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US ARMY CORPS
OF ENGINEERS
New England District

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June 2009

Final Summary Report
Plume Monitoring

BOSTON HARBOR
INNER HARBOR
MAINTENANCE DREDGING PROJECT

FINAL SUMMARY REPORT
PLUME MONITORING

BOSTON HARBOR INNER HARBOR
MAINTENANCE DREDGING PROJECT

Submitted to:

Department of the Army
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New England District

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ACRONYMS AND ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
CAD	Confined Aquatic Disposal
cm/s	centimeters/second
CTD	Conductivity Temperature Depth
cy	Cubic Yards
dB	Decibels
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
ft	feet
HS	High Slack
Kts	Knots
LCS	Laboratory Control Sample
LS	Low Slack
m	meter
MBDS	Massachusetts Bay Disposal Site
ME	Maximum Ebb
MLLW	Mean Lower Low Water
MF	Maximum Flood
MSC	Main Ship Channel
NAE	New England District
NTU	Nephelometric Turbidity Units
OBS	Optical Back-Scatter
PSU	Practical Salinity Unit
SAP	Sampling and Analysis Plan
TSS	Total Suspended Solids
USACE	U.S. Army Corps of Engineers
WQC	Water Quality Certification

1.0 INTRODUCTION

This report documents the observed turbidity and suspended sediment concentrations in the vicinity of clamshell dredge operations and dredged material disposal operations in Boston Harbor, Boston, Massachusetts (Figure 1). The measurement program was undertaken at the request of the U.S. Army Corps of Engineers (USACE), New England District (NAE) to support the Boston Harbor Inner Harbor Maintenance Dredging Project. This report documents the water column monitoring results during the removal of dredged material from locations in Boston Harbor and the monitoring results during placement of dredged material into the Mystic River Confined Aquatic Disposal (CAD) cell including:

1) Dredging of the top layer of silty material, which was determined to be unsuitable for ocean placement, from a potential CAD cell located in the Inner Harbor Main Ship Channel (MSC) just south of the Inner Confluence of the Mystic River and Chelsea Rivers, referred to in this report as the Northern MSC area (Figure 2) in June-July 2008.
2) Placement of some of the material from the Northern MSC area, determined to be unsuitable for ocean placement, into the Mystic River CAD cell, July 1, 2008.
3) Maintenance dredging of silty material, determined to be unsuitable for ocean placement, from the MSC near Governors Island Flats, referred to in this report as the Southern MSC area (Figure 2), in mid-September 2008.
4) Placement of material from the upper portion of the Reserved Navigation Channel (Figure 2), determined to be unsuitable for ocean placement, into the Mystic River CAD cell, in October 3, 2008.
5) Placement of material from the MSC near the Reserved Channel, referred to in this report as the Lower MSC area (Figure 2), determined to be unsuitable for ocean placement, into the Mystic River CAD cell, in October 27-28, 2008.

The turbidity and suspended sediment concentration of plumes produced by the dredging and disposal activity were monitored using continuous, real-time measurements of acoustic backscatter calibrated with TSS data generated from water samples collected on site.

1.1 Site Description

Boston Harbor is the largest port in New England and serves as a major hub for national and international shipping and commerce. Beginning in the spring of 2008, the USACE conducted maintenance dredging of the inner portion of the Federal navigation channels in Boston Harbor. The maintenance dredging was broken into base and optional contract work. The base work involved dredging the Main Ship Channel from a location approximately half-way between Spectacle Island and Castle Island upstream to approximately the North Jetty, the upper Reserved Channel, and the approach channel to the Navy Dry Dock, all to their authorized depths, 40 ft below Mean Lower Low Water (MLLW). The mean tide range in Boston Harbor is approximately 10 ft. The base plan also involved the dredging of a CAD cell in the Mystic River and the removal of the silty layer over a second CAD cell in the Main Ship Channel just south of the Inner confluence (Corps, 2006). The Mystic River CAD cell is located in the Mystic River at the edge of the confluence of the Mystic and Chelsea Rivers (Figure 3). The authorized channel throughout this part of the Mystic River is 40 ft below MLLW. However, due to overdepth dredging that occurs during dredging activities, the water depth is approximatley 42 feet at MLLW. The CAD cell was dredged to 97 ft below MLLW. Material dredged from the Federal channels that was determined to be unsuitable for ocean placement and was placed into CAD cells located beneath the Federal channels. The dredged material from the Federal channels determined to be suitable for ocean placement, plus the suitable parent material excavated during the CAD cell(s) construction, was placed at the Massachusetts Bay Disposal Site (MBDS).

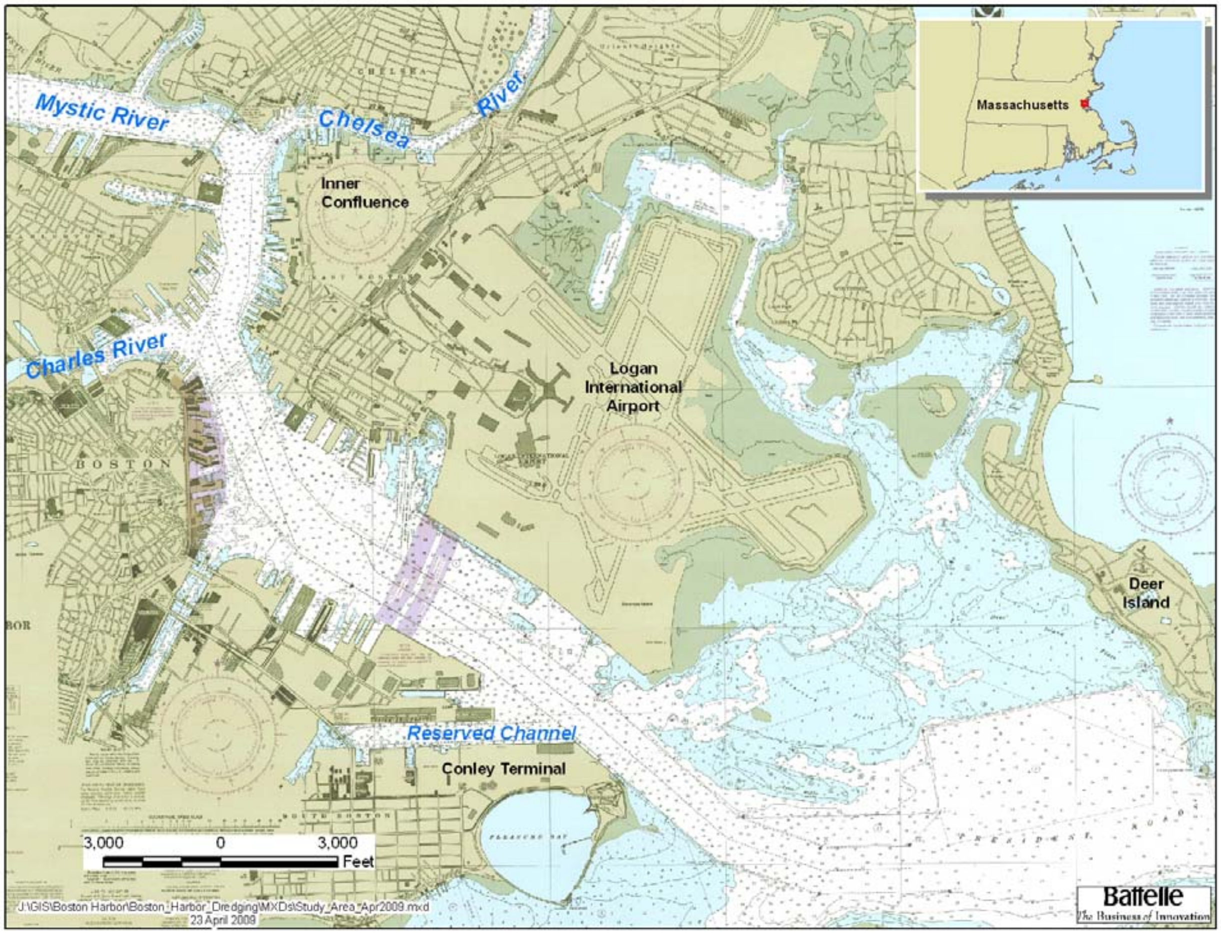


Figure 1. Boston Harbor Study Location.

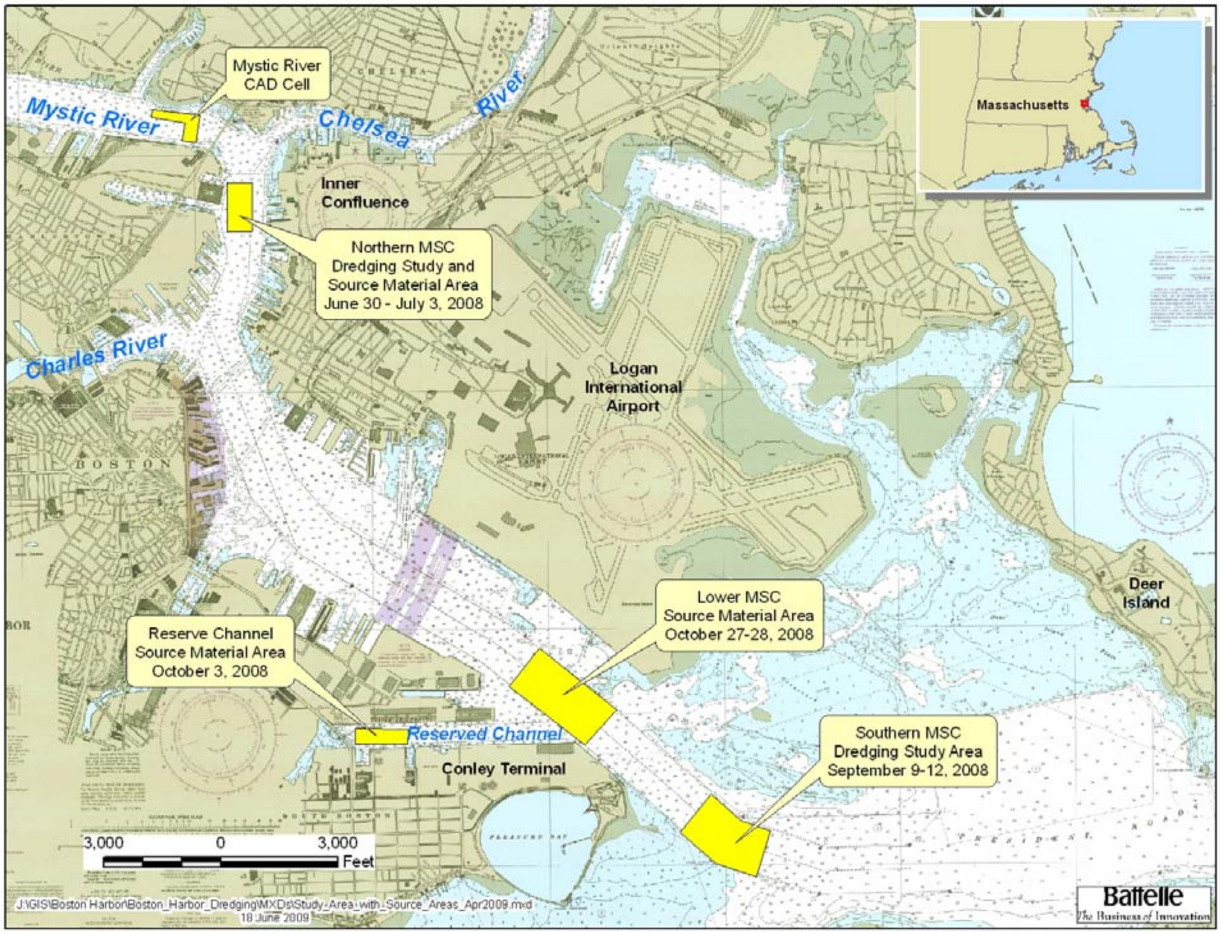


Figure 2. Map of Boston Inner Harbor Showing the Mystic River CAD Cell, Dredging Monitoring Study Areas, and the Source Areas for Disposal Monitoring.

