 10 mm (0.2 to 0.4 in) thickness range) near the jet plow indicating that the extent of the plume is relatively limited.

Diver Burial Assuming No Use of Silt Curtains

The size of the excess SS concentration plumes for the west and east diver burial sections were also examined. It was assumed that no silt curtains were used during this activity (if they had been modeled the amount of excess SS and would be reduced 10-fold outside the silt curtained area). Typically, at 10 mg/L excess SS concentration, the instantaneous total area enclosed by the contour is 8.4 ha (20.7 ac) for the west section and 1.9 ha (4.7 ac) for the east section. However, these total enclosed areas drop dramatically for the higher concentrations near the diver burial activities, i.e., the area at 1,000 mg/L is only about 0.2 ha (0.6 ac) for the west section and 0.0 ha (0.1 ac) for the east section, indicating that the extent of the plume is again relatively limited.

Assuming no silt curtains were used, the total area in the west section that is enclosed by the 10 mg/L excess SS concentration contour is 14.6 ha (36.1 ac) but lasts for only 1 hr. This short duration continues through all the concentration contour thresholds through 5,000 mg/L. The enclosed areas decrease in time for a given concentrations so by 6 hrs the 10 mg/L area has dropped to 8.6 ha (21.2 ac). The 10 mg/L area persists for two days because the initial buildup occurs near slack water with grain size distribution indicating mostly fines (silts and clays). The area coverages decrease for higher concentrations near the diver burial activities. At the east section the 10 mg/L excess SS concentration total area that is enclosed by the contour is 8.2 ha (20.2 ac) but lasts for only 1 hr. This short duration continues through all the concentration contour thresholds through 500 mg/L. The enclosed areas decrease in time for a given concentration so by 6 hrs the 10 mg/L area has dropped to 4.1 ha (10.2 ac). The 10 mg/L area persists for two days because the initial buildup occurs near slack water with grain size distribution indicating mostly fines (silts and clays). The area coverages decrease for higher concentrations near the diver burial activities.

The sizes of the deposition thickness patterns also dropped as the deposition increased. At the 0.1 to 0.5 mm (0.004 to 0.02 in) thickness range the area is 3.4 ha (8.5 ac) for the west and 4.4 ha (10.8 ac) for the east, both including the three cable routes combined. These areas drop dramatically for the higher deposition thicknesses (e.g., 0.5 ha [1.2 ac] for the 10 to 50 mm (0.4 to 2 in) thickness on the west section and 1.2 ha (2.9 ac) for the east section indicating that the extent of the plume is limited.

Diver Burial Assuming Use of Silt Curtains

The effects of using silt curtains were estimated by assuming that 90% of the suspended sediment resuspended from diver burial operations would be trapped by the curtains. That being the case, the results based on no silt curtain use can be reduced by a factor of 10 to estimate the concentrations

outside the silt curtain. At 10 mg/L excess SS concentration the area enclosed by the contour was 1.2 ha (3.0 ac) for the west section and 0.4 ha (0.9 ac) for the east section.

In terms of exposure, for the west section at 10 mg/L excess SS concentration the area that is enclosed by the contour is 5.9 ha (14.7 ac) but lasts for only 1 hr. The areas decrease in time for a given concentrations so by 6 hrs the 10 mg/L area has dropped to 2.3 ha (5.7 ac). For the east section at 10 mg/L excess SS concentration the area that is enclosed by the contour is 2.1 ha (5.1 ac) but lasts for only 1 hr. The areas decrease in time for a given concentration so by 6 hrs the 10 mg/L area has dropped to 1.4 ha (3.6 ac). The area within the silt curtain area would, of course, see a significant increase in concentration until the material has settled out.

With the use of silt curtains the bottom deposition thickness outside the silt curtains can also be reduced by a factor of 10. At the 0.1 -> 0.5 mm (0.004 -> 0.02 in) thickness the area enclosed by the contour is 1.9 ha (4.6 ac) for the west and 1.1 ha (2.6 ac) for the east. Based on the trench geometry for diver burial 90% of the entire west resuspension volume or 181.0 m^3 (6,394 ft^3) spread over the area enclosed by the silt curtain results in an average deposition thickness of 94 mm (3.71 in) while 90% of the entire partial east resuspension volume or 224.5 m^3 (7,927 ft^3) spread over the enclosed area results in an average deposition thickness of 110 mm (4.32 in). Larger thicknesses would be found closest to the burial routes (including in the trenches) and smaller thicknesses found closer to the silt curtains distant from the routes.

Stability of Deposited Sediments

A measure of the stability of deposited sediments to the seabed is a function of the erosion velocity for each grain size in the sediment. Since the freshly deposited sediment is unconsolidated, the fine grains (clay and silt) and sand are eroded at a velocity of about 20 cm/s (0.4 kt). Maximum tidal currents exceed this minimum speed across most of Little Bay except in the shallows very near the shore. Thus sediment particles deposited along much of the route will likely be resuspended on subsequent tides and dispersed from the areas initially affected by deposition.

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1 Introduction

Public Service of New Hampshire d/b/a Eversource Energy (PSNH) has proposed the construction of an electrical cable system to increase the reliability of the electrical transmission grid in southern New Hampshire. This cable, known as the Seacoast Reliability Project, would cross the Little Bay portion of the Great Bay Estuarine System as shown in Figure 1-1. The crossing would entail burial of three separate but parallel cable bundles by jet plowing, which is a technique that liquefies the sediment with high pressure water jets and simultaneously allows the cable to be buried at a predetermined depth. The cable sections in the shallow areas near the western and eastern landfalls will be buried by diver. The environmental consultant for the Project, Normandeau Associates, Inc. (Normandeau), contracted with RPS ASA to supply its modeling capabilities to simulate the jet plowing process along the cable route to determine both the likely suspended sediment concentrations generated in the water column above the cable route and the resulting re-deposition of the sediments in and along the route.

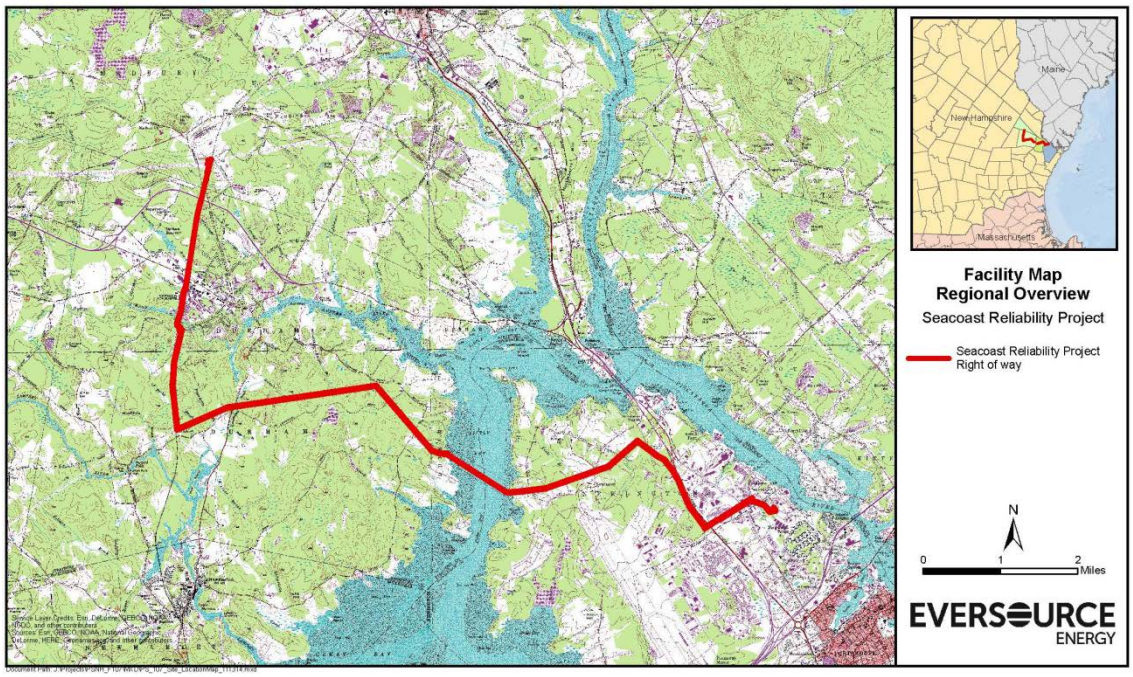

Figure 1-1. Location of the proposed cable route across Little Bay in the Great Bay Estuarine System (image from Normandeau Associates).

This report documents the hydrodynamic and sediment dispersion modeling activities performed to assess the effects from installation of the electrical cable using jet plowing and diver burial. Specifically, Section 1 provides an introduction to the effort by RPS ASA documented in the report, Section 2 presents the hydrodynamic modeling performed, and Section 3 presents the sediment dispersion modeling performed. Section 4 consists of conclusions drawn from the study and references are listed in Section 5.

2 BELLAMY Hydrodynamic Model

2.1 Model Description

A computer model system developed at Dartmouth College and previously applied by RPS ASA to the Great Bay Estuarine System (GBES) (McLaughlin et al. 2003) was used in this analysis and was based on the recent work of Swanson et al. (2014). The model system includes a finite element, two-dimensional, vertically averaged, time stepping circulation model. The circulation model, known as BELLAMY, can calculate the time varying surface elevation and currents under the influence of tides, winds and river flow on a model domain discretized by a large number of finite element triangles. Due to the fact that Great Bay is tidally dominated (currents up to 2 m/sec) and much of it consists of narrow channels in which the tidal currents mostly flow in flood and ebb directions, the effect of wind is expected to show only in areas with relatively larger wet surface areas such as Great Bay proper and not Little Bay where the cable burial will occur. The model includes simulation of wetting and drying of tidal flats.

All simulation parameters were set to be consistent with previously published work. The reader is referred to Swanson et al. (2014), Bilgili et al. (2005) and McLaughlin et al. (2003) for more detailed information. Sensitivity analyses previously reported are the basis for some of the values chosen. Some key assumptions and resulting parameter values are summarized as follows:

- The model domain consists of the entire GBES plus a stretch of the coastal Atlantic Ocean extending from Portland, ME, in the north to the tip of Cape Ann, MA, in the south to incorporate the effect of the Gulf of Maine coastal current. The Little Bay region is shown in Figure 2-1 between the Lower Piscataqua River-North to the east and Great Bay to the south.
- Tidal forcing used the constituent set of M2, N2, S2, O1, K1 and Z0 as described in previously published work (Bilgili et al. 2005).
- No wind forcing was applied to be consistent with previous studies, which showed the wind effect is short term and minimal, particularly since the modeling focused on steady state conditions.
- The model includes annually averaged freshwater discharges from the major rivers as constant values (Bilgili et al. 2005). The effect of time varying discharges is not investigated due to the fact that the total freshwater volume entering the estuary is less than 2% of the tidal prism (Reichard and Celikkol, 1978). The yearly averaged discharges from the WWTF outfalls are also incorporated as constants since these are considered as additional fresh water sources (Trowbridge, 2009).
- The internal hydrodynamic model time step was 99.36 seconds with model predicted velocities output on a 30 min interval. The model was run to capture the 15-day spring-neap cycle.

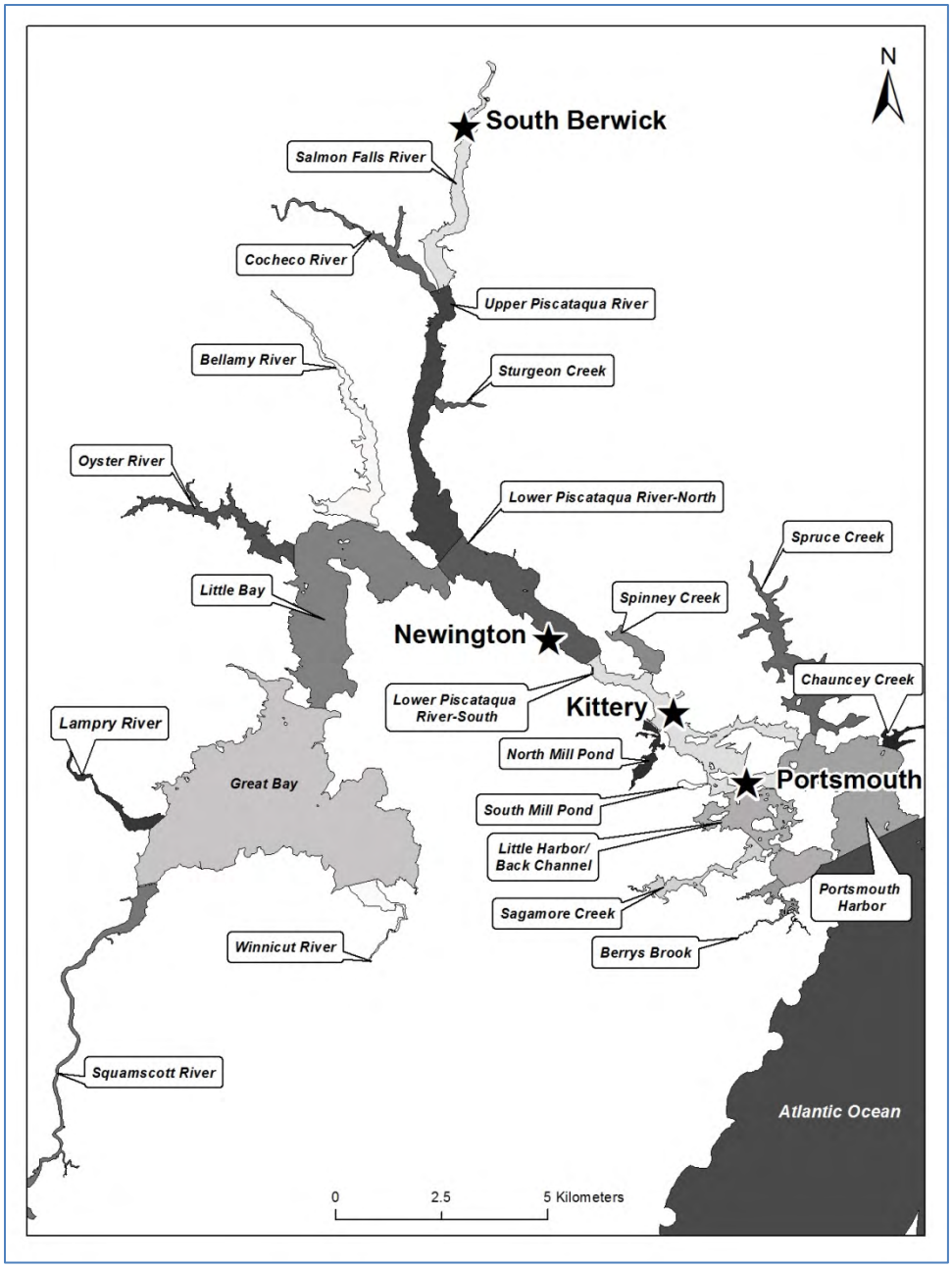

Figure 2-1. Great Bay Estuarine System regions used for previous modeling (Swanson et al., 2014). Little Bay is located in the central portion of the System.

BELLAMY has been tested and calibrated extensively in the Great Bay estuary over the past two decades (Ip et al. 1998; Erturk et al. 2002; McLaughlin et al. 2003; Bilgili et al. 2005). One quantitative statistical measure indicating how well the model reproduces observed currents is "skill", with 0 indicating no match to data and 1 indicating perfect match with data. McLaughlin et al. (2003) report a mean skill of 0.918 while the Bilgili et al. (2005) work improves this to 0.942 for cross-section averaged current velocity comparisons. Point velocity comparisons also show good fit (McLaughlin et al. 2003; Bilgili et al. 2005), especially considering the inherent variability in this type of measurements.

2.2 Model Results

As noted above the current velocities to be used to disperse the excess suspended sediment were based on previous hydrodynamic modeling of the Great Bay System. Example current vectors for flood and ebb tides in lower Little Bay are shown in Figures 2-2 and 2-3. The vectors are scaled as displayed in the window in the upper left portion of the figures. The line shown across the Bay is a representative approximation of the route of the cables. The strength of the currents is similar in both flood and ebb directions at about 50 cm/s (1 kt) except at the shallow areas located on both sides of the Bay where the currents are reduced.

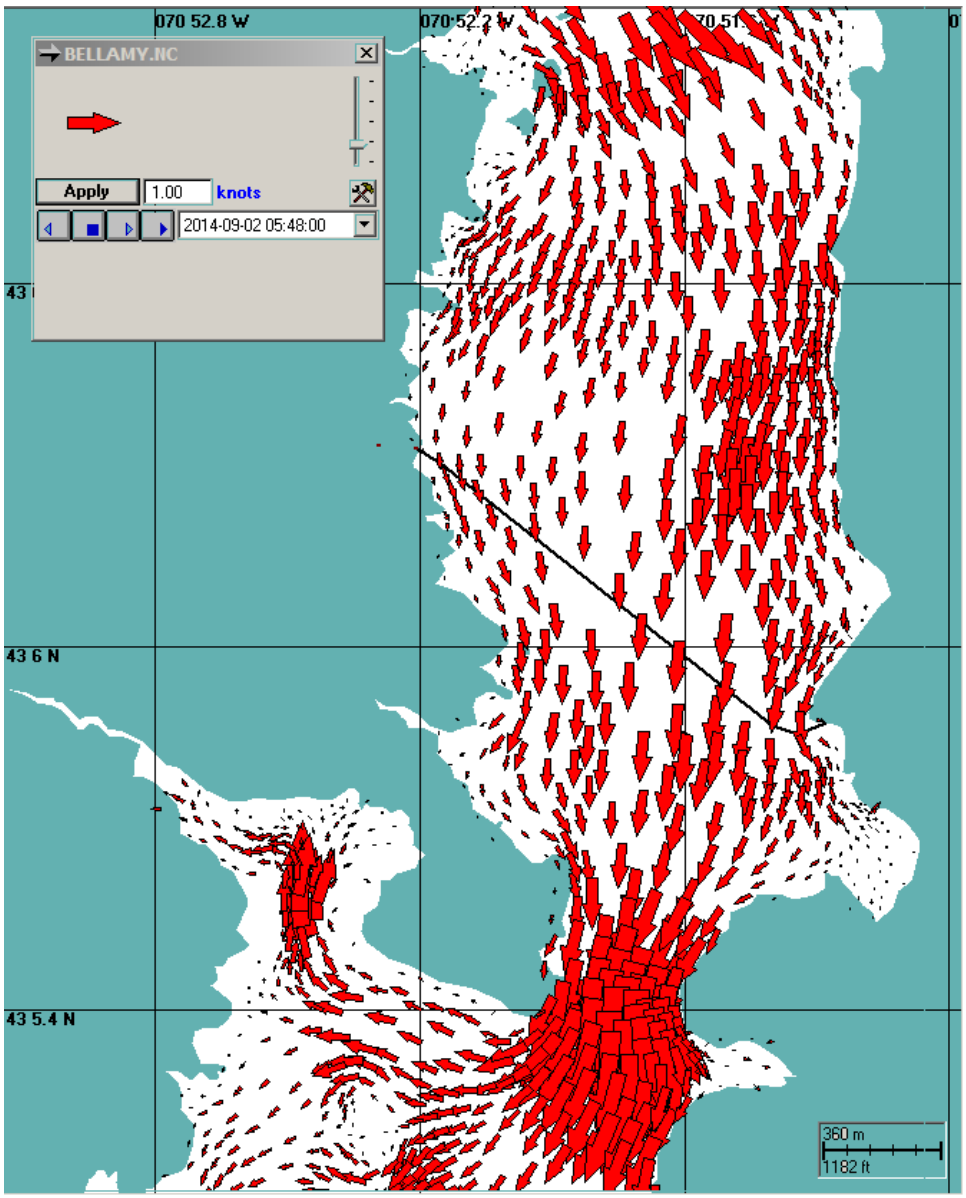

Figure 2-2. Example flood tide currents for lower Little Bay with the solid black line indicating the approximate cable route.

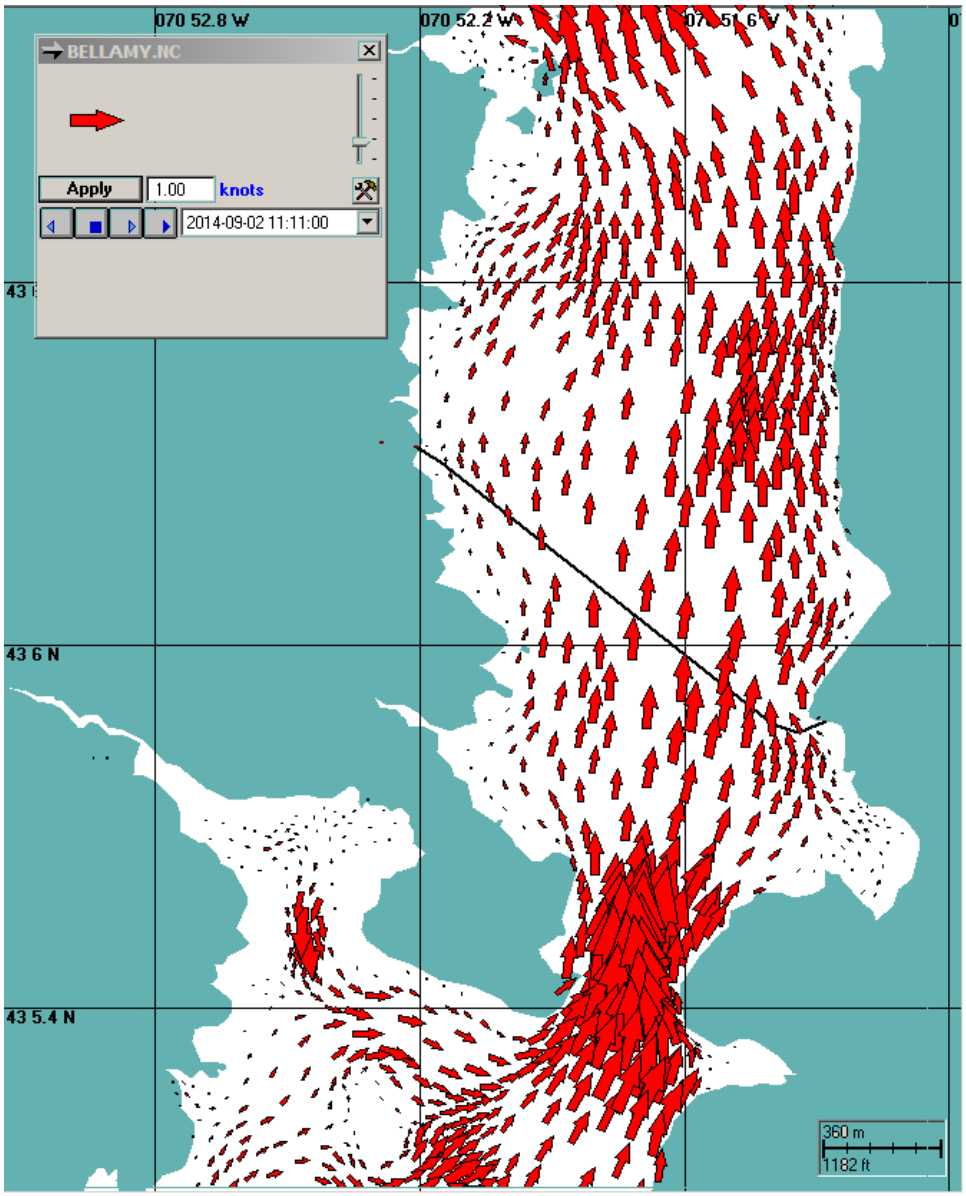

Figure 2-3. Example ebb tide currents for lower Little Bay with the solid black line indicating the approximate cable route.

3 SSFATE Sediment Dispersion Model

3.1 Model Description

The SSFATE (Suspended Sediment FATE) model was utilized to predict the excess suspended sediment concentration and the dispersion of suspended sediment resulting from jetting and diver activities. SSFATE addresses the short term movement of sediments where sediment is introduced into the water column and predicts the path and fate of the sediment particles using the local currents. Excess concentration is defined as the concentration generated by the jetting or diver activities above ambient suspended sediment concentration. In addition SSFATE calculates the resulting deposition thickness of resuspended sediments that have resettled back on the bottom.

SSFATE was jointly developed by ASA and the U.S. Army Corps of Engineers (USACE) Environmental Research and Development Center (ERDC) to simulate the sediment suspension and deposition from jetting operations. It has been documented in a series of USACE Dredging Operations and Environmental Research (DOER) Program technical notes (Johnson et al. 2000 and Swanson et al. 2000); at a previous World Dredging Conference (Anderson et al. 2001) and a series of Western Dredging Association Conferences (Swanson et al., 2004; Swanson and Isaji, 2006). A number of ASA technical reports have been prepared that demonstrate successful application to dredging. In addition SSFATE has been extended to include the simulation of dredged material disposal as well as cable and pipeline burial operations using water jet plows (Swanson et al., 2006; Mendelsohn et al., 2012), diver activities and mechanical plows.

The SSFATE modeling system computes suspended sediment distributions and deposition patterns resulting from various seabed activities. The suspended sediment concentrations are computed in three dimensions while the depositional patterns are computed in two dimensions. The model contains the following features:

- Ambient currents can be imported from a variety of numerical hydrodynamic models;
- The procedure which is a standard numerical approach that mimics the mixing of sediment within the water column due to turbulence;
- SSFATE simulates suspended sediment source strength and vertical distribution from mechanical (e.g., clamshell, long arm excavator) or hydraulic (e.g., cutterhead, hopper) dredges; and water jet plows, divers and mechanical plows;
- SSFATE assumes a continuous release of sediments over time, and calculates average excess sediment concentrations within each grid cell (minimum cell dimension of 10 to 25 m) at each time step;
- Multiple sediment types (different grain sizes) or fractions can be simulated simultaneously;
- SSFATE output consists of excess suspended sediment concentration contours in both horizontal and vertical planes, time series plots of concentrations, and the spatial distribution of sediment deposited on the sea floor.

In far field calculations the mean transport and turbulence associated with ambient currents dominate the distribution of the sediment particles. SSFATE, a particle-based model, predicts the transport and dispersion of the suspended material generated by seabed activities. Particle advection (i.e., transport) is based on the simple relationship that a particle moves linearly with

a local velocity, obtained from the hydrodynamic model, for a specified model time step. Particle diffusion (i.e., dispersion) is assumed to follow a simple random walk process frequently used in simulating the dispersion of particles.

The particle model allows the user to predict the transport and dispersion of the different size classes of particles e.g., sands, silts, and clays. The particle-based approach is extremely robust and independent of the grid spacing. Thus, the method is not subject to artificial diffusion near sharp concentration gradients and is easily interfaced with all types of sediment sources including dredging, jet plowing, and backfilling operations.

In addition to transport and dispersion, sediment particles also settle at some rate through the water column to the bottom. Settling of mixtures of particles, some of which may be cohesive in nature, is a complex but predictable process with the different size classes interacting, i.e., the settling of one particle size is not independent of the other sizes. In addition, the clay-sized particles, typically cohesive, undergo enhanced settling due to flocculation. These processes have been implemented in SSFATE using empirically based formulations based on previous USACE studies (Teeter, 1998).

At the end of each time step, the concentration of each sediment class, as well as the total concentration, is computed on a concentration numerical grid. The size of all grid cells is the same, with the total number of cells increasing as the excess suspended sediment moves away from the source. The settling velocity of each particle size class is computed along with a deposition probability based on shear stress. Finally, the deposition of sediment from each size class from each bottom cell during the current time step is computed and the calculation cycle begins anew. Deposition is calculated as the mass of sediment particles that accumulate over a unit area.

Outputs from the model are sediment concentrations for each grid cell and deposition thickness for each grid cell that shares a boundary with the bottom of the river or bay. Concentrations and thicknesses are available for every time step during the period that the model is run.

3.2 Seabed Sediment Characterization

The sediment grain size information was extracted from vibracore data logs taken during a survey for the project in April 2014 by Normandeau (personal communication). The survey consisted of 12 sampling stations shown in Figure 3-1. The qualitative descriptions of each vibracore sediment sample were converted into fractions of sand, silt and clay based on a classification scheme presented by Flemming (2000). The classification scheme uses a ternary diagram where text descriptions of sediment texture (for example, “silty sand”), as summarized in Table 3-1, are mapped onto the diagram and assigned a sand-silt-clay ratio. If a vibracore contained only one sediment sample, the ratio obtained from the diagram defined the size fractions used in the SSFATE model simulations (Table 3-2). If more than one sediment sample was taken from a vibracore, a composite of the size fractions was calculated based on the relative quantities each sample contributed to the whole. Since the SSAFTE classification scheme divides silt into medium-fine and fine silt, the silt fraction obtained from the ternary diagram was equally divided.

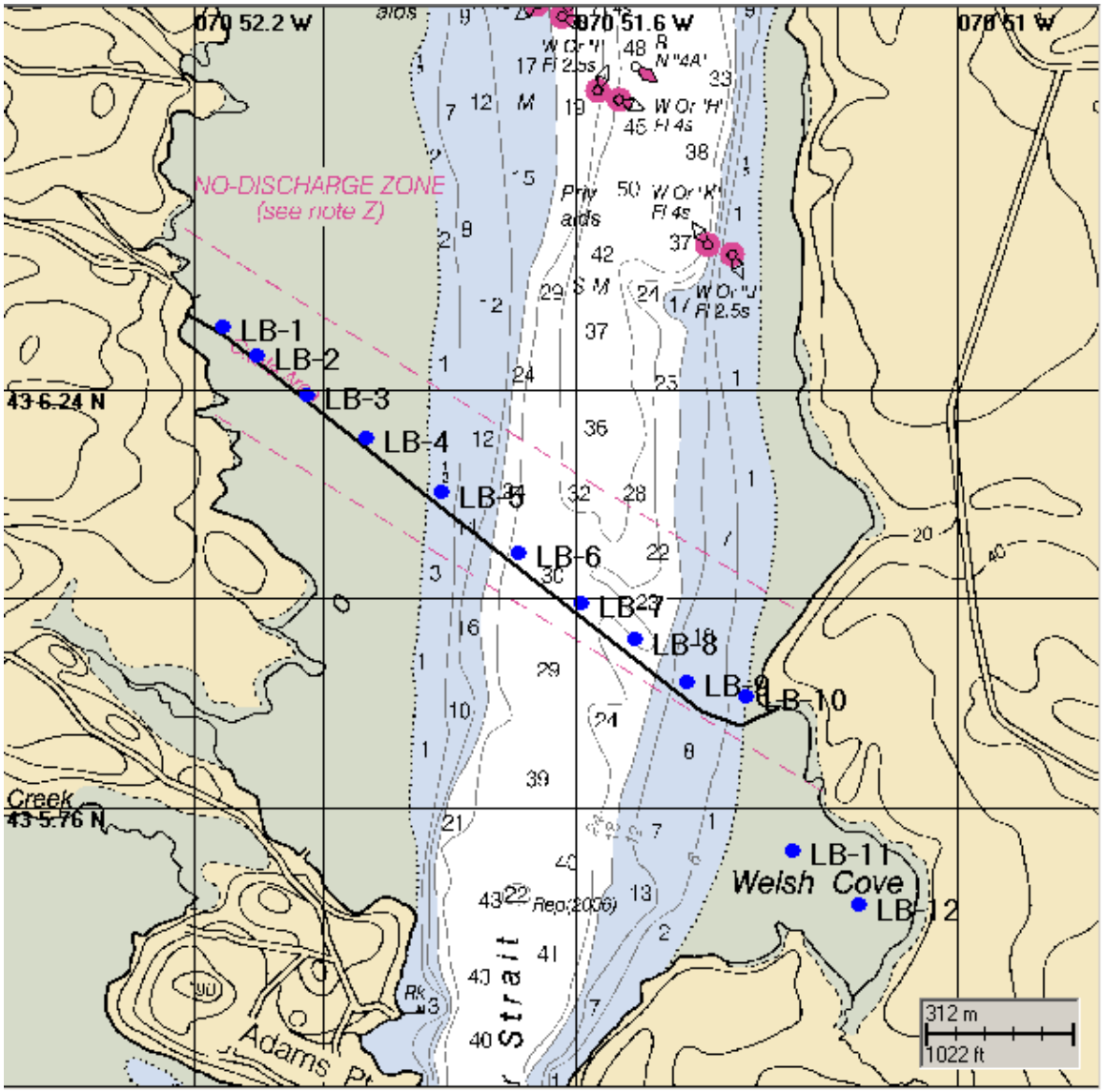

Figure 3-1. Location of vibracore borings across Little Bay along route of cable crossing (indicated by solid line).

Table 3-1 summarizes the vibracore data logs by location across the Bay from tidal flats at the western shore to Welsh Cove at the eastern shore, the Station number, penetration depth and sediment description. Table 3-2 and Figure 3-2 show the resulting sediment grain size distributions for each boring.

Table 3-1. Qualitative description of sediments along cable route from vibracore data logs from survey conducted in April 2014.