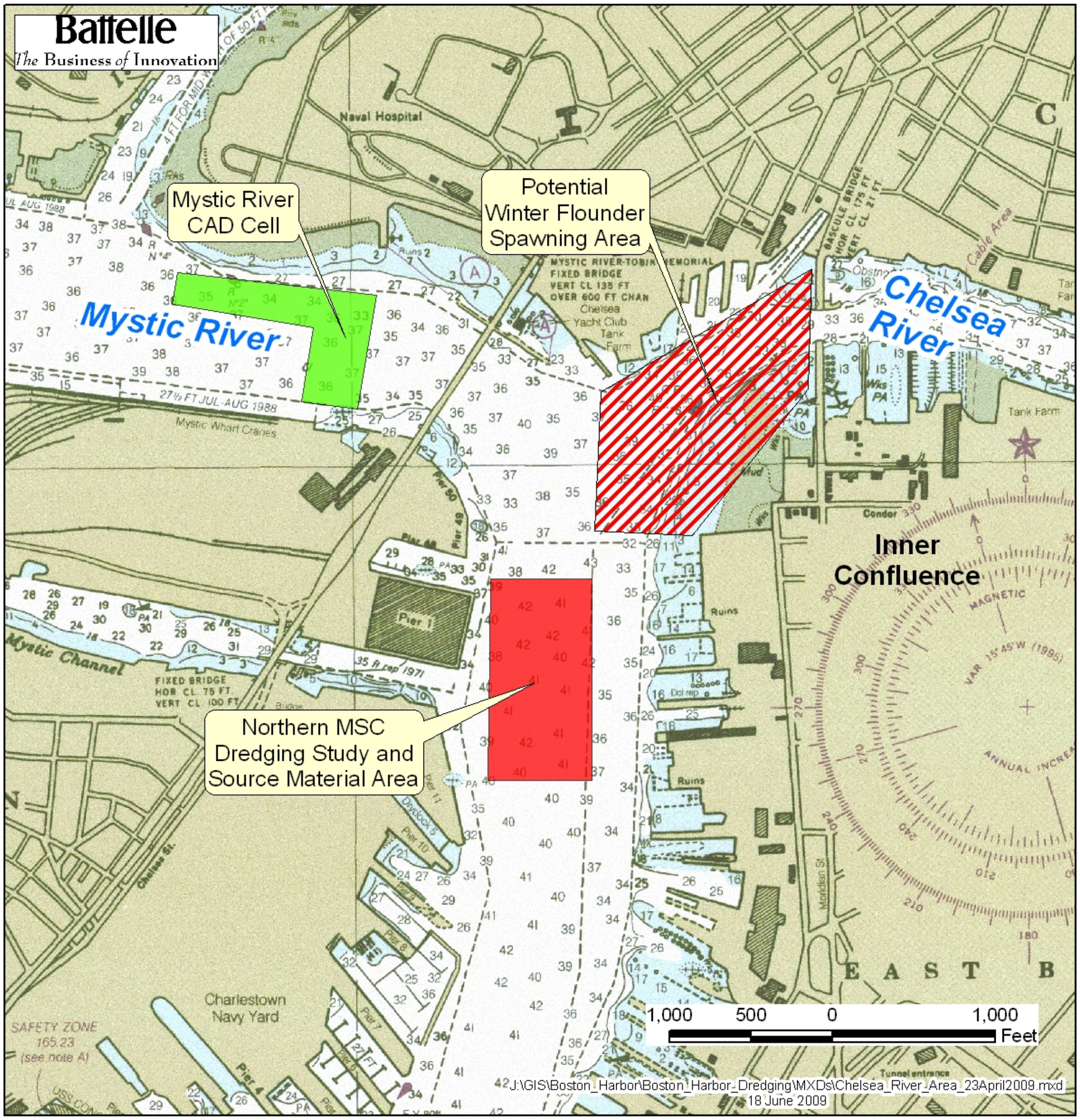


Figure 3. Map of Northern Inner Harbor Showing Location of the Mystic River CAD Cell, Northern Dredging Area in the Main Ship Channel, and Potential Winter Flounder Spawning Area.

1.2 Project Objectives

The first objective of this plume monitoring effort was to conduct shipboard field monitoring to gauge the extent of potential water quality impacts from disposal into the CAD cells, as per the conditions of the Water Quality Certification (WQC) issued for this project. Total suspended solids (TSS) and turbidity were monitored during five disposal events: once during the first week of disposal into the Mystic River CAD cell, twice when the cell was filled to at least 50% of design capacity, and twice when the cell was filled to at least 90% of design capacity. The WQC turbidity performance criteria was <50 nephelometric turbidity units (NTU) above background levels 500 feet down current of the disposal cell in the densest portion of the plume.

The second objective of the monitoring effort, which was not a requirement of the WQC, but was performed to address resource agency concerns, was to determine if suspended sediment was transported and subsequently deposited on potential winter flounder spawning grounds during disposal and dredging activities. These spawning grounds have been identified by the resource agencies as an environmental concern (Figures 3 and 4). TSS and turbidity of suspended sediment plumes produced by continuous dredge activity were monitored during four slack (two high and two low), two ebb and two flood tides in each of the two dredging study areas. The performance criteria was <25 NTU above background level outside of the navigation channel in water depths of less than 25 feet MLLW.

In order to identify any potential project related impacts, this monitoring effort used proven methods from similar past dredge monitoring projects to track real-time migration of dredged material plumes resulting from dredging and disposal operations. This information was available to make operational adjustments during dredge operations as may have been necessary to minimize impacts either to water quality or sediment transport to the potential winter flounder spawning habitats. The measurements consisted of

- velocity, turbidity and suspended sediment concentration derived from real-time, underway Acoustic Doppler Current Profiler (ADCP) measurements of acoustic backscatter;
- turbidity and suspended sediment concentration derived from Optical Back-Scatter (OBS) along with other hydrographic parameters during vertical profiles at discrete locations;
- shipboard turbidity and laboratory TSS analysis of whole water samples collected during vertical profiles.

Measurements of acoustic backscatter using ADCP were made as the survey vessel ran a series of cross-channel transects up and downstream of the dredge or disposal point.

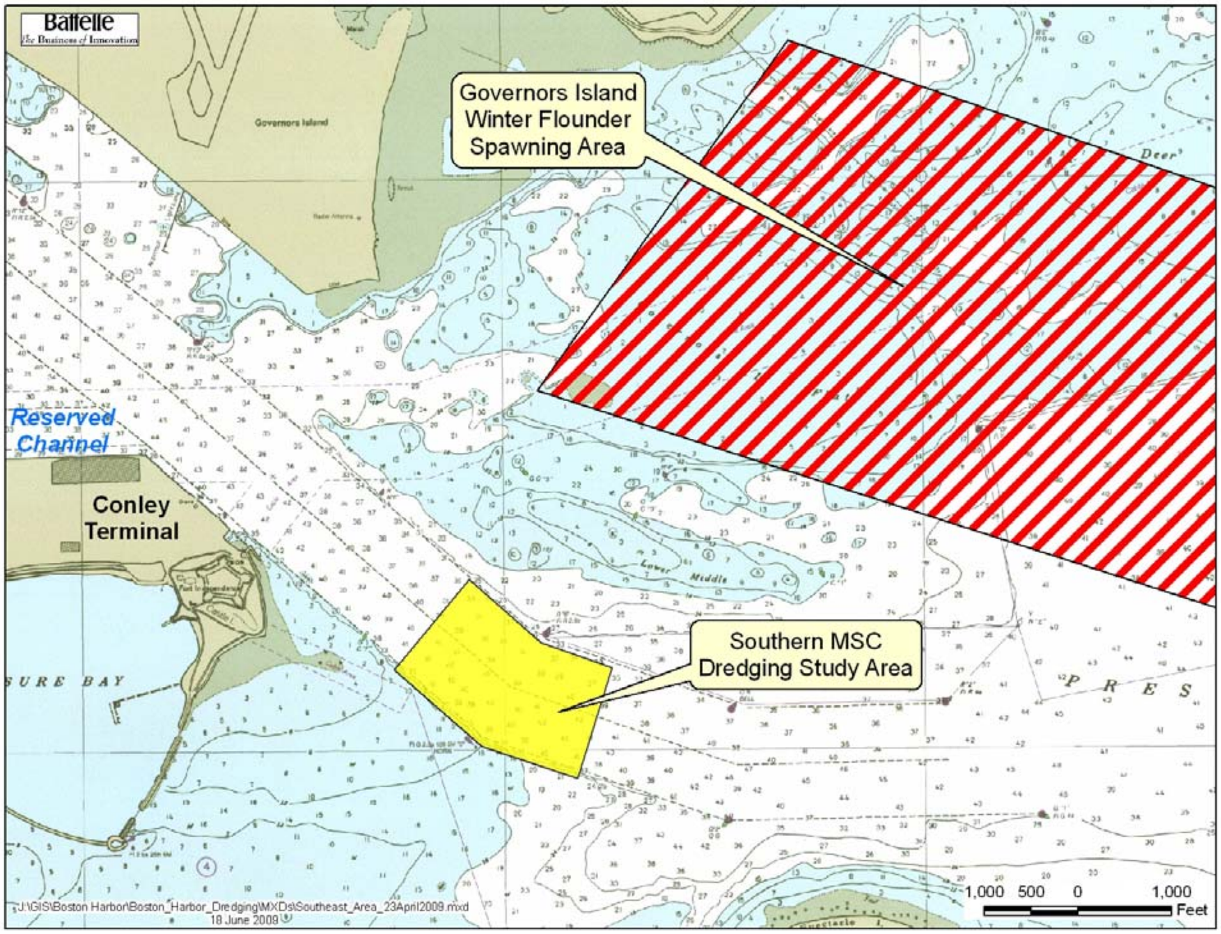


Figure 4. Map of Southern Inner Harbor Showing Location of Southern Dredging Area in the Main Ship Channel and Potential Winter Flounder Spawning Area.

2.0 METHODS

Details on the survey/sampling methods can be found in the project Sampling and Analysis Plan (SAP) (Battelle, 2008). The study design incorporated a broad scale monitoring of sediment plumes using a vessel-mounted ADCP combined with discrete location water column profiling for *in situ* turbidity using a Conductivity-Temperature-Depth (CTD)/Turbidity/rosette sampler and whole water sample collection for TSS analysis.

2.1 Plume Tracking

Plume tracking was conducted using a Teledyne RD Instruments 1200kHz Workhorse Sentinel ADCP mounted on the Battelle R/V *Aquamonitor* (Figure 5). The ADCP was mounted over the side of the *Aquamonitor* so that the acoustic transducers were just below the water surface (Figure 6). The ADCP measures acoustic backscatter intensity in decibels (dB) approximately once per second at 0.5 m vertical intervals throughout the water column while the vessel is underway. The intensity of the acoustic backscatter is proportional to the concentration of suspended sediment present in the water column. The ADCP also provided estimates of the current velocity at the same locations throughout the water column. As the vessel ran transects across the channel and the adjacent shallow areas or in some cases longitudinally along the channel, the ADCP mapped out vertical slices of acoustic backscatter along those transects. These cross sections, although uncalibrated in real-time, nevertheless provided a map of plume location, movement, and dispersion which was used to modify the monitoring vessel track as needed and to select CTD/Turbidity water column vertical profile locations.

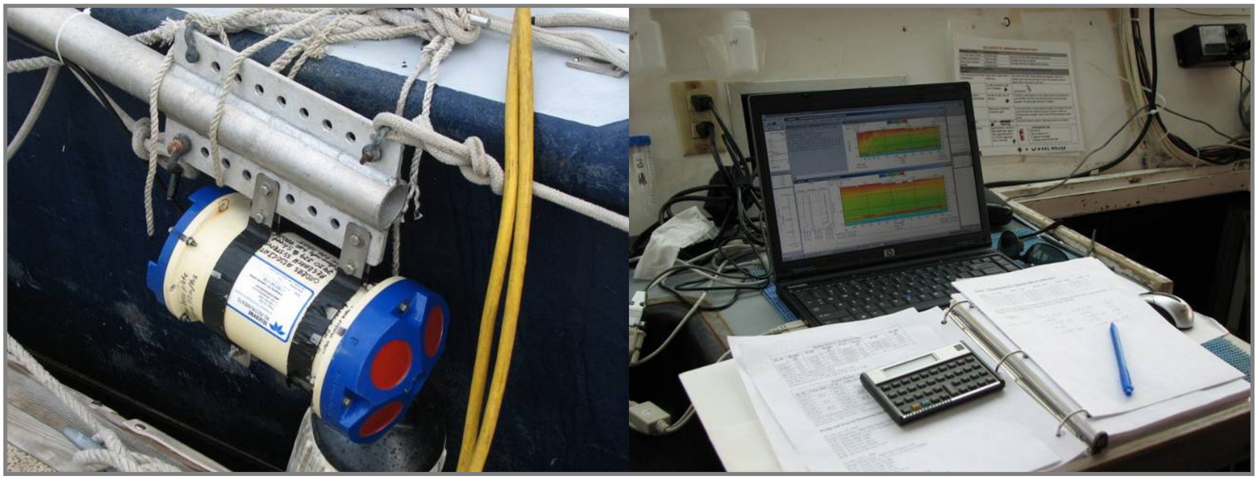


Figure 5. RD Instruments 1200khz Workhorse Sentinel ADCP Mounted on the Battelle *R/V Aquamonitor* and ADCP Real-time Display / Data Collection Laptop.

Figure 6. ADCP Mounted in Operational Position Over the Side of the *Aquamonitor* with the Acoustic Transducers Just Below the Water Surface.

2.1.1 Plume Tracking During Dredging Operations

Plume sampling was conducted when the dredge (Figure 5) had been active during typical dredge activity for a minimum of 4 hours and an established plume had been created. Prior to sampling, the field team used the ADCP to confirm the current direction and velocity near the dredging operation. Reference stations were then profiled and sampled (surface, mid-depth and near-bottom) 1000 ft up current and 1500 ft down current of the dredge. At a minimum for each dredging event, vessel transects consisted of cross-channel transects 300 ft (90 m) up-current of the dredge and from 100 to 1500 ft (30 to 450 m) down-current. An attempt was made to identify the plume centriod from the ADCP record, although this was not always possible particularly when tidal currents were such that the plume was not in a steady state. Once the centroid of the plume had been identified using the ADCP, the vessel held station at that location and conducted a CTD/Turbidity vertical profile. Whole water samples for TSS analysis were collected at three depths: within approximately three feet of the bottom, mid-depth, and approximately one foot below the surface. One depth was selected to coincide with the turbidity maximum. Two lateral and one down plume profile stations were sampled.

Figure 7. Dredging Operations during Removal of Material over the Main Ship Channel CAD Cell.

2.1.2 Plume Tracking During Disposal Operations

Disposal of dredged material into the CAD cell (Figure 8) was limited to the three hour slack window, defined for this activity as the time from one hour before to two hours after predicted slack tide. During each of the disposal events monitored, only one scow disposal occurred during the slack window.

Figure 8. Split Hull Scow Immediately after Placement of Dredged Material into the Mystic River CAD Cell.

Prior to release, the field team used the ADCP to determine the current speed and direction near the disposal operation. Reference stations were then profiled and sampled (mid-depth and near-bottom) 1000 ft up current and 1500 ft down current of the CAD cell. At a minimum for each disposal event, cross-channel transects were conducted with the ADCP at locations 300 feet up current of the CAD cell boundary and 500 and 1000 feet down current of the CAD cell boundary although additional cross-channel and longitudinal transects were performed as needed to best determine the plume extent, trajectory, and dissipation. CTD/Turbidity vertical profiles and whole water samples for TSS analysis were prescribed in the SAP at three stations along the line 500 feet down-current of the CAD cell boundary while the densest portion of the plume crossed the line. However, in most cases the plumes travelled slowly and dissipated quickly so that they never reached the 500 foot down-current compliance transect line. Vertical profiles were instead performed along a transect line closer to the point of release in order to capture physical samples within the plume before it dissipated entirely. At each vertical profile station samples were collected at two depths: 1) within approximately three feet of the bottom, and 2) at the depth of maximum turbidity, or if the turbidity maximum was near-bottom then at mid-depth.

2.1.3 Ship Passage

Additional ADCP transects and CTD/Turbidity vertical profiles were opportunistically taken in the wake of large vessels that transited the area during monitoring. Ship wake measurements were made to record the resuspension of any bottom sediment caused by the prop wash of the vessels for comparison to any dredging related plumes. Attempts were made to make ship passage observations outside of the presence of any dredge related plume in the area.

2.1.4 ADCP Data Reduction

ADCP data were first edited to eliminate superfluous signals from vessel activities. Along-channel and other transects were optionally run to help locate and track the plume as necessary. ADCP data were also collected as the vessel positioned itself for transects and around other vessels. All ADCP data were previewed and full vessel tracks were edited down to a series of cross channel transects. Individual transects that provided the best view of the plume were selected for analysis. The ADCP backscatter data from the selected transects were next calibrated to turbidity and TSS using methods described later. Vertical and horizontal contours of turbidity and TSS were then developed from the selected transects. ADCP derived plots of current velocity (near-surface and near-bottom) were also developed from the selected transects.

2.2 Vertical CTD/Turbidity/Dissolved Oxygen Profiling and Total Suspended Solids Sampling

A CTD/Turbidity sensor and water sampler was lowered over the stern of the R/V *Aquamonitor* (Figure 9) to perform vertical profiles at discrete locations (summarized in Table 1). The profiler was equipped with an underwater instrument package consisting of the CTD, a Dissolved Oxygen (DO) sensor, OBS turbidity sensors, and a water-sampling system including 9L rosette sampling bottles. Three OBSs were included in the sensor suite, each configured for a different turbidity range (0– 25, 0–125, and 0–500 NTU).

Figure 9. CTD/Turbidity/Dissolved Oxygen Profiler and Water Sample Rosette System Being Deployed from the *R/V Aquamonitor.*

Figure 10. LaMotte Model 2020e Bench Top Turbidimeter.

Whole water samples were also collected using the water sampler during vertical profiles. The samples were collected for shipboard measurement of turbidity using a bench top LaMotte Model 2020e Turbidimeter and for laboratory TSS analysis. Samples were collected by triggering the rosette bottles at two depths during disposal monitoring and three depths during dredging monitoring. The designated depths were near-surface (dredging monitoring only), near-bottom, and at the turbidity maximum, if one was observed. If a turbidity maximum wasn't observed then a sample was collected at mid-depth. After the rosette was recovered and on deck, samples were transferred to 1-L opaque bottles and stored on ice (~4°C) in the dark until they were delivered to Alpha Analytical for processing and TSS analysis. Water from the rosette bottles was also transferred to 10mL glass vials for immediate onboard turbidity analysis (Figure 10). The outside of the vial was cleaned and dried prior to insertion into the Turbidimeter to prevent particles and condensation on the outside of the vial from interfering with the measurements. The instrument was configured to collect two separate readings from each sample and average the results, which was transcribed onto the field data sheet.

Table 1. Summary of CTD/Turbidity Profiles and TSS Samples

Date	Type of Monitoring	Monitoring Period	Number of Profile Stations	Number of TSS Samples (including Field Quality Control)	Total Number of Samples Per Day
6/30/2008	Dredging	High Slack	6	18 + 1 duplicate (dup)	60
		Max Ebb	6	18 + 1 dup	
		Low Slack	6	18 + 1 dup	
	Ship Passage	Ship Passage	1	3	
7/1/2008	Disposal	High Slack	5	10	10
7/2/2008	Dredging	Max Flood	6	20[c] + 1 dup	62
		Max Ebb	6	18 + 2 dup	
		Low Slack	6	18 + 1 dup	
	Ship Passage	Ship Passage	1	2[b]	
7/3/2008	Dredging	Max Flood	6	18 + 1 dup	38
		High Slack	6	18 + 1 dup	
9/9/2008	Dredging	High Slack	6	18 + 1 dup	41
		Max Flood	6	17 + 1 dup[a]	
	Ship Passage	Ship Passage	2	2[b]	
	Ship Passage	Ship Passage	2	2[b]	
9/10/2008	Dredging	High Slack	6	18 + 1 dup	40
		Max Ebb	6	18 + 1 dup	
	Ship Passage	Ship Passage	1	2[b]	
9/11/2008	Dredging	Max Ebb	6	18 + 1 dup	59
		Low Slack	6	18 + 1 dup	
		Max Flood	6	18 + 1 dup	
	Ship Passage	Ship Passage	1	2[b]	
9/12/2008	Dredging	Low Slack	6	18 + 1 dup	19
10/3/2008	Disposal	Low Slack	5	10	20
10/3/2008	Disposal	High Slack	5	10	
10/27/2008	Disposal	Low Slack	5	10 + 1 dup	11
10/28/2008	Disposal	High Slack	5	10	10

[a] A mid depth sample was not collected at one of the lateral extents due to water depths of less than 4 meters.
[b] The near-surface sample not taken.
[c] Two extra samples taken during high turbidity conditions to supplement ADCP calibration at the high end.