Zone	Station	Penetration Depth	Sediment Description
Tidal Flat (west)	LB-1-A	94”	Cohesive Clay with silt
	LB-2-B	104”	
	LB-3-B	104”	
	LB-4-A	120”	Cohesive Clay with silt and trace of fine sands
	LB-5-B	86”	
Channel	LB-6-A	44”	Cohesive Fine to medium sand with small amount of clay and silt
	LB-7-B	63”	0-19”: Cohesive Fine to medium sand with small amount of clay and silt
			19-63”: cohesive Clay with silt
	LB-8-B	29”	0-15”: cohesive Fine to medium sand with small amount of clay and silt
			15-22”: cohesive Fine sand and clay, shell fragments present
			22-29”: cohesive Clay
Slope	LB-9-A	97”	0-22”: cohesive Fine to medium sand with small amount of clay and silt
			22-97”: cohesive Clay with silt, minor shell fragments throughout
Tidal Flat (east)	LB-10-D	44”	Cohesive Fine to medium sand with small amounts of clay

Zone	Station	Penetration Depth	Sediment Description
Welsh Cove	LB-11-B	103”	Cohesive Clay and fine sand with silt
	LB-12-B	46”	0-18”: cohesive Clay and fine sand with silt
			Cohesive Fine to medium sand with little clay and silt; minor amount of wood debris and shell fragments

Table 3-2. Grain size distributions (in percent) for vibracore stations (composited over vertical).

CORE	Coarse Sand	Fine Sand	Med Fine Silt	Fine Silt	Clay
LB-1-A	0.00	0.00	10.00	10.00	80.00
LB-2-B	0.00	0.00	10.00	10.00	80.00
LB-3-B	0.00	0.00	10.00	10.00	80.00
LB-4-A	0.00	5.00	7.50	7.50	80.00
LB-5-B	0.00	5.00	7.50	7.50	80.00
LB-6-A	9.00	81.00	2.50	2.50	5.00
LB-7-B	1.78	16.03	10.52	10.52	61.15
LB-8-B	1.41	17.03	2.32	2.32	76.93
LB-9-A	2.06	18.56	10.21	10.21	58.96
LB-10-D	9.00	81.00	2.50	2.50	5.00
LB-11-B	0.00	20.00	2.50	2.50	75.00
LB-12-B	7.31	69.56	2.50	2.50	18.13

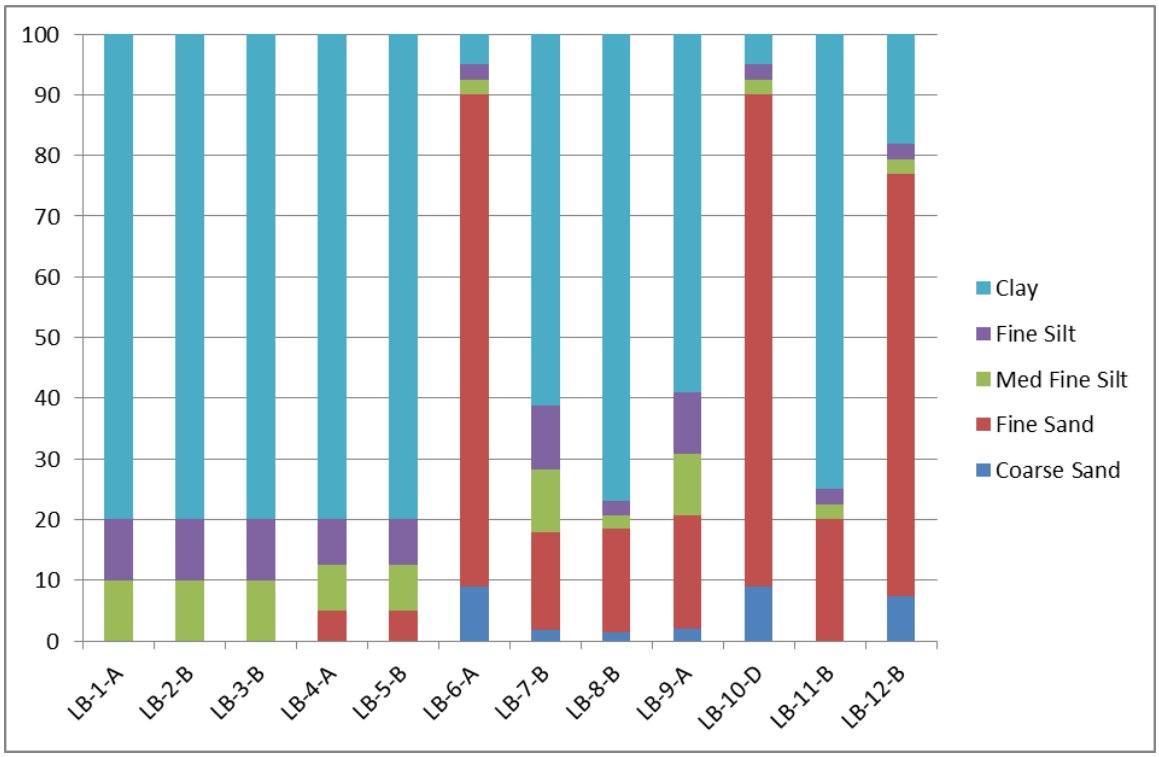

Figure 3-2. Histogram of grain size distributions (in percent) for vibracore stations in Little Bay.

The first five cores exhibit a large fraction (80%) of clay with smaller fractions of fine silt, medium fine silt and fine sand. In contrast cores LB-6-A and LB-10-D show 81% fine sand followed by LB-12-B with 70% fine sand, all within a range of 7 to 9% coarse sand. Cores LB-7-B, LB-8_B, LB-9-A and LB-11-B show clay fractions between 59 and 77% clay and between 16 and 20% fine sand. In general the cores with higher fines fractions will tend to generate larger suspended sediment plumes while those with higher sand fractions smaller plumes.

3.3 Model Input Parameters

The details of the planned route across Little Bay are shown in Figure 3-3 with the upper panel showing the western half of the route and the lower panel showing the eastern half. The three angled parallel lines represent the jet plow portion of the crossing for the three bundled cables with a separation of 9.4 m (30 ft). The western and eastern ends connecting the jet plowing portions to the land are represented by non-parallel routes ending at the shore which use diver burial.

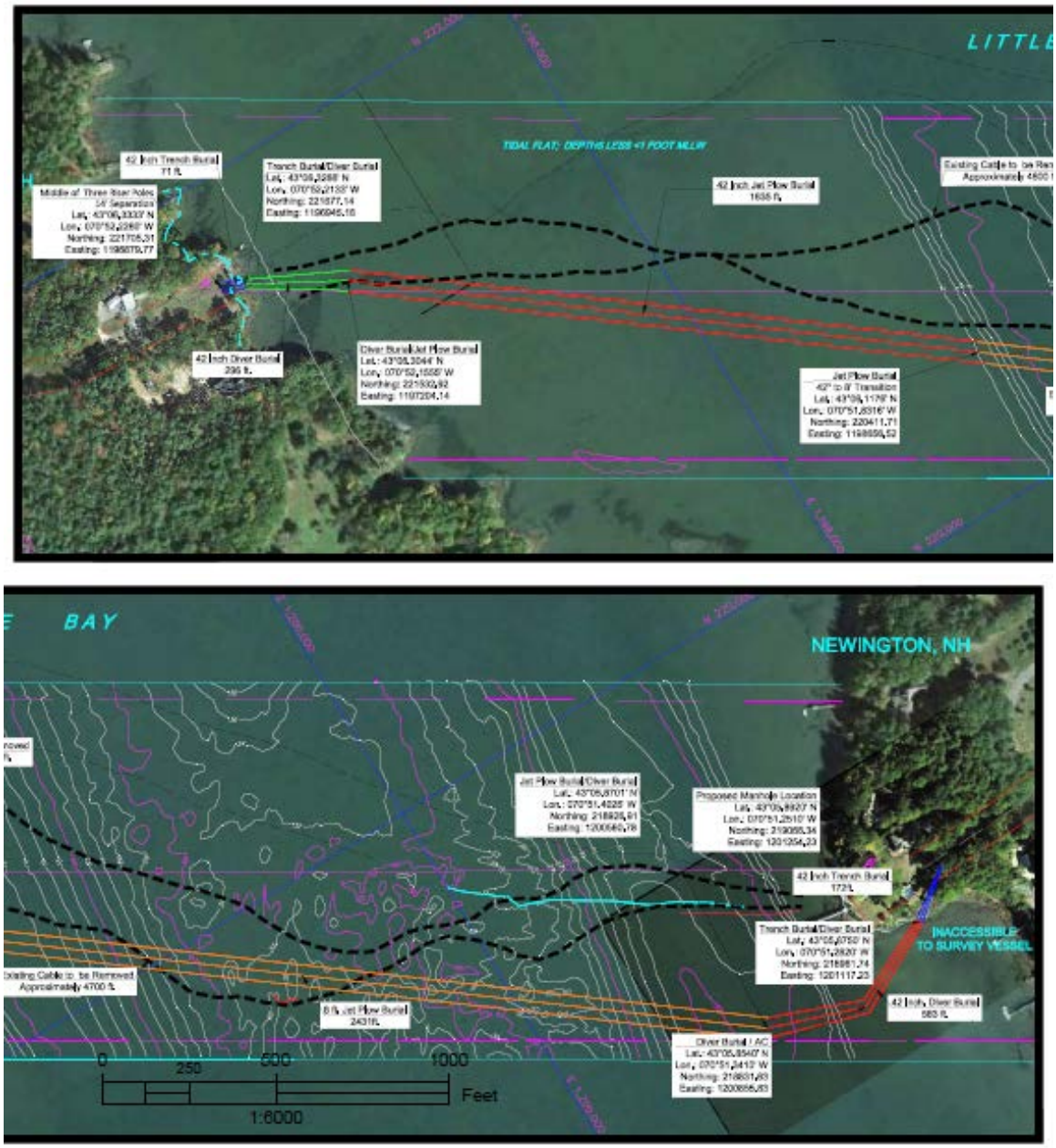

Figure 3-3. Details of proposed cable routes across Little Bay developed by Caldwell (Rev 6 Issue 01 – 20150424). Upper panel shows western half and lower panel shows eastern half.

3.3.1 Jet Plow Burial

The jet plow rate of advance was provided by the cable installer, Caldwell Marine International, LLC to be 100 m/hr (328 ft/hr). The central cable route among the three cable bundles crossing Little Bay was chosen for modeling since the cables are to be separated by only 9.4 m (30 ft).

The cables are to be buried by jet plowing to minimum depths of 1.07 m (42 in) deep in the shallows on the western but offshore section of Little Bay and 2.44 m (8 ft) in the center and east sections. For ease of discussion, this report refers to the jet plow disturbance as a trench

although while the jet plow will be occupying a three-dimensional space, the "trench" is very temporary as it will fill in immediately behind the jet plow. The total depth of the trench included the minimum burial depth plus the cable diameter of 0.15 m (6 in) and an overage of 0.20 m (8 in) totaling 1.42 m (96 in) for the western section and 2.79 m (110 in) for the central and eastern sections. Based on Caldwell's specification the vertical-walled trench width was defined as 0.32 m (12.75 in) resulting in a trench cross sectional area of 0.46 m^2 (5.0 ft^2) in the shallow western portion and an area of 0.90 m^2 (9.7 ft^2) in the deeper central and eastern portions. The length of the each trench was defined by Caldwell to be 559 m (1,835 ft) for the shallow burial and 741 m (2,431 ft) for the deeper burial. The model run was started on the west side of Little Bay at slack high water which is the beginning of the ebb tide.

It was assumed that 25% of the material in the trench would be resuspended into the water column by the jetting activity. This is a conservative estimate consistent with previous studies that found a range of 10 to 35% (Foreman, 2002). Caldwell indicated that the jet plow technology they will be using generates significantly lower resuspension rates, closer to about 10%.

Table 3-3 summarizes the trench dimensions and SSFATE input parameters used in the jet plow simulation.

Table 3-3. Summary of trench dimensions and SSFATE input parameters for the jet plow portion of the cable burial simulation.

Parameter	Shallow Jet Plow Burial	Deep Jet Plow Burial
Cable burial depth	1.07 m 3.50 ft	2.44 m 8.00 ft
Cable diameter	0.15 m 0.5 ft	0.15 m 0.5 ft
Overage amount	0.2 m 0.67 ft	0.2 m 0.67 ft
Total trench depth	1.42 m 4.67 ft	2.79 m 9.17 ft
Trench width	0.32 m 12.75 in	0.32 m 12.75 in
Trench cross sectional area	0.46 m^2 4.96 ft^2	0.90 m^2 9.7 ft^2
Route distance	559 m 1835 ft	741 m 2431 ft
Advance Rate	100 m/hr 328 ft/hr	100 m/hr 328 ft/hr
Duration	5.6 hr	7.4 hr
Timing	Start at high slack	Continue after shallow portion
Resuspension Fraction	25% of trench volume	25% of trench volume

3.3.2 Diver Burial

The diver rate of advance was much slower than the jet plow at 2.3 m/hr (7.5 ft/hr). Again the central cable route among the three cable bundles crossing Little Bay was chosen for modeling since the cables are to be separated by a maximum of 9.4 m (30 ft) and decreased as they approached the landfalls.

The cables are to be buried by divers in trenches with a minimum depth of 1.07 m (42 in) deep in the shallows on both the western and eastern portions of Little Bay with lengths of 90 m (296 ft) in the western portion and 178 m (584 ft) in the eastern portion. The total depth of the trench included the minimum burial depth plus the cable diameter of 0.15 m (6 in) which equals 1.22 m (48 in). Based on Caldwell's specification the trench width was defined as 1.22 m (48 in) resulting in a trench cross sectional area of 1.49 m^2 (16.0 ft^2). The model run was started two hours before high slack water and continued for four hours due to diver requirements of working in lower currents and deeper water. It was also assumed, based on past experience, that 50% of the material in the trench would be resuspended into the water column by the diver activity. This rate is twice the rate for jet plowing because the technology used, high pressure water hoses, is expected to cause a higher resuspension rate. Modeling was done assuming that silt curtains would not be employed during the diver installation.

Table 3-4 summarizes the trench dimensions and SSFATE input parameters used in the diver portion of the simulation.

Table 3-4. Summary of trench dimensions and SSFATE input parameters for the diver portion of the single cable burial simulation.

Parameter	West Diver Burial	East Diver Burial
Cable burial depth	1.07 m 3.50 ft	1.07 m 3.50 ft
Cable diameter	0.15 m 0.5 ft	0.15 m 0.5 ft
Total trench depth	1.22 m 4.00 ft	1.22 m 4.00 ft
Trench width	1.22 m 4.00 ft	1.22 m 4.00 ft
Trench cross sectional area	1.49 m^2 16.0 ft^2	1.49 m^2 16.0 ft^2
Route distance	90 m 296 ft	178 m 583 ft
Advance Rate	2.29 m/hr 7.5 ft/hr	2.29 m/hr 7.5 ft/hr
Duration	4 hr/day for 9.9 days	4 hr/day for 19.4 days
Timing	Start at 2 hrs before high slack	Start at 2 hrs before high slack
Resuspension Fraction	50% of trench volume (no silt curtains used)	50% of trench volume (no silt curtains used)

3.4 Model Results

3.4.1 Jet Plow Results

3.4.1.1 Water Column Concentrations

The total duration of the cable burial by jet plowing is 13 hours based on an average advance rate of 100 m/hr (328 ft/hr) and a route distance of 1,300 m (4,266 ft) (see Table 3-3). To best display the resulting water column concentration a series of figures were generated for each hour of the crossing resulting in 13 "snapshots" of the submerged plume at that time. Figures 3-4 through 3-7 shows the plan view of the predicted instantaneous excess SS concentration in 1-hr increments after the start of jet plowing at high slack tide with four panels shown per page. The submerged SS concentration plume extends north of the cable route for hours 1 through 7 indicating an ebb condition and south of the route for hours 8 through 13 indicating a flood condition. The water column concentration contours shown, which are defined by a single concentration level, totally surround an enclosed area where concentrations are at or above the specified concentration, i.e., the area is cumulative. Thus the areas with higher concentrations must be smaller than areas with lower concentrations since those areas are enclosed within the lower concentration contour.

The contours show a decreasing concentration away from the immediate location of the jet plow on the cable route as material dilutes and settles out. The colored contours can be identified from the legend in the upper left corner of each panel showing concentrations from 10 mg/L and higher. A larger SS concentration legend is shown in the upper left panel of Figure 3-4.

A vertical section view defined along the cable route looking north is inserted at the bottom left of each hourly panel. The insert shows that the highest concentrations occur just above the jet plow near the bottom with reduced concentrations extending up into the water column above the plow. In the shallows, suspended sediments from the jet plow activity are likely to reach nearly to the water surface. In the channel, excess suspended sediments will be restricted to the lower half of the water column.