2.3 Laboratory TSS Processing

The whole water samples collected during the survey were analyzed by Alpha Analytical Laboratory for TSS using a modified US Environmental Protection Agency (EPA) method 160.2 procedure. A well-mixed sample was filtered through a 0.45 µ membrane filter and the residual retained on the filter was dried and weighed. For each batch of 20 or fewer samples, a laboratory method blank, laboratory control sample (LCS), and laboratory duplicate (if sufficient material was available), was processed and analyzed with the field samples. Results are reported on a dry-weight basis.

2.4 Calibration

Data were collected to calibrate the optical and acoustic instruments to TSS and turbidity correcting for site-specific factors including particle size distribution, particle type, and particle surface roughness. At vertical profile stations, the CTD/Turbidity sensor package and rosette water sampler was lowered over the stern of the vessel to collect OBS profile data and discrete water samples. Simultaneously, the ADCP collected acoustic backscatter data. With the time and depth of sample bottle closure digitally recorded, it is a simple matter to compare turbidity and TSS from water samples at a given depth and time with optical and acoustic backscatter from OBS and ADCP at the same depth and time. All data pairs from both dredge and disposal surveys were used in a combined calibration curve. The turbidity and TSS sample volumes were not the same which, in a turbulent, heterogeneous suspended sediment plume could result in the introduction of some error into the calibration. However, the method has been commonly used with good results in many field studies with a range of current velocities, sediment types, and sediment grain size distributions (see the review paper by Poerbandono and Mayerle [2004]).

The OBS sensors are factory calibrated to turbidity in NTU but experience has shown the need for an *in situ* calibration to account for site-specific particle characteristics. ADCPs are not factory calibrated for turbidity or suspended sediment concentration. ADCP and OBS were calibrated for turbidity against water samples analyzed with the bench top turbidimeter and for suspended sediment concentration (TSS) against water samples analyzed in the laboratory. All samples available from both the disposal monitoring and dredging monitoring surveys were used in the calibrations. The theoretical response of the OBS sensors to suspended sediment concentration, measured either as turbidity or TSS, is linear and the calibration curves (Figure 11 and Figure 12) have been plotted accordingly.

The ADCP is primarily designed and used to quantify current velocity by measuring the Doppler frequency shift in the acoustic backscatter signal. The acoustic backscatter intensity is measured and recorded but processed no further by the ADCP since only the frequency shift is used to calculate velocity and the frequency shift is independent of the backscatter intensity. The backscatter intensity, however, is dependent on the suspended sediment concentration, but in order to calibrate backscatter to suspended sediment concentration, losses dues to acoustic beam spreading and acoustic absorption by water must be accounted for in the backscatter signal. Based on the energy of acoustic intensity, Deines (1999) simplified the active sonar equation from underwater acoustic theory for the broadband ADCP:

$$10\log_{10}(SSC) = C_k + K_C E + 10\log_{10}(R^2) + 2\alpha_w R$$

where SSC is suspended sediment concentration, R is the range along the beam to the scatterer, α_w is the attenuation coefficient due to water absorption (primarily dependent on the frequency and provided by the instrument manufacturer), and E is the acoustic echo strength (in instrument counts). The last two terms in the equation represent the effects of acoustic beam spreading and acoustic absorption by water, respectively. C_k and K_C are constants that cannot be measured directly. Least squares regression analysis was used to estimate the best values for the constants C_k and K_C (Figure 13). The estimated values for C_k and K_C are -19.208 mg/L and 0.3188 mg/L/dB, respectively and are within the range suggested by Poerbandono and Mayerle (2004). The error on C_k with 95% confidence is ± 4.50 mg/L. Assuming a linear relationship between turbidity and suspended sediment concentration, an equation of the same form was used for calibration of the ADCP to turbidity (Figure 14). The estimated values for C_k and K_C for turbidity are -21.421 NTU and 0.2996 NTU/dB, and the error on C_k with 95% confidence is ± 4.14 NTU.

The calibration scatter and calculated regressions (presented in Figure 11 - Figure 14) suggest that the OBS sensors provide a better estimate of suspended sediment concentration, which is consistent with the literature for measurements in coastal waters and estuarine environments. The ADCP has the advantage over the OBS, however, of providing surface to bottom water column measurements continuously while the vessel is underway. This allows rapid, broad-scale plume tracking coverage. The OBS, by contrast, provides a point measurement only and must therefore be lowered through the water column at individual stations or towed at individual depths.

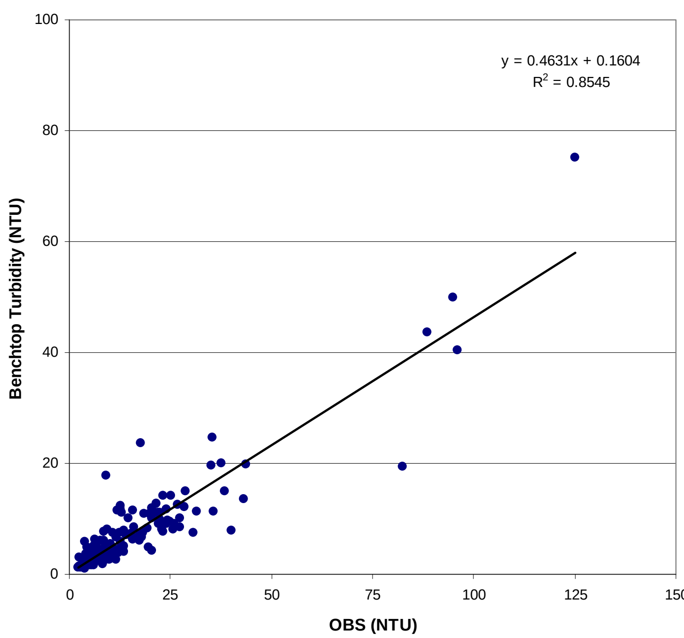


Figure 11. Least Squares Regression Analysis of Turbidity from Water Samples Measured by Bench Top Turbidimeter versus *In Situ* Optical Backscatter Readings (Uncalibrated Turbidity) from Vertical Profiles for the 0 – 125 Range OBS.

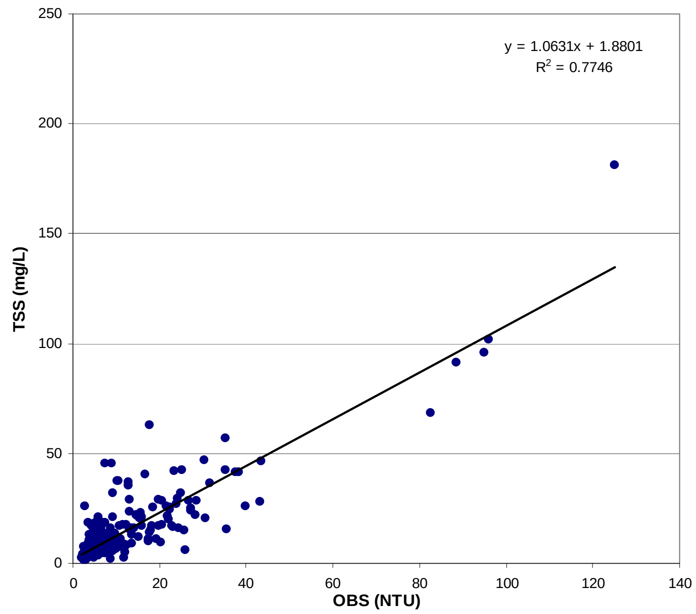


Figure 12. Least Squares Regression Analysis of Suspended Sediment Concentration (TSS) from Water Samples Measured in the Laboratory versus *In Situ* Optical Backscatter Readings (Uncalibrated Turbidity) from Vertical Profiles for the 0 – 125 Range OBS.

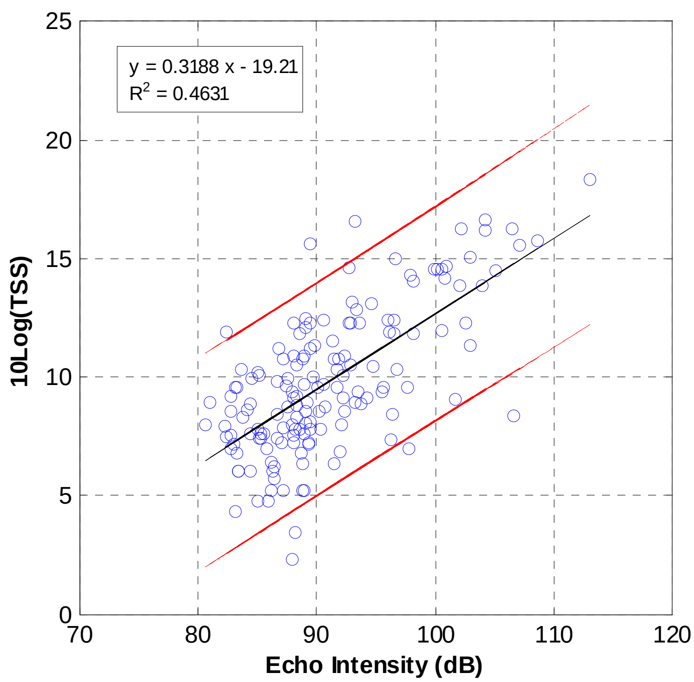


Figure 13. Least Squares Regression Analysis of Suspended Sediment Concentration (TSS) from Water Samples Measured in the Laboratory versus ADCP Echo Intensity in Decibels (dB). Red Lines Indicate the Regression 95% Confidence Interval.

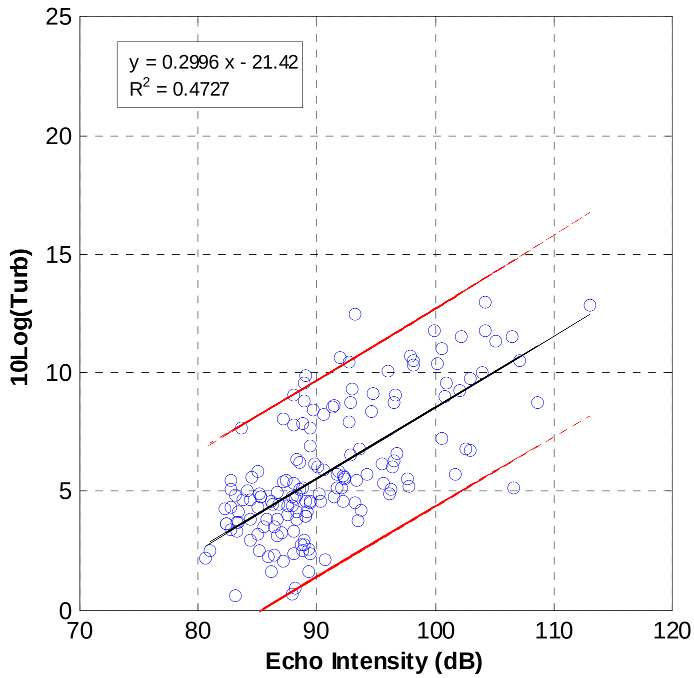


Figure 14. Least Squares Regression Analysis of Turbidity from Water Samples Measured by Bench Top Turbidimeter versus ADCP Echo Intensity in Decibels (dB).
Red Lines Indicate the Regression 95% Confidence Interval.

3.0 RESULTS

3.1 Dredging Operation Plumes

3.1.1 General Conditions

Tidal currents dominate the movement of water in Boston Harbor and thereby the movement of any suspended sediment in the water column. Peak tidal flows are generally less that 35 cm/s (0.7 kts) in the Northern MSC area and less than 50 cm/s (1.0 kts) in the Southern MSC area. The configuration of the harbor in the Southern MSC area results in a flow which is nearly rectilinear, flowing either up or down channel. In the southern area, the flow is more complex. During the flood tide (westward flow) the currents tend to diverge near Castle Island with most of the current moving northwestward following the navigation channel and some moving southwestward into Quincy Bay. During the ebb tide (eastward flow) the pattern reverses and the current following the navigation channel converges with a current from Quincy Bay.

The Charles, Mystic, Chelsea, and Neponset Rivers all feed into Boston Harbor and provide freshwater inflow to the Harbor that varies seasonally. The freshwater driven currents are weaker than the tides except occasionally during large spring freshet events. The evidence of freshwater input to the Harbor can be seen both in the horizontal gradients in surface salinity and temperature across the harbor and in vertical profiles of salinity and temperature (Figures 15 and 16). Water column density stratification was observed in both the Northern and Southern MSC areas. The effect was stronger during the northern survey in June-July as seen in the salinity profiles (compare Figures 15 and 16). Water column stratification is important because of its potential effect on harbor circulation and in turn affects sediment plume transport. Estuarine circulation is the density driven movement of fresher surface water down the estuary simultaneous with the movement of saltier bottom water up the estuary. In Boston Harbor, the effect is vertical shear in the water column velocity, the result of which is that ebb currents are stronger near-surface and flood currents are stronger near-bottom. During slack tide, the presence of water column shear can result in the movement of near-surface water in one direction and near-bottom water in another. Shear can have a dramatic effect on a suspended sediment plume by significantly increasing the plume dispersion as the shearing currents stretch or tear the plume and by increasing mixing caused by the increased turbulence. Water column velocity shear observed during plume tracking will be seen in velocity measurements presented later.

The protected nature of Boston Harbor is such that winds (even storm winds) have a limited effect on harbor circulation. Weather conditions during the study period were mild (Table 2) and no evidence of wind driven circulation was observed. The absence of any wind-driven circulation simplifies the interpretation of the plume tracking data.

Table 2. Weather Conditions from NOAA Hindcast for Boston Harbor during Dredging Operations Monitoring.

Date	Temperature (°C)	Wind Speed and Direction
6/30/2008	19.1 to 21.4°C	Southwest 5 to 10kts becoming southeast 10 to 15kts
7/2/2008	18.3 to 20.4°C	Southwest 5 to 10kts becoming southeast
7/3/2008	19.1 to 24.1°C	Southwest 10 to 15kts Gust up to 20kts after 15:00
9/9/2008	19 to 23.1°C	Southwest 5 to 10kts increasing to 10 to 20 kts with gust to 25 kts
9/10/2008	15.9 to 18.8°C	Northwest around 20kts with gusts to 25 kts diminishing to 5 to 10 kts
9/11/2008	16.0 to 17.3°C	Northeast 5 to 10 kts
9/12/2008	16.0 to 18.0°C	Southwest 10 to 15kts Gust up to 20kts after 15:00

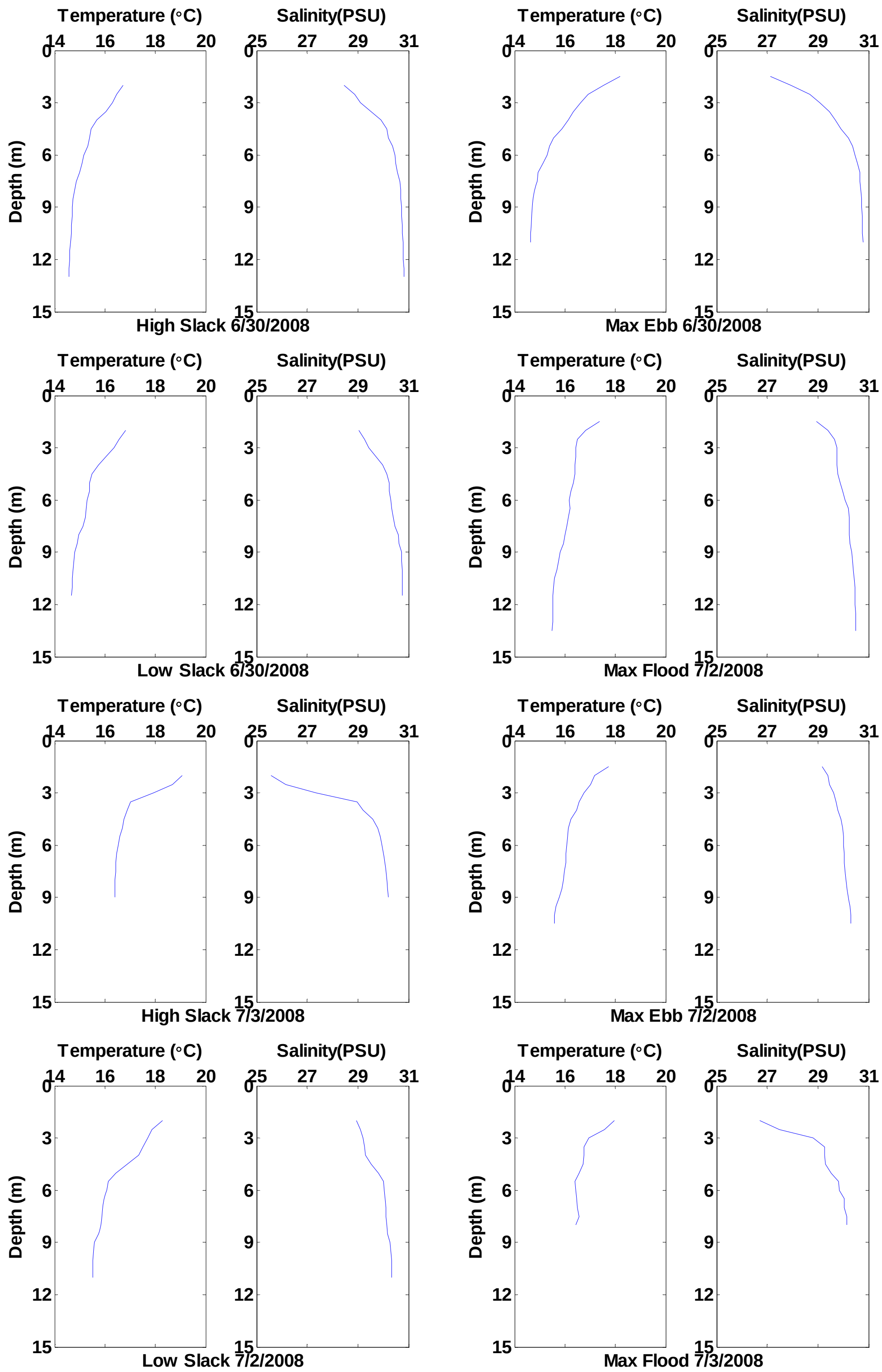


Figure 15. Water Column Stratification as Measured by Vertical Profiles of Temperature and Salinity during Dredged Material Plume Tracking in the Northern Area (late June and early July).

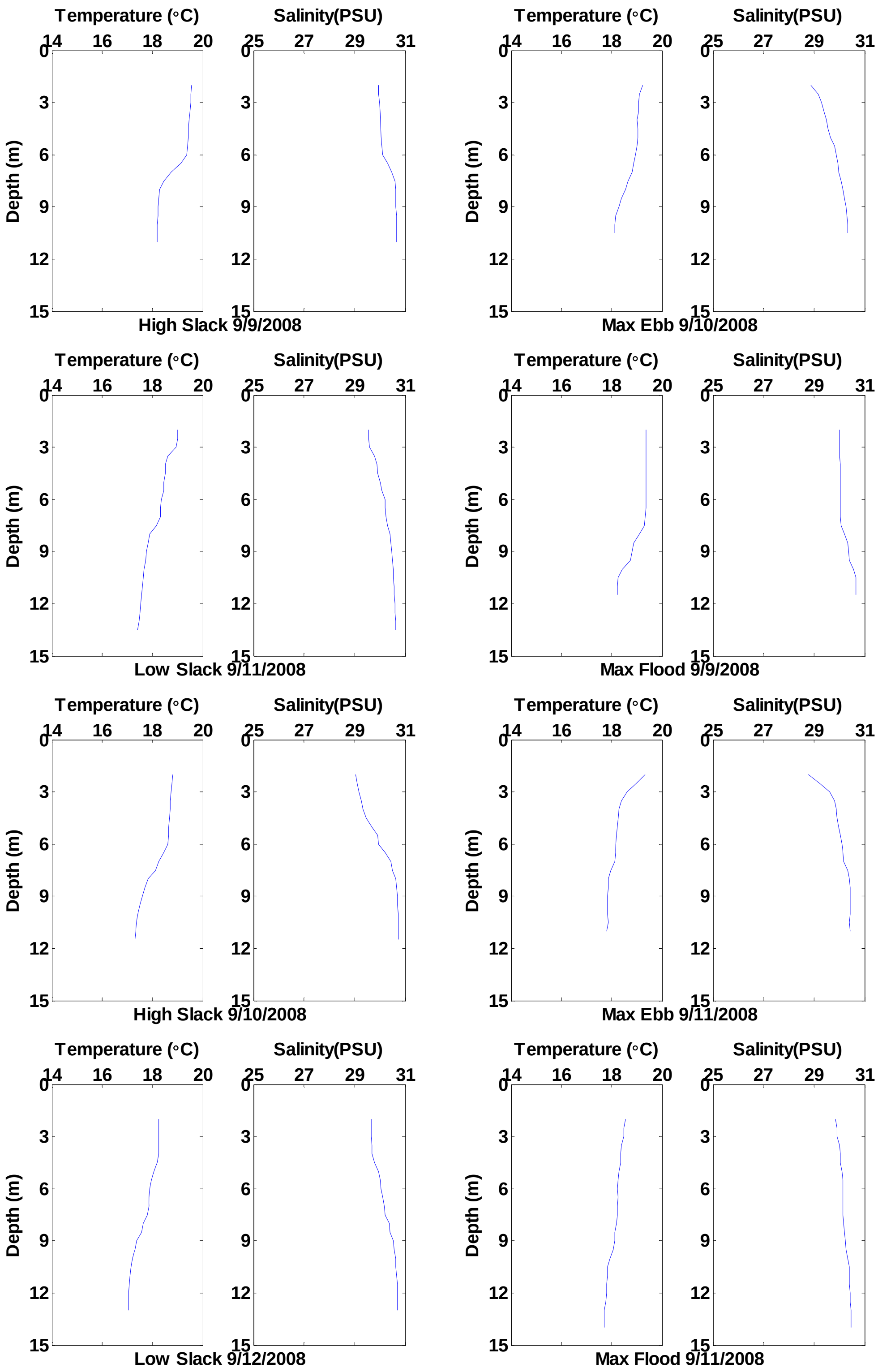


Figure 16. Water Column Stratification as Measured by Vertical Profiles of Temperature and Salinity during Dredged Material Plume Tracking in the Southern Area (mid-September).