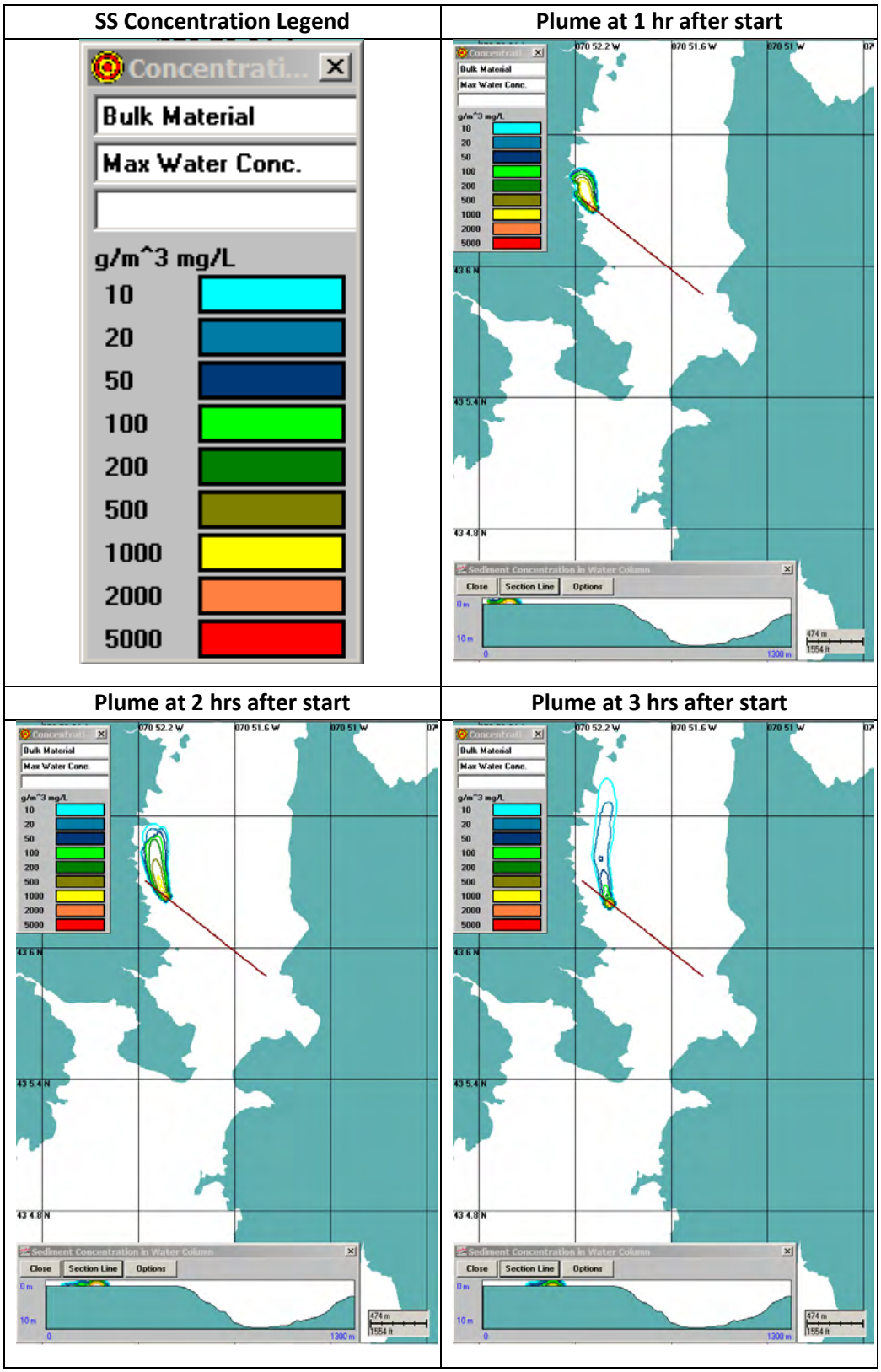

Figure 3-4. Plan view of instantaneous excess SS concentrations at 1 through 3 hrs after start of jet plowing. Vertical section view at lower left of each panel.

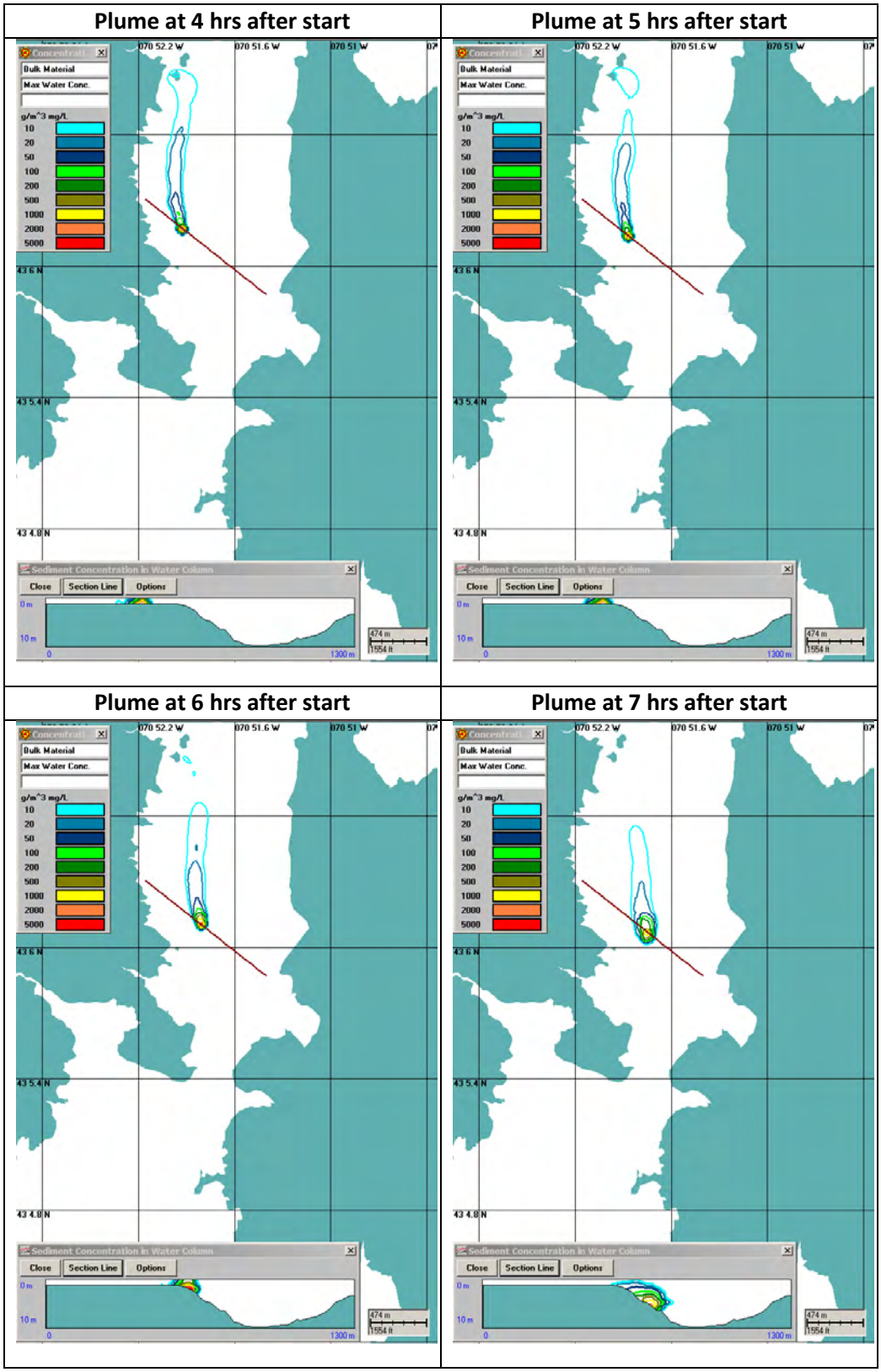

Figure 3-5. Plan view of instantaneous excess SS concentrations at 4 through 7 hrs after start of jet plowing. Vertical section view at lower left of each panel.

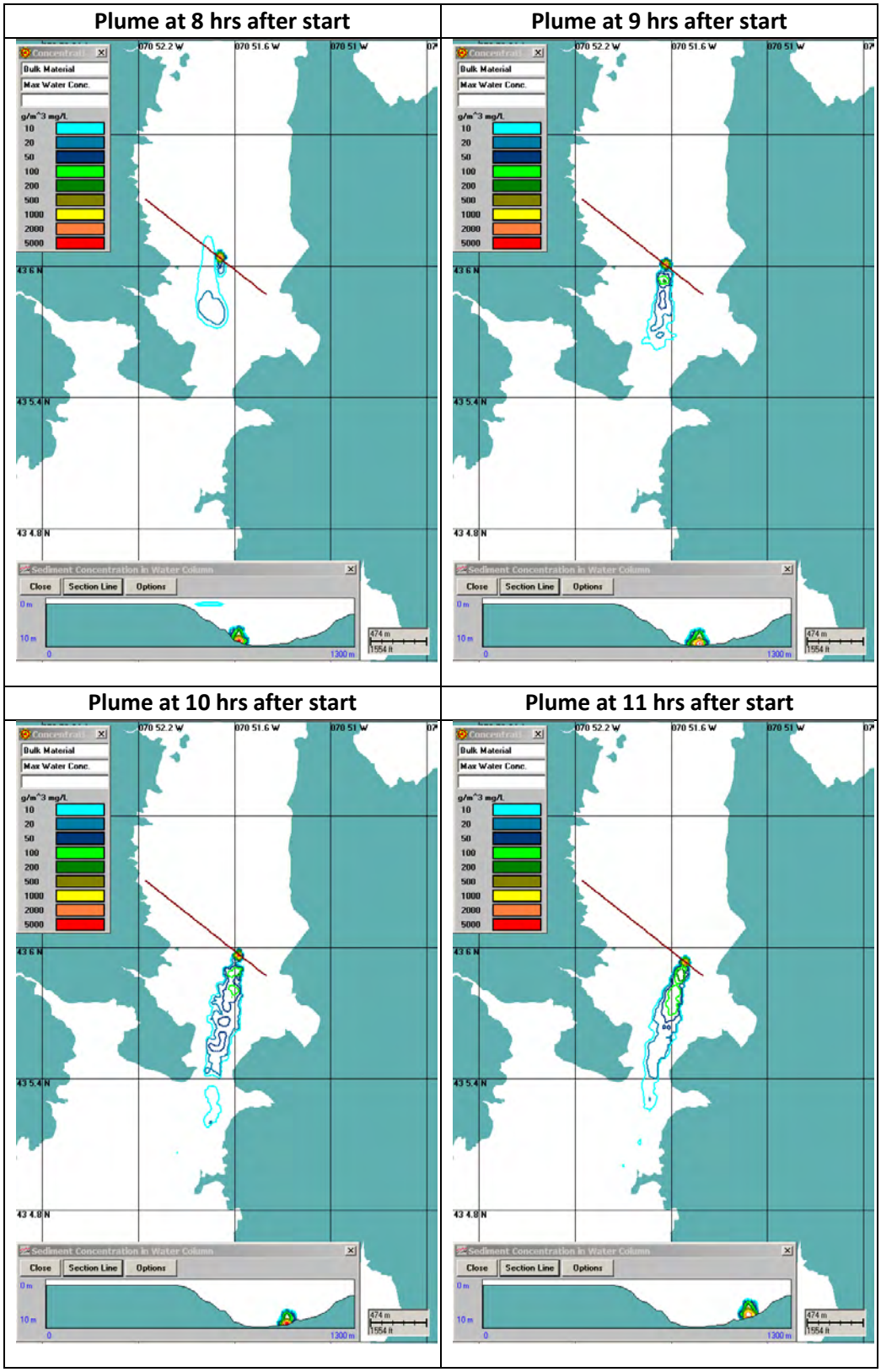

Figure 3-6. Plan view of instantaneous excess SS concentrations at 8 through 11 hrs after start of jet plowing. Vertical section view at lower left of each panel.

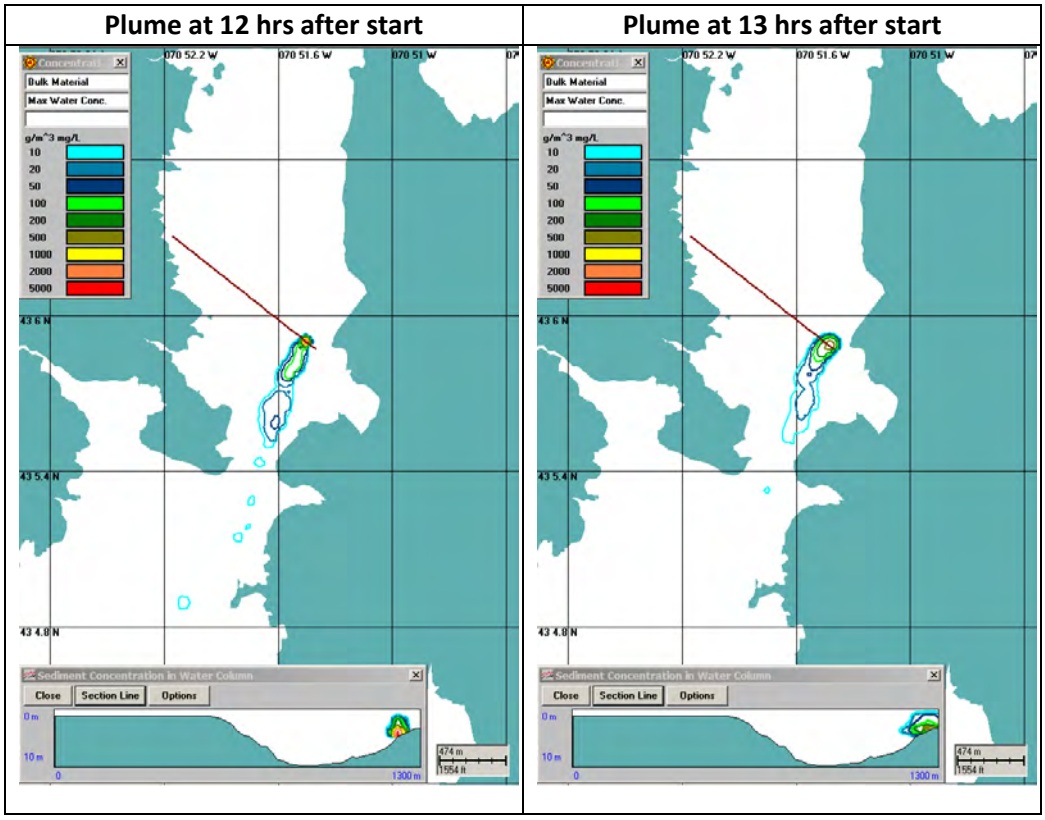

Figure 3-7. Plan view of instantaneous excess SS concentrations at 12 through 13 hrs after start of jet plowing. Vertical section view at lower left of each panel.

Since the currents are smaller right after slack water, the extent of the plume is smaller for hrs 1 and 2. The plume is at its greatest northern extent for hrs 4, 5, and 6. By hr 8 the tide has turned and the plume reaches its maximum southern extent by hrs 10, 11, and 12.

The instantaneous total enclosed area of the excess SS concentration plumes seen in Figures 3-4 through 3-7 is quantitatively summarized in Tables 3-5 (in area units of hectares) and 3-6 (in units of acres) for each 1-hr increment identified at the top of each figure panel. On average the entire area encompassed by the plume (as defined by the 10 mg/L excess SS concentration contour) was 14.8 ha (36.58 ac), ranging from a low of 5.91 ha (14.61 ac) at 1 hr to a high of 22.36 ha (55.25 ac) at 10 hrs. These total enclosed areas dropped dramatically for the higher concentrations, averaging 1.94 ha (4.79 ac) at 100 mg/L, 0.28 ha (0.68 ac) at 1,000 mg/L and 0.02 ha (0.05 ac) at 5,000 mg/L. indicating that the extent of the plume is limited for higher concentrations.

Table 3-5. Summary of the total area (hectares) enclosed by the excess SS threshold concentration contours shown in Figures 3-4 through 3-7 due to jet plowing. Hours start at high slack tide.