3.1.2 Background Turbidity

When possible, background samples were collected at least 1000 ft (300 m) up-current or 1500 ft (450 m) down-current of the dredging operation. The measured background levels where quite low and relatively consistent over long distances. Figure 17 presents the calibrated turbidity and TSS from OBS profiles at reference locations from both the Northern and Southern MSC areas. With the exception of a few profiles with elevated near-bottom turbidity and suspended sediment[1], the background turbidity during dredging operations was approximately 1 – 4 NTU and the background TSS was approximately 2 – 15 mg/L. The black lines in Figure 17 represent the depth average of the background profiles not exhibiting a near-bottom peak. With a range of background values observed, a conservative approach was taken; the minimum of the average vertical profile was selected (2 NTU and 5 mg/L) as the background value and used throughout the following analysis.

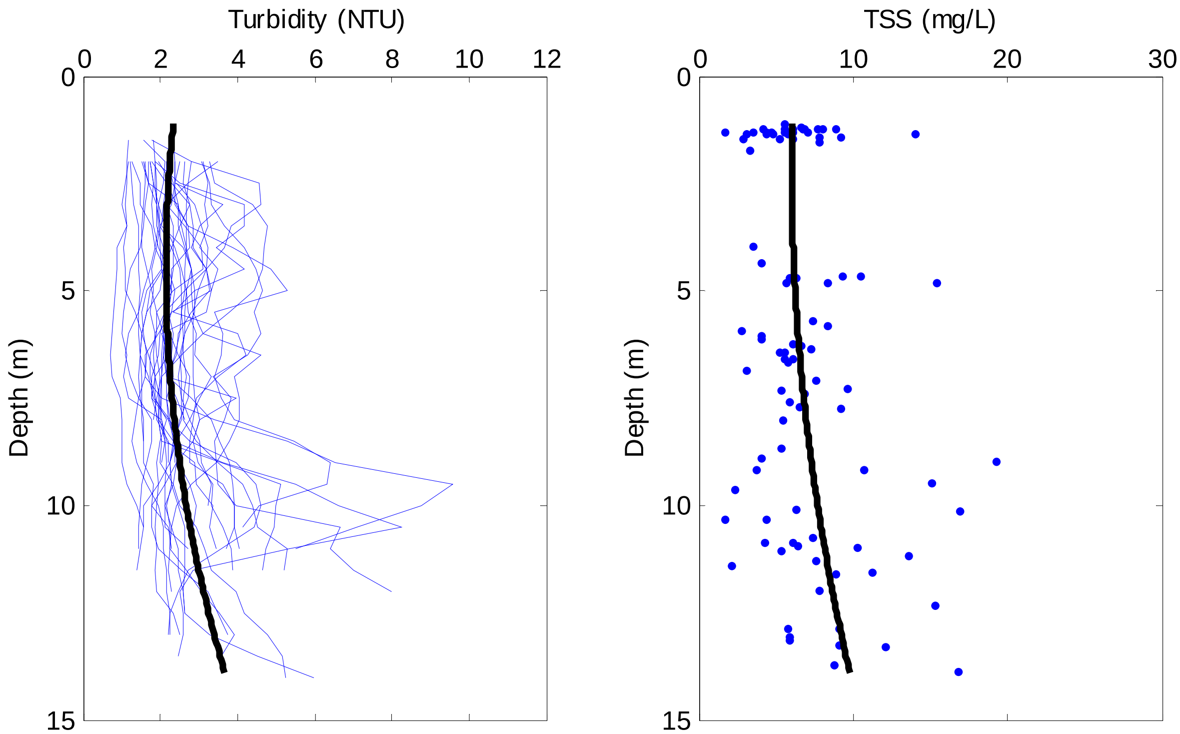


Figure 17. Ambient Turbidity and TSS during All Background Vertical Profiles.

Presented are data from all 32 background profiles (blue) and the 2nd order polynomial fit (black) of those 28 profiles without elevated near-bottom turbidity.

[1] Reference profiles with elevated near-bottom turbidity were all collected at in-channel reference locations during on-going dredging operations and no such elevated near-bottom turbidity was observed at reference stations out of the navigation channel or while dredging operations were suspended. This suggested the possible presence of a dredging related near-bottom turbidity signal at in-channel reference stations. After this was observed (7-1-08), reference (background) stations were chosen outside the channel where conditions were likely more representative of background.

3.1.3 Dredge Plume Turbidity and Suspended Sediment

Dredge plumes were monitored during four slack (two high and two low), two ebb and two flood tides in each study area. In the series of figures that follow (Figures 18-33), current velocity and suspended sediment measurements collected during the dredge plume surveys in the northern and southern areas are presented. Each figure presents results from a single tide phase survey. Included in each figure is a series of panels presenting the locations of measurements, current velocity, and vertical and plan-view contours of observed turbidity. The location panel shows the approximate location of the dredge barge during the tide phase survey, the locations of cross-current vessel transects, and the locations of vertical profile stations. The vessel transects are labeled and are referred to in a later panel. Two panels present the current velocity measured near surface and near bottom at the transect closest to the dredge. The velocity is represented as arrows with lengths proportional to the speed of the current and direction representing the direction of current flow. The next panel presents vertical contours of calibrated turbidity in NTU (above background) along each vessel transects. The contours are oriented relative to their locations as seen in the location figure and the approximate location of the channel boundaries are shown as dashed lines. The last series of panels present three plan-view contours of estimated turbidity near-surface, mid-depth, and near-bottom. The near-surface and mid-depth contours represent turbidity at constant depths below the surface, while the near-bottom contours represents turbidity at a constant height above the bottom. Also visible in these panels are the turbidity values measure by OBS during vertical profiles for the same depths. The full vertical profiles of turbidity and other parameters are available in the Survey Reports (Battelle, 2008b and Battelle, 2008c).

Vertical and plan-view contours of suspended sediment concentration in mg/L above background have also been developed. These figures were derived from the same set of ADCP acoustic backscatter data using the suspended sediment concentration calibration curve presented previously and so appear similar to the turbidity contour figures. They are presented separately in Appendix A of this report. In the following sections, TSS values from Appendix A will be referenced alongside corresponding turbidity values.

3.1.3.1 Dredge Plume at Max Ebb in the Northern MSC

Figures 18 and 19 document the suspended sediment plume observed in the presence of strong ebb currents in the Northern MSC. In each figure, the current is flowing southward parallel to the channel and is stronger at the surface than near-bottom (estuarine circulation effect). This coherent flow pattern results in a coherent plume observable at some distance from the dredge. Transect A in each survey was located approximately 300 ft (90 m) up-current of the dredge and shows background levels of turbidity. All other transects are located down-current of the dredge and show the evolution of each plume as it moves with the ebb tide (Figures 18 and 19). Both suspended sediment plumes start narrow, 150-250 ft wide (50-75 m) and concentrated (up to 20 NTU; 40 mg/L[2]) at Transect B approximately 300 ft (90 m) down-current of the dredge, then widen and dissipate as they are moved down-current. Transect E of the second ebb survey (Figure 19) approximately 1000 ft (300 m) down-current shows the plume has widened to nearly the full width of the channel in a layer only 6-9 ft (2-3m) thick above the bottom at low concentration (<5 NTU; 10 mg/L). The plume is still present at a level just above background at the furthest transects in both surveys approximately 1000 and 1500 ft (300 and 450 m) down-current. This suggests that,

[2] TSS is presented in the corresponding figures in Appendix A of this report.

assuming an average current speed of 20 cm/s, suspended sediment remains in the water column for approximately 1.5 to 2 hours. No evidence of the plume can be seen outside of the navigation channel.

3.1.3.2 Dredge Plume at Low Slack in the Northern MSC

Figures 20 and 21 document the suspended sediment plume observed in the water column during dredging around the time of low slack in the Northern MSC. The figures demonstrate the sensitivity of the plume to the tidal currents. Near slack, the highest observed turbidity is noticeably lower than during the ebb tide survey reaching only 12 – 15 NTU (25 – 30 mg/L) at Transect D (approximately 200 ft north of the dredge) and with the size of the plumes much smaller, especially during the second low slack (Figure 21). The currents seen in both figures are weak and variable but beginning to flow to the north during the first survey. The result of the weak currents is that the dredge plume is not transported very far from the source. With little current to transport and disperse the suspended sediment, the dredge plume pools beneath the dredge where it is not possible to safely make measurements. During the first low slack survey (Figure 20), the plume is predominately visible to the north of the dredge (see Transect B, 700 ft north of the dredge) but is also slightly visible to the south at Transect E (<5 NTU), 500 ft south of the dredge. This is probably a residual of the plume from before the turn of the tide. The other transects show the dissipation and dispersion of both plumes away from the dredge. The “hot-spot” visible on the mid-depth plan-view contour of Figure 21 of the second low slack survey is due to the school of fish seen in Transect C. No evidence of the plume can be seen outside of the navigation channel.

3.1.3.3 Dredge Plume at Max Flood in the Northern MSC

The max flood survey results (Figure 22 and 23) exhibit a pattern very similar to the max ebb surveys in the Northern MSC. The current is flowing northward parallel to the channel and is weaker at the surface (estuarine circulation effect). The coherent tidal flow results in a plume observable at some distance from the dredge, but no evidence of the plume can be seen outside of the navigation channel. The up-current transects, located approximately 300 ft (90 m) from the dredge, show background levels of turbidity suggesting that no residual plume is present from the previous ebb tide. All other transects are located down-current of the dredge and show the plume dissipating as it moves with the flood tide from a narrow 150-250 ft wide (50-75 m) and concentrated (20 NTU; 50 mg/L) plume at Transects 4 and 5 (Figure 22 and 23) to a weaker plume (<5 NTU; <15 mg/L) over 800 ft (250 m) wide at Transect A and B, in Figure 22 and 23, respectively (1000 ft downdrift). In each figure, the current shows evidence of a slight horizontal shear with the surface water veering left of the bottom water, the effect of which can be seen in both the vertical and plan-view contours (particularly in the vertical contours and the mid-depth plan-view contour of Figure 22).