TSS (mg/L)	Area (ha) 1 hr Ebb	Area (ha) 2 hr Ebb	Area (ha) 3 hr Ebb	Area (ha) 4 hr Ebb	Area (ha) 5 hr Ebb	Area (ha) 6 hr Ebb	Area (ha) 7 hr Ebb
10	5.91	11.66	14.42	18.73	16.77	15.38	15.14
20	5.47	9.55	8.43	7.59	7.23	5.91	5.99
50	4.55	7.59	2.24	2.08	1.68	1.96	2.64
100	3.87	6.43	0.88	0.64	0.72	1.24	1.84
200	3.16	4.59	0.28	0.28	0.44	0.72	1.24
500	2.32	1.92	0.20	0.20	0.20	0.48	0.32
1000	1.44	0.44	0.20	0.20	0.20	0.28	0.08
2000	0.08	0.04	0.04	0.04	0.04	0.08	0.04
5000	0.00	0.00	0.04	0.00	0.00	0.04	0.00

TSS (mg/L)	Area (ha) 8 hr Flood	Area (ha) 9 hr Flood	Area (ha) 10 hr Flood	Area (ha) 11 hr Flood	Area (ha) 12 hr Flood	Area (ha) 13 hr Flood	Area (ha) Average
10	13.62	11.30	22.36	20.13	13.74	13.26	14.80
20	4.95	5.99	15.14	14.22	9.07	7.71	8.25
50	0.52	2.24	5.63	5.75	3.44	3.24	3.35
100	0.32	0.80	1.36	3.36	1.84	1.92	1.94
200	0.16	0.28	0.20	0.72	0.28	1.28	1.05
500	0.16	0.20	0.16	0.20	0.20	0.32	0.53
1000	0.16	0.16	0.16	0.08	0.20	0.00	0.28
2000	0.04	0.04	0.04	0.04	0.04	0.00	0.04
5000	0.04	0.04	0.04	0.00	0.04	0.00	0.02

Table 3-6. Summary of the total area (acres) enclosed by the excess SS threshold concentration contours shown in Figures 3-4 through 3-7 due to jet plowing.

TSS (mg/L)	Area (ac) 1 hr Ebb	Area (ac) 2 hr Ebb	Area (ac) 3 hr Ebb	Area (ac) 4 hr Ebb	Area (ac) 5 hr Ebb	Area (ac) 6 hr Ebb	Area (ac) 7 hr Ebb
10	14.61	28.81	35.63	46.28	41.44	38.00	37.41
20	13.52	23.59	20.82	18.75	17.86	14.61	14.80
50	11.25	18.75	5.53	5.13	4.14	4.84	6.51
100	9.57	15.89	2.17	1.58	1.78	3.06	4.54
200	7.80	11.35	0.69	0.69	1.09	1.78	3.06

TSS (mg/L)	Area (ac) 1 hr Ebb	Area (ac) 2 hr Ebb	Area (ac) 3 hr Ebb	Area (ac) 4 hr Ebb	Area (ac) 5 hr Ebb	Area (ac) 6 hr Ebb	Area (ac) 7 hr Ebb
500	5.72	4.74	0.49	0.49	0.49	1.18	0.79
1000	3.55	1.09	0.49	0.49	0.49	0.69	0.20
2000	0.20	0.10	0.10	0.10	0.10	0.20	0.10
5000	0.00	0.00	0.10	0.00	0.00	0.10	0.00

TSS (mg/L)	Area (ac) 8 hr Flood	Area (ac) 9 hr Flood	Area (ac) 10 hr Flood	Area (ac) 11 hr Flood	Area (ac) 12 hr Flood	Area (ac) 13 hr Flood	Area (ac) Average
10	33.66	27.92	55.25	49.74	33.95	32.77	36.58
20	12.24	14.80	37.41	35.14	22.40	19.05	20.38
50	1.28	5.53	13.91	14.21	8.49	7.99	8.27
100	0.79	1.97	3.36	8.29	4.54	4.74	4.79
200	0.39	0.69	0.49	1.78	0.69	3.16	2.59
500	0.39	0.49	0.39	0.49	0.49	0.79	1.31
1000	0.39	0.39	0.39	0.20	0.49	0.00	0.68
2000	0.10	0.10	0.10	0.10	0.10	0.00	0.11
5000	0.10	0.10	0.10	0.00	0.10	0.00	0.05

The simulation was continued for an additional six hours after jet plowing was completed (hour 13 after the start of installation) to ensure that all residual concentrations had dissipated. Figure 3-8 showing the plan view of the maximum time-integrated excess SS concentration contours includes that additional post operational period. The time-integrated maximum concentration is generated from the model results by determining the highest concentration in each SSFATE grid cell which overlays Little Bay during the entire simulation. This plot shows only the maximum excess SS concentration integrated over time and would not be actually seen in the Bay (the results shown in Figures 3-4 through 3-7 are representative of what would be seen instantaneously). The advance rate is sufficiently slow that one sees the ebb-directed plume heading north on the west side of the Bay at the beginning of the simulation, then the flood-directed plume heading south in the center of the Bay and finally another ebb-directed plume heading north on the east side of the Bay (after the jetting operation has ceased and the plume is dissipating). The contours again show decreasing concentration from either side of the cable route with higher concentrations adjacent to the jet plow route.

A vertical section view defined by the jet plow route is shown at the bottom left of the figure. The highest concentrations, between 2,000 and 5,000 mg/L occur just above the bottom at the jet plow with reduced concentrations extending up into the water column along the route.

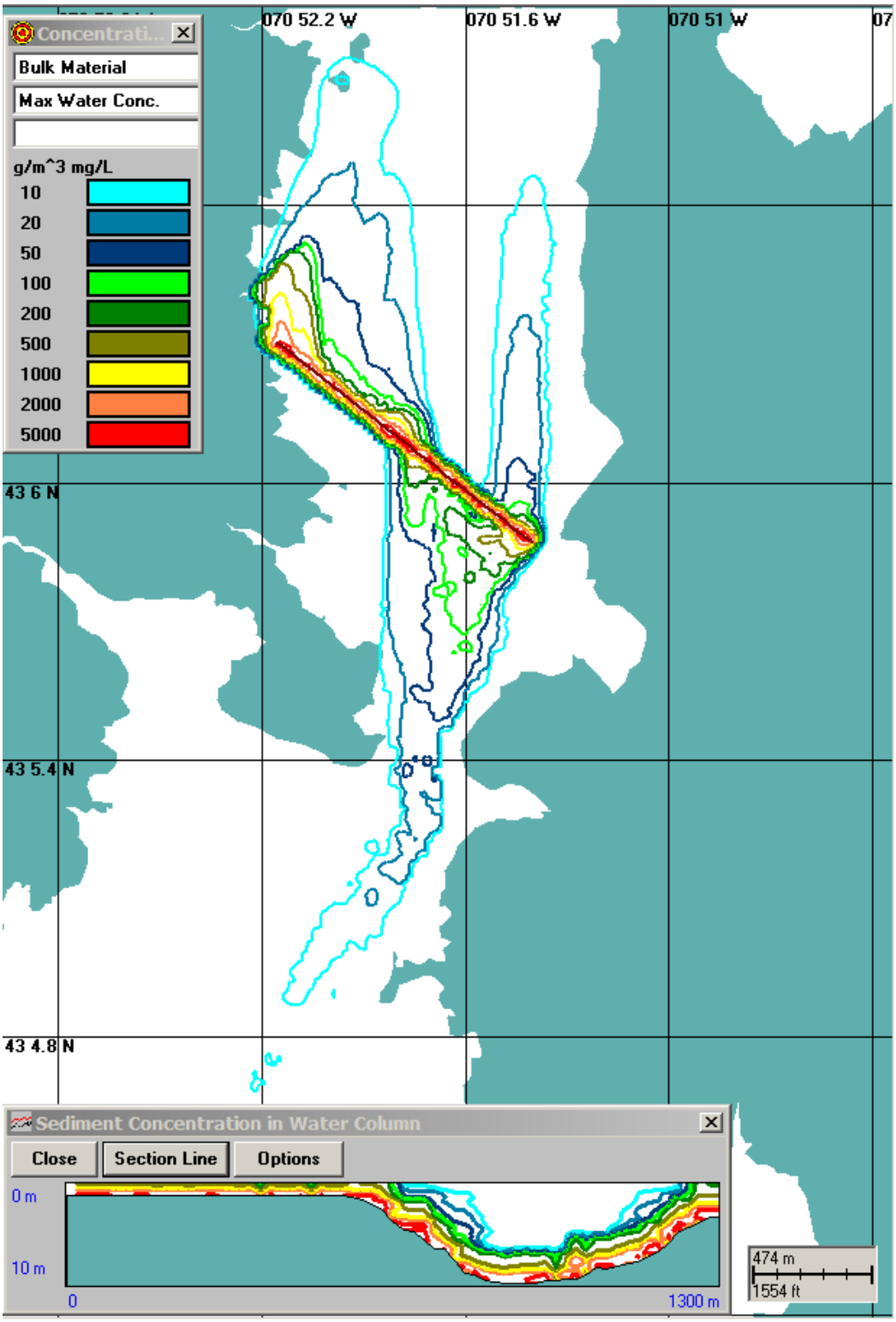

Figure 3-8. Plan view of maximum time integrated excess SS concentration contours over the entire jet plowing operation and the post operational period (while concentrations dissipate). Vertical section view at lower left.

Table 3-7 summarizes the total area enclosed by the maximum time-integrated excess SS concentration contours over the entire jet plowing operation and the post operational period (while concentrations dissipate) shown in Figure 3-8. This table shows that during the operation and post operational period an area of 165.1 ha (408.0 ac) sees a 10 mg/L concentration for a minimum of 5 minutes (the SSFATE model output timestep) but at different times during the simulation. The 5,000 mg/L time integrated enclosed area is 1.9 ha (4.6 ac) and is restricted to the area averaging about 14 m (46 ft) wide straddling the cable route and lasting only a short time.

Table 3-7. Summary of the total area (hectares and acres) enclosed by the maximum time-integrated excess SS concentration contours over the entire jet plowing operation and the post operational period (while concentrations dissipate) in Figure 3-8.

TSS (mg/L)	Area (ha)	Area (ac)
10	165.1	408.0
20	107.4	265.4
50	56.2	138.9
100	35.9	88.7
200	22.0	54.3
500	14.2	35.1
1000	9.3	23.1
2000	4.2	10.3
5000	1.9	4.6
10000	0.0	0.0

An important metric defining the plume is its duration for different concentrations, which could have biological significance if exposure (duration multiplied by concentration) is sufficiently elevated. Figure 3-9 and Table 3-8 summarize the area that experiences a specific exposure (duration at or above concentration) due to jet plow operations. Areas totaling 90.20 ha (222.89 ac), 32.2 ha (79.57 ac), 3.57 ha (8.82 ac) are exposed to a concentration of 10 mg/L or greater for 1 hr, 2 hrs and 4 hrs respectively while no areas are exposed to such a concentration for a duration of six hours; note that these areas are summations and not necessarily contiguous. The area coverages drop dramatically for the exposures of higher concentrations near the jet plow indicating that the duration and extent of the plume is relatively limited. Furthermore, once the jet plow stops operating, no additional sediments will be dispersed into the water column and concentrations above 10 mg/L dissipate within approximately 2 hrs (Figure 3-10).

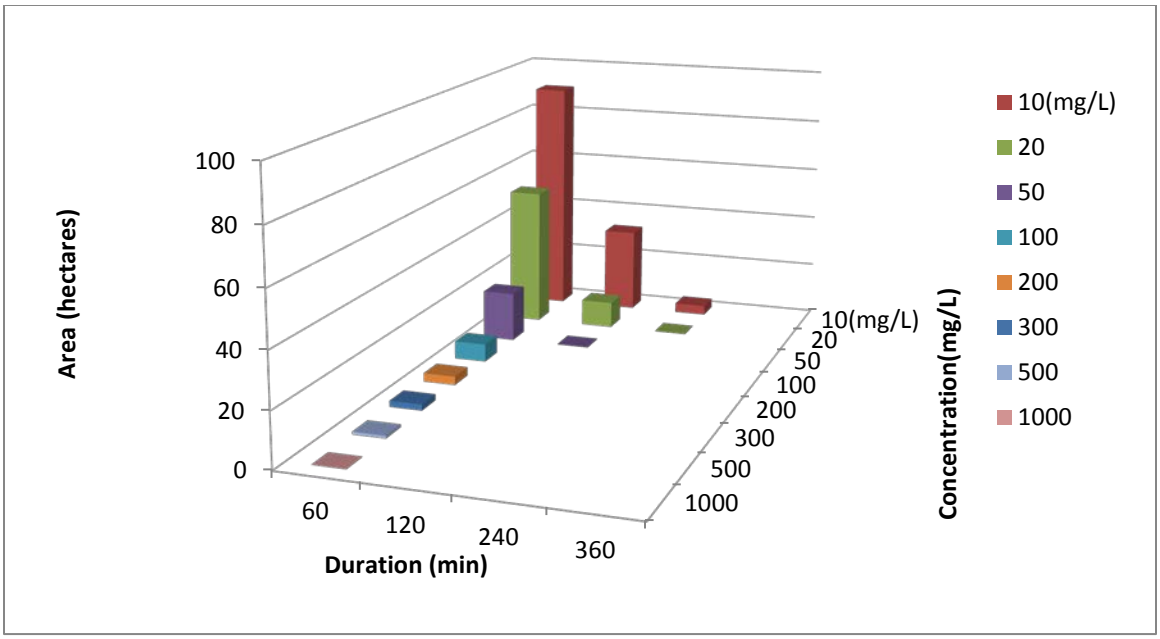

Figure 3-9. Duration (minutes) and total enclosed area (hectares) of maximum time integrated excess SS concentration contours over the entire jet plowing operation and the post operational period (while concentrations dissipate).

Table 3-8. Duration (minutes) and total enclosed area (hectares and acres) of maximum time integrated excess SS concentration contours over the entire jet plowing operation and the post operational period (while concentrations dissipate).

SS Concentration	Hectares				Acres			
	60	120	240	360	60	120	240	360
(mg/L)	(min)	(min)	(min)	(min)	(min)	(min)	(min)	(min)
10	90.20	32.20	3.57		222.89	79.57	8.82	
20	52.60	10.00	0.12		129.98	24.71	0.30	
50	18.70	0.16			46.21	0.40		
100	6.72				16.61			
200	3.20				7.91			
300	2.24				5.54			
500	1.04				2.57			
1000	0.08				0.20			

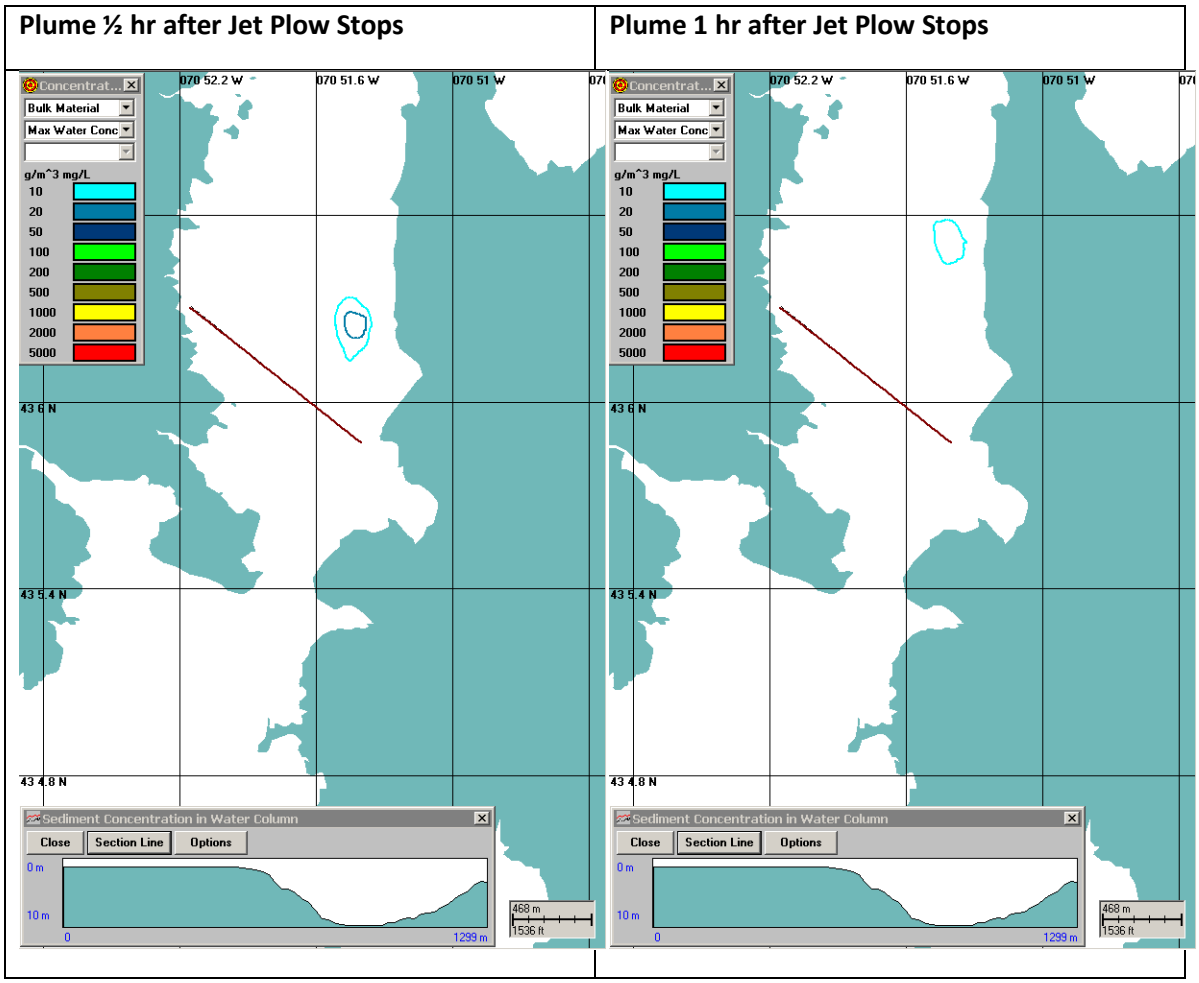

Figure 3-10. Plan view of instantaneous excess SS concentrations at 0.5 and 1 hour after cessation of jet plowing (13.5 and 14 hrs after start of jet plowing). Vertical section view at lower left of each panel.