3.1.3.4 Dredge Plume at High Slack in the Northern MSC

The first high slack survey (Figure 24) in the Northern MSC exhibits a pattern similar to the low slack surveys: weak, variable currents, especially near-bottom. Monitoring data indicates that these currents do not transport the dredge plume very far, resulting in low suspended sediment concentrations (<10 NTU; <25 mg/L) across all transects during the first survey. The second high slack survey (Figure 25), however, shows that the near-bottom current, although turning, was primarily flowing northward at a rate of up to 15 cm/s while the surface current was essential slack. This condition resulted in the detection of a distinct plume signal in the lower half of the water column at the first down-current transects (~20 NTU; ~50 mg/L) 200 ft from the dredge. There is no evidence of plume migration outside the navigation channel.

3.1.3.5 Dredge Plume at Max Ebb in the Southern MSC

During the southern area surveys, the dredge was working the channel slope along the south edge of the MSC except during the second low slack survey when it was working the along the north edge of the MSC. The more complex flow pattern in this area (described earlier) generally dispersed the dredge plumes more widely resulting in a weaker, less coherent plume signal. Note that the southern area surveys were performed around tidal neap (September 9 – 12, 2008) with maximum currents predicted to be 40% less than the bi-weekly spring tide maximum.

Figures 26 and 27 depict the suspended sediment plume observed around the time of maximum ebb in the Southern MSC. It is apparent in the velocity panels that the published time of maximum ebb corresponds to the time of maximum ebb of the surface layer; in each figure, the surface current is flowing seaward at approximately 25 cm/s and the bottom current is nearly slack. The result is that the dredge plume, which tends to remain in the lower portion of water column, is by and large not transported away from the dredge. The dredge plume is evident at low concentrations near bottom at Transect A (~5 NTU; ~10 mg/L) located approximately 300 ft (90 m) up-current (west) of the dredge. On the down-current side, the plume concentration at Transect B approximately 300 ft from the dredge is ~12 NTU; ~35 mg/L. From there the plume dissipates to a concentration of ~5 NTU; ~10 mg/L at transect D, 1000 ft down-current. Unlike the max ebb in the Northern MSC, the flow is not particularly uniform and the dredge plumes do not appear to start narrow and spread as they are carried away from the dredge. For example, in Transect B in each figure, 300 ft down-current of the dredge, the plume width is already quite broad at low concentrations 500 ft wide (150 m) at ~5 NTU with some intensification nearest the dredge. The plume is still present at a level just above background at the furthest transects in both surveys approximately 1500 ft (450 m) down-current. While the plume is evident across the entire navigation channel at low concentration, again, there is no evidence of plume migration outside of the channel.

3.1.3.6 Dredge Plume at Low Slack in the Southern MSC

As found during the slack surveys in the Northern MSC, the currents are weak and variable resulting in little plume transport during the first Southern MSC low slack surveys (Figure 28). Turbidity levels near the dredge are <8 NTU (<25 mg/L), and what plume is present is localized to the south side of the channel and scarcely visible at Transect A located 1000 ft (300 m) down-current of the dredge (to the northwest). The surface current direction suggests that some of the plume may be transported out of the channel onto the flats to the southwest and this is substantiated by the concentration profiles which show a filament of the plume approximately 800 ft (250 m) out of the channel. The turbidity of this filament is low, at or below 5 NTU above background.

In the second low slack survey (Figure 29), the bottom current is weak and variable, but the surface current is still ebbing. As a result, the plume moves eastward with the current and is visible out to Transect F, 1500 ft (450 m) down-current of the dredge, although with moderate turbidity and suspended sediment concentrations (<15 NTU; <32 mg/L). It appears that the slope of the channel keeps the higher concentration plume in the channel at Transect B and Transect C located 400 and 500 ft (120 and 150 m) seaward of the dredge, but as no slope separates the channel from the anchorage area the current carries the plume beyond the channel into the anchorage area due east of the dredge at concentrations just above background. There is no evidence of plume migration beyond the anchorage area.

3.1.3.7 Dredge Plume at Max Flood in the Southern MSC

The max flood surveys in the Southern MSC (Figures 30 and 31) document the transport of the dredge plume by relatively strong currents in a way similar to the max ebb and flood surveys of the Northern MSC. In the first survey (Figure 30), the near-surface and near-bottom currents are primarily flowing up-channel (to the northwest) with only a weak divergence (as discussed earlier). The currents are not particularly strong, so the concentrated plume is transported only as far as Transect B located 500 ft (150 m) down-current. The plume is still present at a level just above background at Transect A approximately 300 m (1000 ft) down-current. There is no evidence that the plume moves outside the navigation channel during the first survey.

In the second max flood survey (Figure 31), there is a strong shear between the near-surface current flowing southwest and near-bottom current flowing northwest (steered that way by the channel) which disperses the plume rapidly. This results in a plume which does not maintain a coherent form. A filament of the plume is transported up the slope of the channel and southwest out of the channel onto the shallow flats no further than approximately 160 ft (50 m) from the channel slope. The turbidity in that filament of the plume is ~12 NTU (~30 mg/L). In the channel the plume concentration is as high as ~15 NTU (~35 gm/L).

3.1.3.8 Dredge Plume at High Slack in the Southern MSC

In first high slack survey (Figure 32) the variable currents made tracking difficult with the result that the survey team misjudged the time of the turn of the tide and measurements were made primarily southeast of the dredge barge when it probably should have been run to the northwest. The plume is visible on Transect A, 300 ft (90 m) up-channel, to the northwest, of the dredge but hardly visible above background at the down-channel transects. A filament of the plume appears at the surface as far as approximately 400 ft (125 m) out of the channel to the southwest. The filament concentration is low at <10 NTU (<25 mg/L). The peak observed concentration of the plume in the channel along Transect A 300 ft from the dredge is ~20 NTU (~50 mg/L).

The second high slack survey results (Figure 33) exhibit a pattern similar to the typical slack surveys: variable currents that disperse the dredge plume and do not transport the intense portion of the plume far from the dredge. Figure 33 shows the resulting low suspended sediment concentrations (<10 NTU; <25 mg/L) across all transects. Again a filament of the plume is carried out of the channel to the south as far as approximately 650 ft (200 m) from the edge of the channel at concentrations no greater than 7 NTU (26 mg/L).

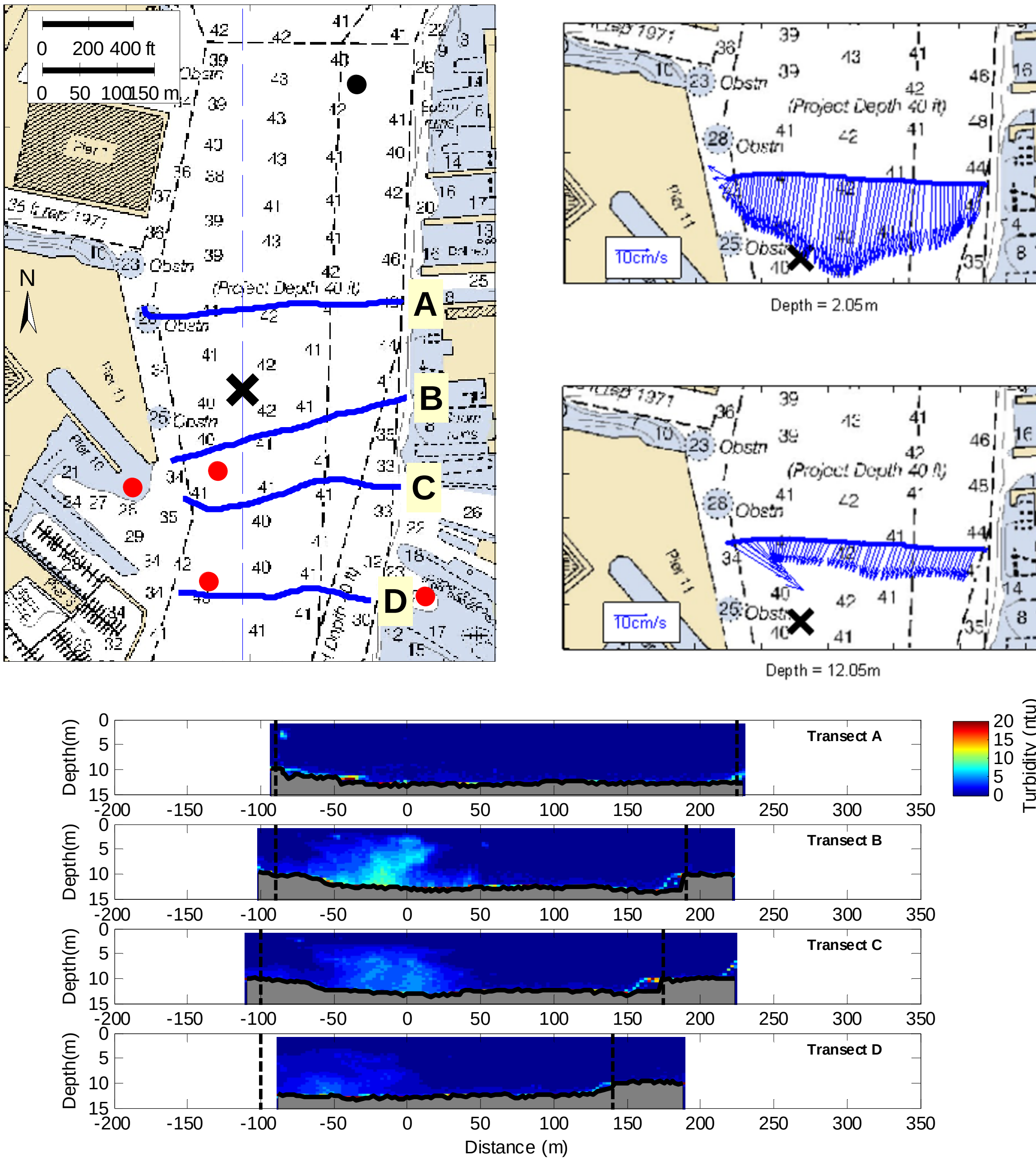


Figure 18. Dredge Plume Observations during First Max Ebb in the Northern MSC.

The upper left panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The upper right panels present near-surface and near-bottom velocities measured with ADCP at Transect A. The lower panel presents vertical slices of calibrated turbidity above background measured with ADCP along each vessel transect (dashed lines represent the approximate channel boundaries).