3.4.1.2 Bottom Deposition

Figure 3-11 shows the plan view of the bottom deposition thickness distribution from 0.1 to 10 mm (0.004 to 0.4 in) due to jet plowing all three cable routes combined and assuming that any sediment deposited on the bottom remains in place. The color filled areas are defined by the legend for different deposition thickness ranges, e.g., 1 mm to 5 mm (0.04 to 0.2 in) denoted by yellow. In contrast to the water column concentration contours, which are defined by a single concentration value totally surrounding an enclosed area where concentrations are at or above the specified concentration (i.e., the area is cumulative), the bottom deposition thickness is defined for the area exclusively between the range of thicknesses described (i.e., the area is not cumulative). Thus the areas with larger thicknesses are not necessarily smaller than areas with smaller thicknesses. The shape of the distribution pattern is generally similar to the water column plume (ebb-then-flood) but reduced in extent. The higher deposition areas are at and adjacent to the cable route and occur when the sediment distribution is weighted toward the sand fractions. There are a few non-contiguous areas of 0.1 to 0.5 mm (0.004 to 0.02 in)

deposition further south of the cable route that are due to the slight changes in current direction transporting water column plumes from slightly different locations on the route so that they happen to form a thin deposit at the same place.

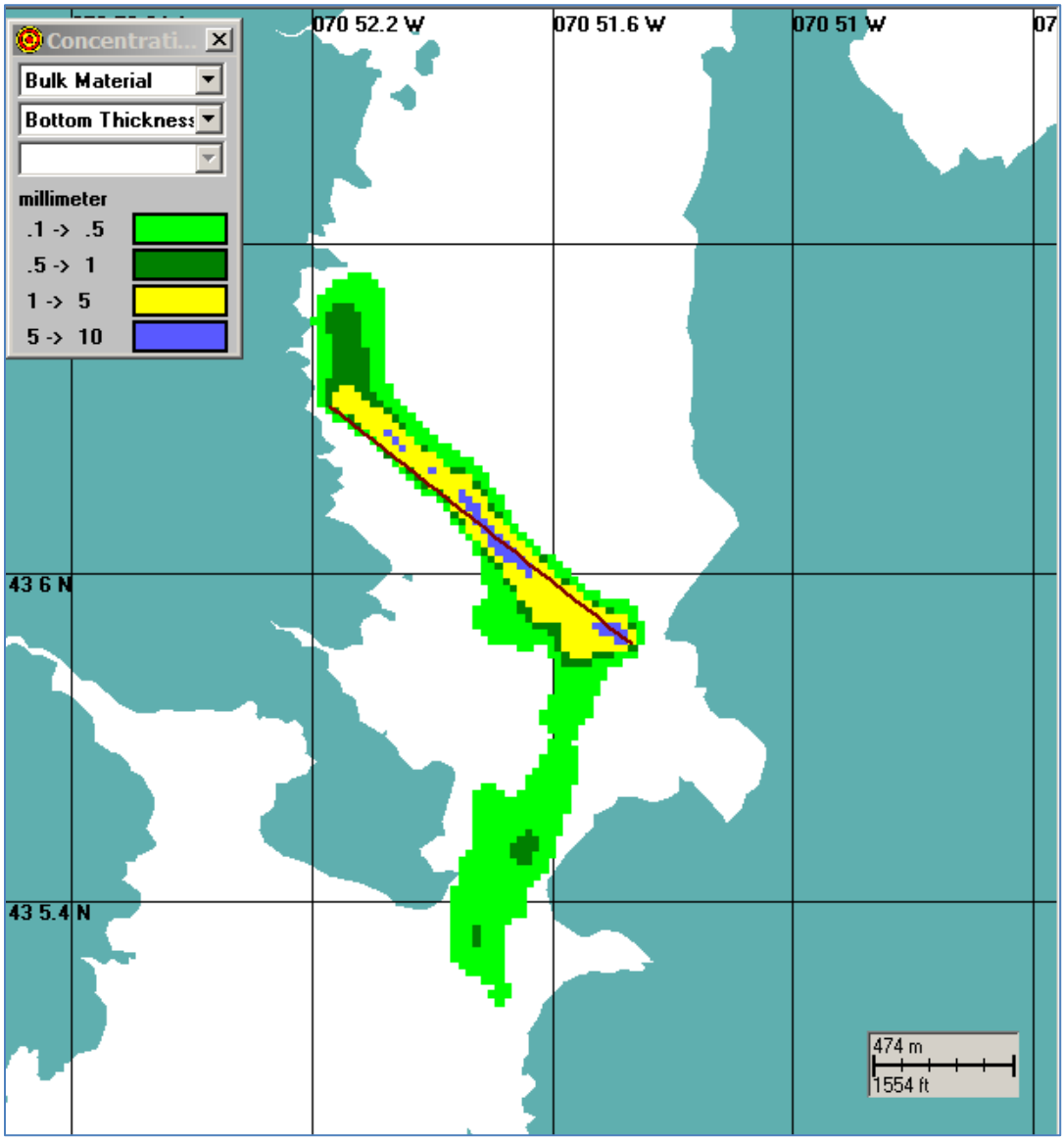

Figure 3-11. Plan view of integrated bottom thickness (mm) distribution due to jet plowing for the three cable trenches combined.

The areal sizes of the deposition thickness patterns seen in Figure 3-11 are summarized in Table 3-9 for each thickness increment range. At the range of 0.1 to 0.5 mm (0.004 to 0.02 in) thickness range the area is 35.6 ha (87.9 ac) due to jet plowing the three cable routes. These areas generally drop in size, but not always, for the higher deposition thicknesses. For example, the area of 12.4 ha [30.7 ac] for the 1 to 5 mm [0.04 to 0.2 in) thickness range is larger than the 0.5 to 1 mm (0.02 to 0.04 in) area of 8.1 ha (20.0 ac).

Table 3-9. Bottom thickness (millimeter and inch) areal distribution (hectare and acre) due to jet plowing for the three cable routes combined.

Thickness (mm)	Area (ha)	Thickness (in)	Area (ac)
0.1 to 0.5	35.6	0.004 to 0.02	87.9
0.5 to 1	8.1	0.020 to 0.04	20.0
1 to 5	12.4	0.04 to 0.2	30.7
5 to 10	2.4	0.2 to 0.4	5.9
Totals 0.1 to 10	58.5	0.004 to 0.4	144.5

3.4.2 Diver Burial Results

3.4.2.1 Water Column Concentrations

The total duration of the cable burial by divers is 4 hr/day for 9.9 days for the west area and 4 hr/day for 19.4 days for the east area for each of the three cable bundles to be buried. This is based on an estimated advance rate of 2.29 m/hr (7.5 ft/hr) for the 4 hrs around high slack water for a 90 m (296 ft) route distance for the west area and 178 m (583 ft) for the east area (see Table 3-4). To best display the resulting water column concentration a figure was generated for each area for 1 day at a representative location in the area. Figure 3-12 shows the plan view of the predicted instantaneous excess SS concentration contours for both the west and east area. The submerged SS concentration plumes extend both north and south of the cable route due to the timing of operations before and after slack water. Again, the water column concentration contours shown, which are defined by a single concentration level, totally surround an enclosed area where concentrations are at or above the specified concentration, i.e., the area is cumulative. Thus the areas with higher concentrations must be smaller than areas with lower concentrations since those areas are enclosed within the lower concentration contour.

The contours in Figure 3-12 show a decreasing concentration away from the location of the diver activities on the cable route as material dilutes and settles out. The colored contours can be identified from the legend in the upper right corner of the figure showing concentrations from 10 mg/L and higher. Modeling was done assuming that silt curtains would not be employed during the diver installation.

A vertical section view defined along the cable route looking north is inserted at the bottom left of the figure. The insert shows that the highest concentrations occur near the bottom with reduced concentrations extending up into the water column. In the western shallows, suspended sediments from the diver burial activity are likely to reach nearly to the water surface. In the somewhat deeper eastern area, excess suspended sediments will be restricted to the lower half of the water column.

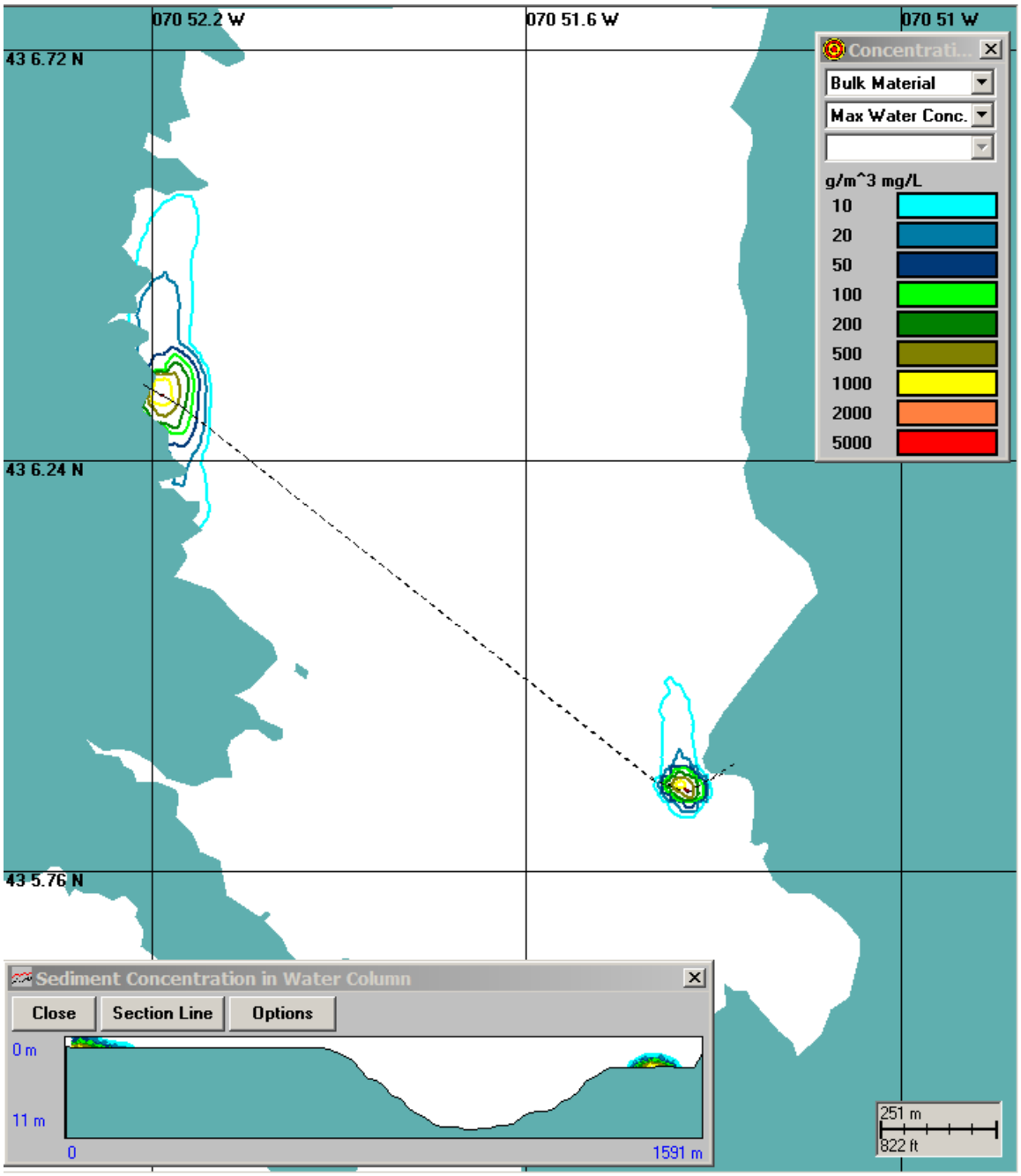

Figure 3-12. Plan view of instantaneous maximum excess SS concentration contours for 1 day approximately midway across the west and east diver burial sections. Vertical section view at lower left. Assumes silt curtains were not used.

The instantaneous total enclosed area of the excess SS concentration plumes for the west and east diver burial sections seen in Figure 3-12 is summarized in Table 3-10 for each increment identified in the color legend. At 10 mg/L excess SS concentration the total area enclosed by the contour is 8.4 ha (20.7 ac) for the west section and 1.9 ha (4.7 ac) for the east section. However, these total enclosed areas drop dramatically for the higher concentrations near the diver burial activities, i.e., the area at 1,000 mg/L is only about 0.2 ha (0.6 ac) for the west section and 0.0 ha

(0.1 ac) for the east section, indicating that the extent of the plume is again relatively limited for higher concentrations.

Table 3-10. Summary of the total area (hectares and acres) enclosed by the excess SS threshold concentration contours shown in Figure 3-11 due to diver burial. Assumes silt curtains were not used.

	West Section	West Section	East Section	East Section
TSS	Area	Area	Area	Area
(mg/L)	(ha)	(ac)	(ha)	(ac)
10	8.4	20.7	1.9	4.7
20	4.5	11.0	0.8	2.0
50	2.0	4.9	0.5	1.2
100	1.2	3.0	0.4	0.9
200	1.0	2.5	0.3	0.7
500	0.5	1.2	0.1	0.3
1000	0.2	0.6	0.0	0.1

Figure 3-13 shows the plan view of the maximum time-integrated excess SS concentration contours for both diver burial sections. As before, these concentrations are generated from the model results by determining the highest concentration in each SSFATE grid cell during the entire simulation, approximately 10 and 20 days for the west and east sections, respectively. This plot shows only the maximum excess SS concentration integrated over time and would not be actually seen in the Bay. The contours again show decreasing concentration from either side of the cable route with higher concentrations adjacent to the jet plow route. This model run assumed silt curtains were not used.

A vertical section view defined by the jet plow route is shown at the bottom left of the figure. The highest concentrations, above 5,000 mg/L on the west side, occur just above the bottom with dramatically reduced concentrations extending up into the water column along the route. The same is true for the east section but the highest concentrations there are between 500 and 1,000 mg/L.

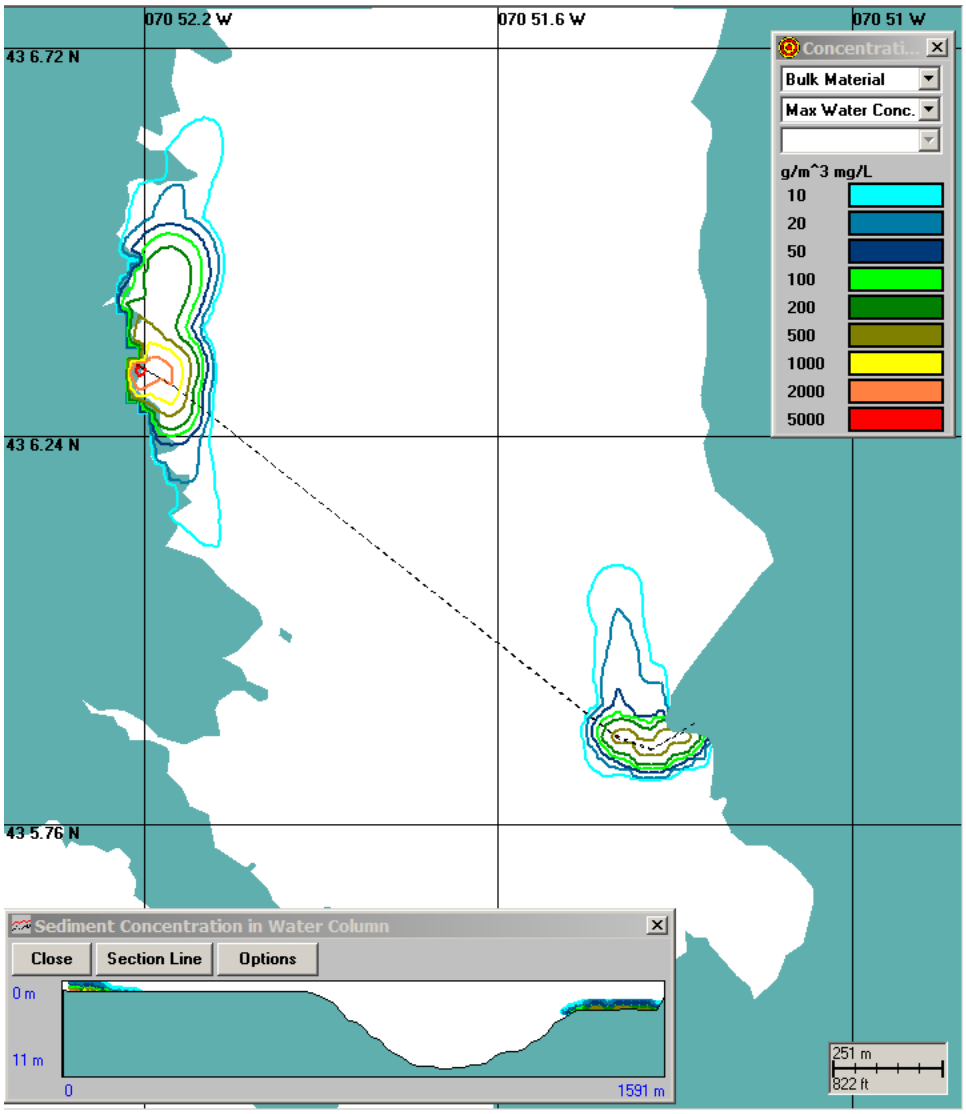

Figure 3-13. Plan view of maximum time integrated excess SS concentration contours over both diver burial operations. Vertical section view at lower left. Assumes silt curtains were not used.

Table 3-11 summarizes the total western and eastern areas enclosed by the maximum time-integrated excess SS concentrations over the diver burial operations shown in Figure 3-13. This table shows that during the diver burial activities on the west side, a total enclosed area of 14.5 ha (35.9 ac) sees a minimum 10 mg/L concentration for a minimum of 5 minutes (the SSFATE model output timestep) but at different times during the simulation. For the east side the 10 mg/L concentration contour encloses a total area of 8.2 ha (20.2) ac.

Table 3-11. Summary of the total area (hectares and acres) enclosed by the maximum time-integrated excess SS threshold concentration contours shown in Figure 3-13 due to diver burial for the west and east sections. Assumes silt curtains were not used.

TSS (mg/L)	West Area (ha)	West Area (ac)	East Area (ha)	East Area (ac)
10	14.5	35.9	8.2	20.2
20	9.7	24.0	5.1	12.5
50	7.2	17.7	2.9	7.1
100	5.9	14.6	2.1	5.1
200	4.5	11.1	1.6	3.9
500	2.0	4.9	0.5	1.2
1000	1.2	3.1		
2000	0.6	1.4		
5000	0.1	0.2		
10000				

An important metric defining the plume is its duration for different concentrations, which could have biological significance if exposure (duration multiplied by concentration) is sufficiently elevated. The total enclosed area and duration of the time-integrated maximum west section plume seen in Figure 3-13 is summarized in Figure 3-14 and Table 3-12 for each contour identified in the color legend. At 10 mg/L excess SS concentration the total area that is enclosed by the contour is 14.6 ha (36.1 ac) but lasts for only 1 hr. This short duration continues through all the concentration contour thresholds through 5,000 mg/L. The enclosed areas decrease in time for a given concentrations so by 6 hrs the 10 mg/L area has dropped to 8.6 ha (21.2 ac). The 10 mg/L area persists for two days because the initial buildup occurs near slack water with grain size distribution indicating mostly fines (silts and clays). The area coverages decrease for higher concentrations near the diver burial activities.

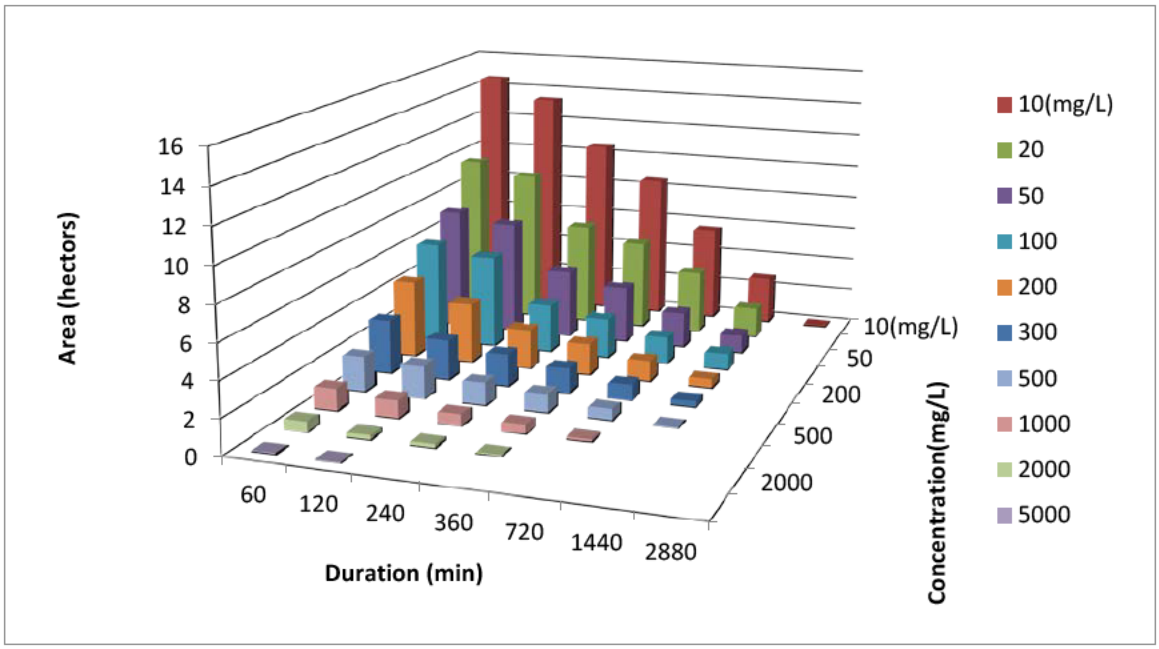

Figure 3-14. Duration (minutes) and total enclosed area (hectares) of maximum time integrated excess SS concentration due to diver burial for west section with total duration of 9.9 4-hour days (2,368 min). Assumes silt curtains were not used.

Table 3-12. Duration (minutes) and total enclosed area (hectares and acres) of maximum time integrated excess SS concentration due to diver burial for west section with total duration of 9.9 4-hour days (2,368 min). Assumes silt curtains were not used.

West	Area (ha)						
Max SS	Minutes						
(mg/L)	60	120	240	360	720	1440	2880
10	14.6	13.4	10.5	8.6	5.6	2.8	0.1
20	9.8	9.1	6.0	5.3	3.7	1.8	
50	7.2	6.7	4.0	3.3	2.1	1.1	
100	5.9	5.4	2.8	2.3	1.6	0.9	
200	4.5	3.5	2.3	1.8	1.2	0.5	
300	3.1	2.3	1.9	1.4	0.9	0.4	
500	2.0	1.9	1.3	1.1	0.6	0.1	
1000	1.3	1.1	0.6	0.5	0.1		
2000	0.6	0.3	0.2	0.1			
5000	0.1	0.1					

West	Area (ac)						
Max SS	Minutes						
(mg/L)	60	120	240	360	720	1440	2880
10	36.1	33.1	26.0	21.2	13.9	6.8	0.2
20	24.1	22.4	14.9	13.0	9.1	4.3	

West	Area (ac)						
Max SS	Minutes						
(mg/L)	60	120	240	360	720	1440	2880
50	17.8	16.5	9.9	8.2	5.1	2.6	
100	14.7	13.4	7.0	5.7	3.9	2.3	
200	11.1	8.6	5.6	4.5	2.9	1.2	
300	7.7	5.7	4.6	3.6	2.2	0.9	
500	4.9	4.6	3.2	2.6	1.5	0.2	
1000	3.1	2.6	1.6	1.2	0.3		
2000	1.4	0.6	0.5	0.2			
5000	0.2	0.2					

The total enclosed area and duration of the time-integrated maximum east section plume seen in Figure 3-13 is summarized in Figure 3-15 and Table 3-13 for each contour identified in the color legend. At 10 mg/L excess SS concentration the total area that is enclosed by the contour is 8.2 ha (20.2 ac) but lasts for only 1 hr. This short duration continues through all the concentration contour thresholds through 500 mg/L. The enclosed areas decrease in time for a given concentration so by 6 hrs the 10 mg/L area has dropped to 4.1 ha (10.2 ac). The 10 mg/L area persists for two days because the initial buildup occurs near slack water with grain size distribution indicating mostly fines (silts and clays). The area coverages decrease for higher concentrations near the diver burial activities. These results assumed silt curtains were not used.

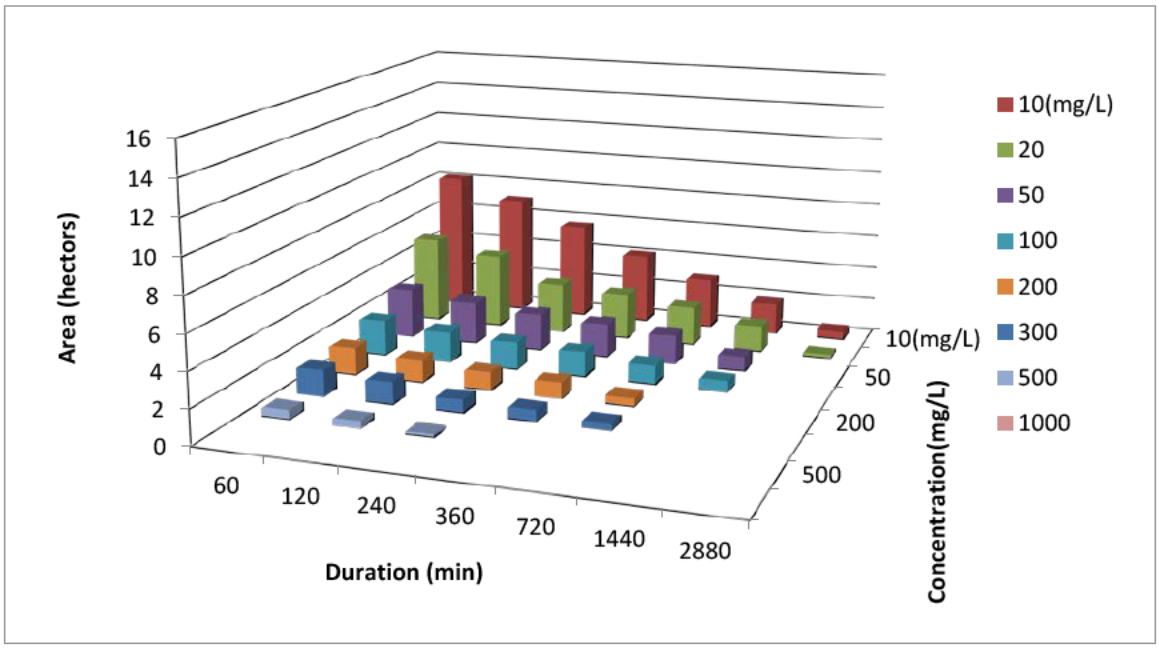

Figure 3-15. Duration (minutes) and total enclosed area (hectares) of maximum time integrated excess SS concentration due to diver burial for east section with total duration of 19.4 4-hour days (4,664 min). Assumes silt curtains were not used.

Table 3-13. Duration (minutes) and total enclosed area (hectares and acres) of maximum time integrated excess SS concentration due to diver burial for east section with total duration of 19.4 4-hour days (4,664 min). Assumes silt curtains were not used.

East	Area (ha)						
Max SS	Minutes						
(mg/L)	60	120	240	360	720	1440	2880
10	8.2	7.1	5.7	4.1	2.9	1.8	0.5
20	5.1	4.4	2.9	2.7	2.3	1.5	0.2
50	2.9	2.5	2.1	1.9	1.7	0.8	
100	2.1	1.8	1.6	1.4	1.1	0.6	
200	1.6	1.3	1.0	0.9	0.5		
300	1.5	1.3	0.8	0.6	0.4		
500	0.5	0.4	0.1				
1000							

East	Area (ac)						
Max SS	Minutes						
(mg/L)	60	120	240	360	720	1440	2880
10	20.2	17.4	14.0	10.2	7.3	4.5	1.2
20	12.5	10.8	7.2	6.6	5.6	3.7	0.5
50	7.1	6.2	5.3	4.8	4.2	2.0	
100	5.1	4.5	3.9	3.6	2.8	1.5	
200	3.9	3.2	2.5	2.2	1.2		
300	3.7	3.1	1.9	1.5	0.9		
500	1.2	0.9	0.3				
1000							

Use of Silt Curtains

The effects of using silt curtains can greatly reduce the size of the water column areas affected which has been described above. The US Army Corps of Engineers refers to reductions in loss rates up to 80 to 90% when silt curtains are correctly employed (Francingues and Palermo, 2005). A recent model application by the USACE (Lackey, et. al., 2012) assumed reductions of 90 to 100% in loss rates due to the use of silt curtains to be protective of coral reefs in Guam.

If a 90% reduction is assumed with the use of silt curtains then the excess suspended sediment concentration results presented above can be reduced by a factor of 10 for areas outside the silt curtains. This means that the legend appearing in Figures 3-12 through 3-15 showing concentration levels ranging from 10 to 5000 mg/L can be reduced to 1 to 500 mg/L to be representative of the results from using silt curtains. In addition, Tables 3-10 through 3-13 can also be reinterpreted for the use of silt curtains by reducing the listed concentrations by a factor of 10. The area inside the silt curtains adjacent to the cable routes will, of course, see a local increase in concentrations.

3.4.2.2 Bottom Deposition

Figure 3-16 shows the plan view of the bottom deposition thickness distribution from 0.1 mm to 50 mm (0.004 to 2 in) due to diver activity for both the west and eastern sections of all three cable routes combined and assumed that any sediment deposited on the bottom remained in place. The color filled areas are defined by the legend for different deposition thickness ranges, e.g., 1 mm to 5 mm (0.04 to 0.2 in) denoted by yellow. The bottom deposition thickness is defined for the area exclusively between the range of thicknesses described, i.e., the area is not cumulative. Thus the areas with larger thicknesses are not necessarily smaller than areas with smaller thicknesses. The distribution pattern is generally similar to the water column plume (ebb) but much reduced in extent. The higher deposition areas are adjacent to the cable route.

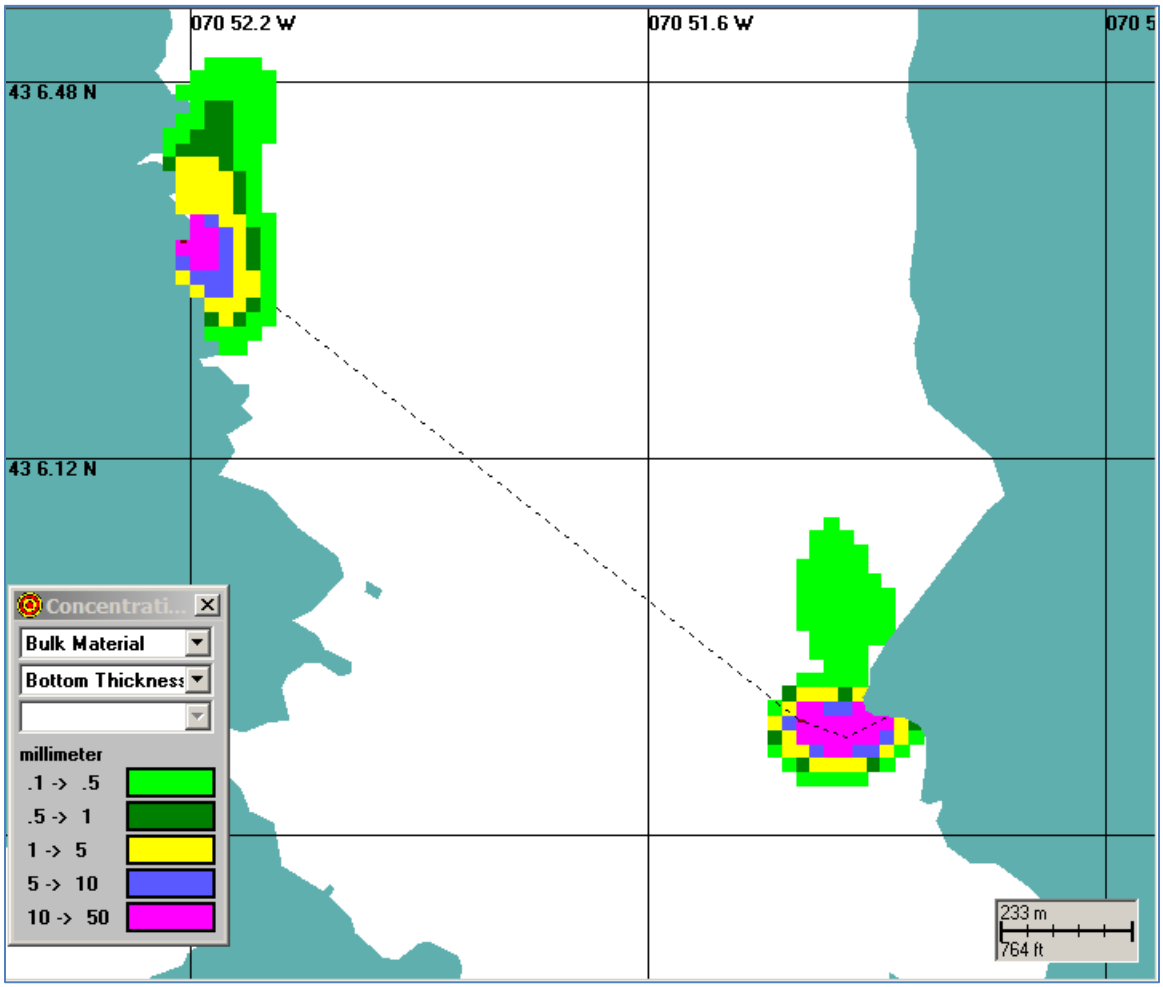

Figure 3-16. Plan view of time integrated bottom thickness (mm) distribution due to diver burial for west and east sections for three cable routes combined. Assumes that silt curtains were not used.

The areal sizes of the deposition thickness patterns seen in Figure 3-16 for both the west and east sections are summarized in Table 3-14 for each thickness increment range. At the 0.1 to 0.5 mm (0.004 to 0.02 in) thickness range the area is 3.4 ha (8.5 ac) for the west and 4.4 ha (10.8 ac) for the east, both including the three cable routes combined. These areas generally drop in size, for example, the west area of 1.9 ha [4.6 ac] and the east area of 1.1 ha [2.6 ac] for the 1 to 5

mm [0.04 to 0.2 in) thickness range is larger than the 0.5 to 1 mm (0.02 to 0.04 in) areas but not always, for the higher deposition thicknesses.

Table 3-14. Bottom thickness (millimeter and inch) areal distribution (hectare and acre) due to diver burial for west and east sections for the three cable routes combined. Assumes silt curtains were not used.

	West	East		West	East
Thickness	Area	Area	Thickness	Area	Area
(mm)	(ha)	(ha)	(in)	(ac)	(ac)
0.1 to 0.5	3.4	4.4	0.004 to 0.02	8.5	10.8
0.5 to 1	1.4	0.4	0.02 to 0.04	3.4	0.9
1 to 5	1.9	1.1	0.04 to 0.2	4.6	2.6
5 to 10	0.6	0.5	0.2 to 0.4	1.5	1.2
10 to 50	0.5	1.2	0.4 to 2	1.2	2.9
Totals 0.1 to 50	7.8	7.6	0.004 to 2	19.2	18.4

Use of Silt Curtains

As with the 10-fold reduction in suspended sediment concentrations with the use of silt curtains, the results shown for bottom deposition can also be reduced by a factor of 10. This means that the legend appearing in Figure 3-16 showing bottom thickness levels ranging from 0.1 to 50 mm (0.004 to 2 in) can be reduced to 0.01 to 5 mm (0.0004 to 0.2 in) to be representative of the results from using silt curtains. In addition, Table 3-14 can also be reinterpreted for the use of silt curtains by reducing the listed thickness ranges by a factor of 10.

The area inside the silt curtains adjacent to the cable routes will, of course, see a significant local increase in bottom deposition thickness. Current velocities in the area where diver burial will be required on the western tidal flat and in the intertidal portion of the diver burial area on the eastern side are in the range for which silt curtains can be used effectively. In the more exposed portion of the diver burial area on the eastern end of the route, currents are likely to exceed those for which silt curtains can be used. The project proposes that silt curtains will be used to enclose the entire three western diver burial routes 90 m (296 ft) long with an area of 1,923 m^2 (20,695 ft^2) and also used along a portion (112 m [367 ft]) of the three eastern diver burial routes enclosing an area of 2,046 m^2 (22,021 ft^2). Approximately 66 m (216 ft) of each of the three cables on the eastern end of the route will not be enclosed during diver burial. Based on the trench geometry for diver burial summarized in Table 3-4 90% of the entire west resuspension volume or 181.0 m^3 (6,394 ft^3) spread over the enclosed area results in an average deposition thickness of 94 mm (3.71 in) while 90% of the entire partial east resuspension volume or 224.5 m^3 (7,927 ft^3) spread over the enclosed area results in an average deposition thickness of 110 mm (4.32 in). Larger thicknesses would be found closest to the burial routes (including the trenches) and smaller thicknesses found closer to the silt curtains distant from the routes.

3.5 Effects of Multiple Cable Laying Operations

Since there are three cable bundles to be laid in individual trenches the question arises as to what happens to the water column concentration and bottom deposition created by a single pass and whether it might affect the subsequent pass. The schedule to embed each cable by jet plowing is planned to occur on a 5 to 7 day interval. The water column concentration duration analysis shows that the excess concentration will drop to zero within approximately 6 hours. Thus there will be no cumulative increases in suspended sediment concentrations as a result of these installations.

A measure of the stability of deposited sediments to the seabed is a function of the erosion velocity for each grain size in the sediment. This relationship is shown via a Hjulstrom diagram as shown in Figure 3-17. Here the y-axis is the current velocity in Little Bay and the x-axis is sediment grain size. Since the freshly deposited sediment is unconsolidated, the fine grains (clay and silt) and sand would be eroded at a velocity of about 20 cm/s (0.4 kt). Examining the example figures of flood and ebb tide velocities in Figures 2-2 and 2-3, respectively, this minimum speed is exceeded across most of Little Bay except in the shallow tidal flat very near the shore where there could be some accumulation. Thus most of the fine sediment is likely to be resuspended on subsequent tides and dispersed from the areas initially affected by deposition unless flocculation of the clay particles occurs and they remain in place. The larger grain sizes will quickly drop back into the channel when first resuspended by the jetting process.

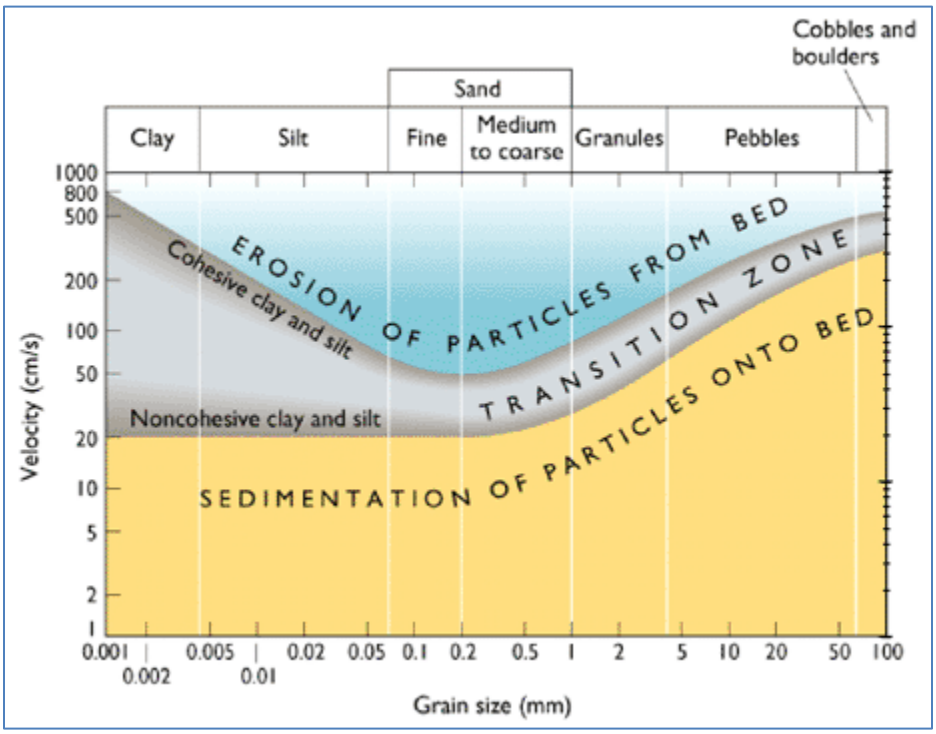

Figure 3-17. Hjulstrom diagram showing relationship between velocity and gran size (from http://eesc.columbia.edu/courses/ees/lithosphere/homework/hmwk1_s08.html).

4 Conclusions

Two computer models were used in the analysis: BELLAMY, a hydrodynamic model used for predicting the currents in Little Bay, and SSFATE, a sediment dispersion model used for predicting the fate and transport of sediment resuspended by the jet plowing and diver burial operations. BELLAMY is a finite element, two-dimensional, vertically averaged, time stepping circulation model developed at Dartmouth College and previously applied to the Great Bay Estuarine System. The SSFATE (Suspended Sediment FATE) model was utilized to predict the excess suspended sediment concentration and the dispersion of suspended sediment resulting from jetting activities. The model predicts excess concentration, which is defined as the concentration above ambient suspended sediment concentration generated by the seabed activities. The SSFATE model results are summarized below for the jetting and diver burial activities.

Jet Plowing

The size of the resulting excess suspended sediment (SS) concentration plume in the lower water column is defined as a series of areas enclosed by different concentration levels. The water column concentration contours shown, which are defined by a single concentration level, totally surround an enclosed area where concentrations are at or above the specified concentration, i.e., the area is cumulative. The entire area encompassed by the plume (as defined by the 10 mg/L excess SS concentration contour averaged over time was 14.8 ha (36.58 ac) ranging from a low of 5.91 ha (14.61 ac) at 1 hr to a high of 22.36 ha (55.25 ac) at 10 hrs. These total enclosed areas dropped dramatically for the higher concentrations, averaging 1.94 ha (4.79 ac) at 100 mg/L, 0.28 ha (0.68 ac) at 1,000 mg/L and 0.02 ha (0.05 ac) at 5,000 mg/L. indicating that the extent of the plume is limited for higher concentrations. In the shallows, suspended sediments from the jet plow activity are likely to reach nearly to the water surface. In the channel, excess suspended sediments will be restricted to the lower half of the water column.

An important metric defining the plume is its duration for different concentrations, which could have biological significance if exposure (duration multiplied by concentration) is sufficiently elevated. The maximum plume size and duration at 10 mg/L excess SS concentration in the area that is totally enclosed by the contour is 90.20 ha (222.89 ac) but lasts for only 1 hr. This short duration continues for all the concentration contour thresholds through 1,000 mg/L. The enclosed areas quickly drop in time for a given concentrations so by 2 hrs the 10 mg/L area has dropped to 32.20 ha (79.57 ac) and by 6 hrs the plume is completely gone. The area coverages drop dramatically for the higher concentrations near the jet plow indicating that the duration and extent of the plume is relatively limited.

The areal sizes of the deposition thickness patterns also generally drop in size, but not always. At the range of 0.1 to 0.5 mm (0.004 to 0.02 in) thickness the area is 35.6 ha (87.9 ac) due to jet plowing the three cable routes. These areas drop overall for the higher deposition thicknesses (e.g., 2.4 ha [5.9 ac] for the 5 to 10 mm (0.2 to 0.4 in) thickness range) near the jet plow indicating that the extent of the plume is relatively limited.

Diver Burial Assuming No Use of Silt Curtains

The total enclosed area of the excess SS concentration plumes for the west and east diver burial sections were also examined, specifically assuming that silt curtains were not used. Typically, at

10 mg/L excess SS concentration the instantaneous total area enclosed by the contour is 8.4 ha (20.7 ac) for the west section and 1.9 ha (4.7 ac) for the east section. However, these total enclosed areas drop dramatically for the higher concentrations near the diver burial activities, i.e., the area at 1,000 mg/L is only about 0.2 ha (0.6 ac) for the west section and 0.0 ha (0.1 ac) for the east section, indicating that the extent of the plume is again relatively limited.

Assuming no silt curtains were used, the total area in the west section that is enclosed by the 10 mg/L excess SS concentration contour is 14.6 ha (36.1 ac) but lasts for only 1 hr. This short duration continues through all the concentration contour thresholds through 5,000 mg/L. The enclosed areas decrease in time for a given concentrations so by 6 hrs the 10 mg/L area has dropped to 8.6 ha (21.2 ac). The 10 mg/L area persists for two days because the initial buildup occurs near slack water with grain size distribution indicating mostly fines (silts and clays). The area coverages decrease for higher concentrations near the diver burial activities. At the east section the 10 mg/L excess SS concentration total area that is enclosed by the contour is 8.2 ha (20.2 ac) but lasts for only 1 hr. This short duration continues through all the concentration contour thresholds through 500 mg/L. The enclosed areas decrease in time for a given concentration so by 6 hrs the 10 mg/L area has dropped to 4.1 ha (10.2 ac). The 10 mg/L area persists for two days because the initial buildup occurs near slack water with grain size distribution indicating mostly fines (silts and clays). The area coverages decrease for higher concentrations near the diver burial activities.

The sizes of the deposition thickness patterns also dropped as the deposition increased. At the 0.1 to 0.5 mm (0.004 to 0.02 in) thickness range the area is 3.4 ha (8.5 ac) for the west and 4.4 ha (10.8 ac) for the east, both including the three cable routes combined. These areas drop dramatically for the higher deposition thicknesses (e.g., 0.5 ha [1.2 ac] for the 10 to 50 mm (0.4 to 2 in) thickness on the west section and 1.2 ha (2.9 ac) for the east section indicating that the extent of the plume is limited.

Diver Burial Assuming Use of Silt Curtains

The effects of using of silt curtains were estimated by assuming that 90% of the suspended sediment resuspended from diver burial operations would be trapped by the curtains. That being the case, the results based on no silt curtain use can be reduced by a factor of 10 to estimate the concentrations outside the silt curtain. At 10 mg/L excess SS concentration the area enclosed by the contour was 1.2 ha (3.0 ac) for the west section and 0.4 ha (0.9 ac) for the east section.

In terms of exposure, for the west section at 10 mg/L excess SS concentration the area that is enclosed by the contour is 5.9 ha (14.7 ac) but lasts for only 1 hr. The areas decrease in time for a given concentrations so by 6 hrs the 10 mg/L area has dropped to 2.3 ha (5.7 ac). For the east section at 10 mg/L excess SS concentration the area that is enclosed by the contour is 2.1 ha (5.1 ac) but lasts for only 1 hr. The areas decrease in time for a given concentration so by 6 hrs the 10 mg/L area has dropped to 1.4 ha (3.6 ac). The area within the silt curtain area would, of course, see a significant increase in concentration until the material has settled out.

With the use of silt curtains the bottom deposition thickness outside the silt curtains can also be reduced by a factor of 10. At the 0.1 -> 0.5 mm (0.004 -> 0.02 in) thickness the area enclosed by the contour is 1.9 ha (4.6 ac) for the west and 1.1 ha (2.6 ac) for the east. Based on the trench geometry for diver burial 90% of the entire west resuspension volume or 181.0 m^3 (6,394 ft^3)

spread over the area enclosed by the silt curtain results in an average deposition thickness of 94 mm (3.71 in) while 90% of the entire partial east resuspension volume or 224.5 m^3 (7,927 ft^3) spread over the enclosed area results in an average deposition thickness of 110 mm (4.32 in). Larger thicknesses would be found closest to the burial routes (including in the trenches) and smaller thicknesses found closer to the silt curtains distant from the routes.

Stability of Deposited Sediments

A measure of the stability of deposited sediments to the seabed is a function of the erosion velocity for each grain size in the sediment. Since the freshly deposited sediment is unconsolidated, the fine grains (clay and silt) and sand are eroded at a velocity of about 20 cm/s (0.4 kt). This minimum speed is exceeded across most of Little Bay except in the shallow very near the shore. Thus sediment particles deposited along much of the route will likely be resuspended on subsequent tides and dispersed from the areas initially affected by deposition.

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