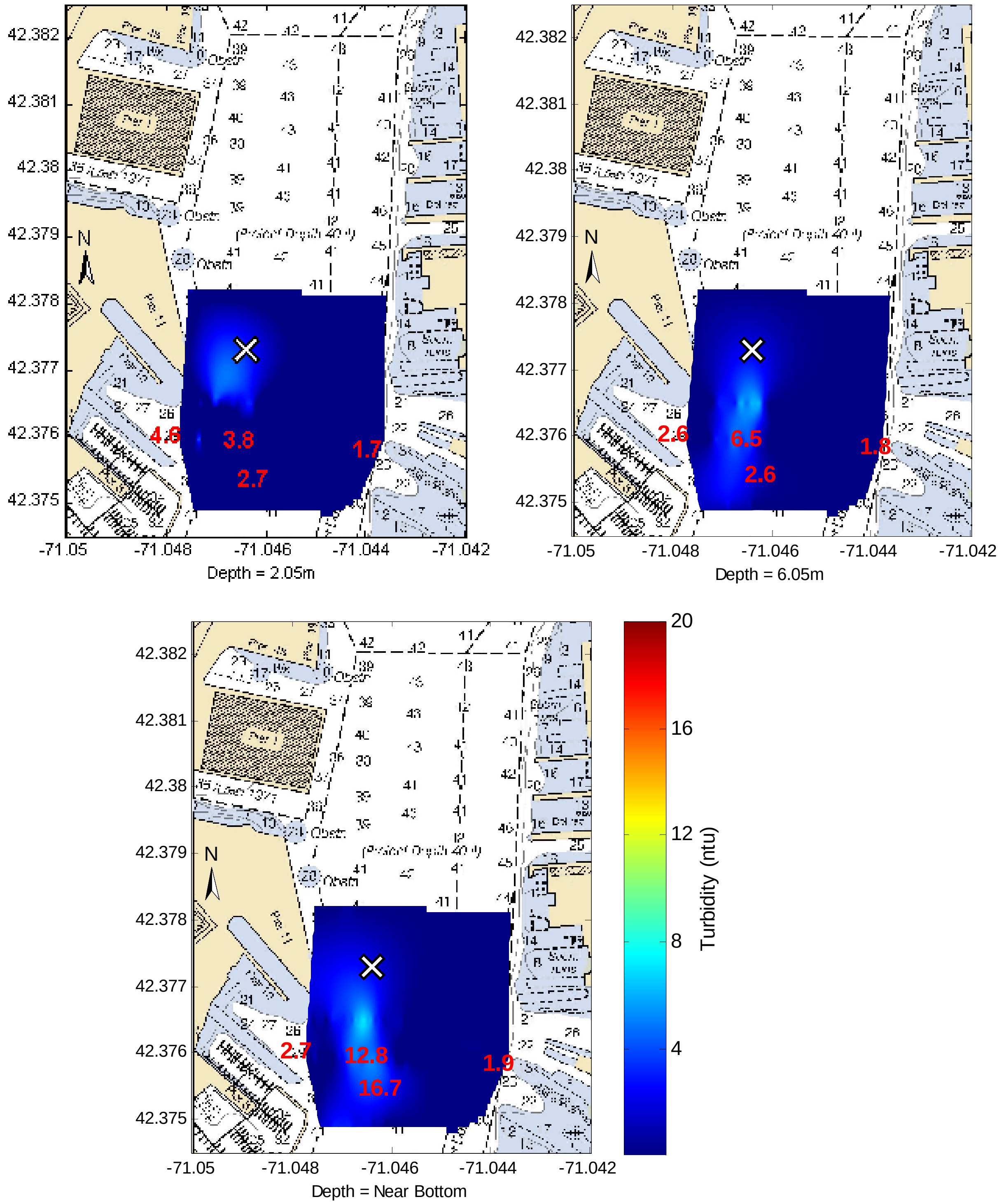


Figure 18 (continued). Dredge Plume Observations during First Max Ebb in the Northern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper left), mid-depth (upper right), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths.

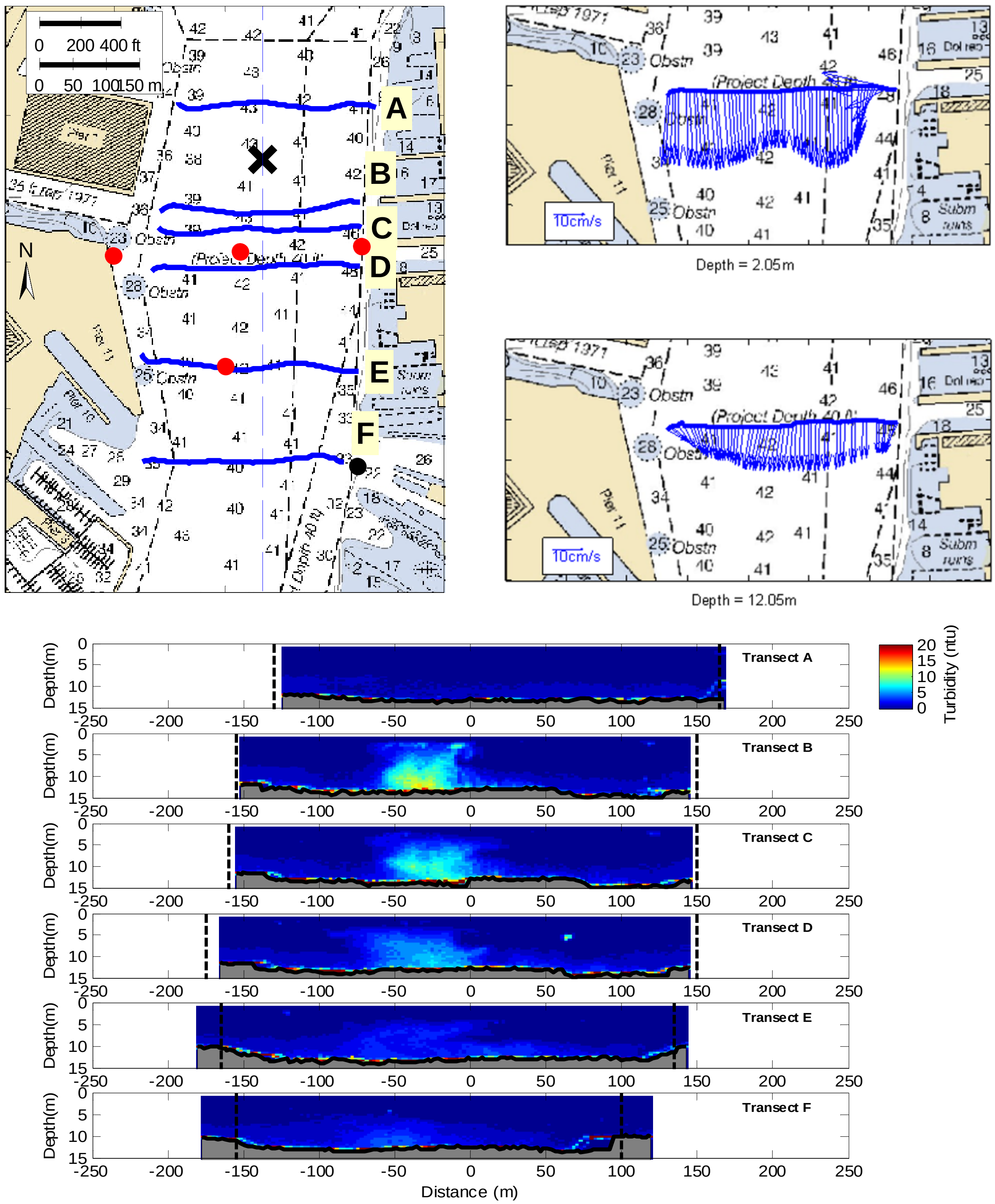


Figure 19. Dredge Plume Observations during Second Max Ebb in the Northern MSC.

The upper left panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The upper right panels present near-surface and near-bottom velocities measured with ADCP at Transect D. The lower panel presents vertical slices of calibrated turbidity above background measured with ADCP along each vessel transect (dashed lines represent the approximate channel boundaries).

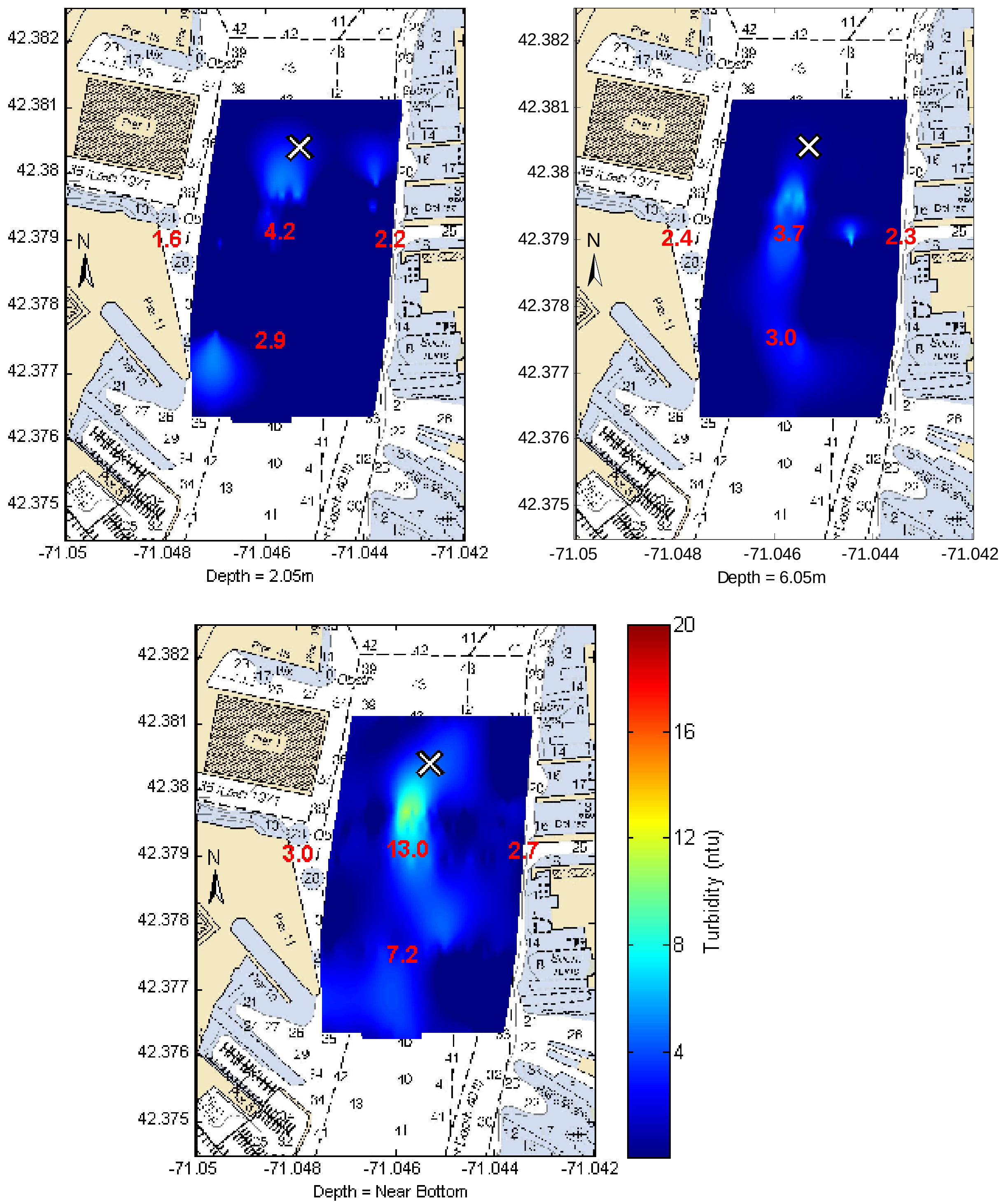


Figure 19 (continued). Dredge Plume Observations during Second Max Ebb in the Northern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper left), mid-depth (upper right), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths.

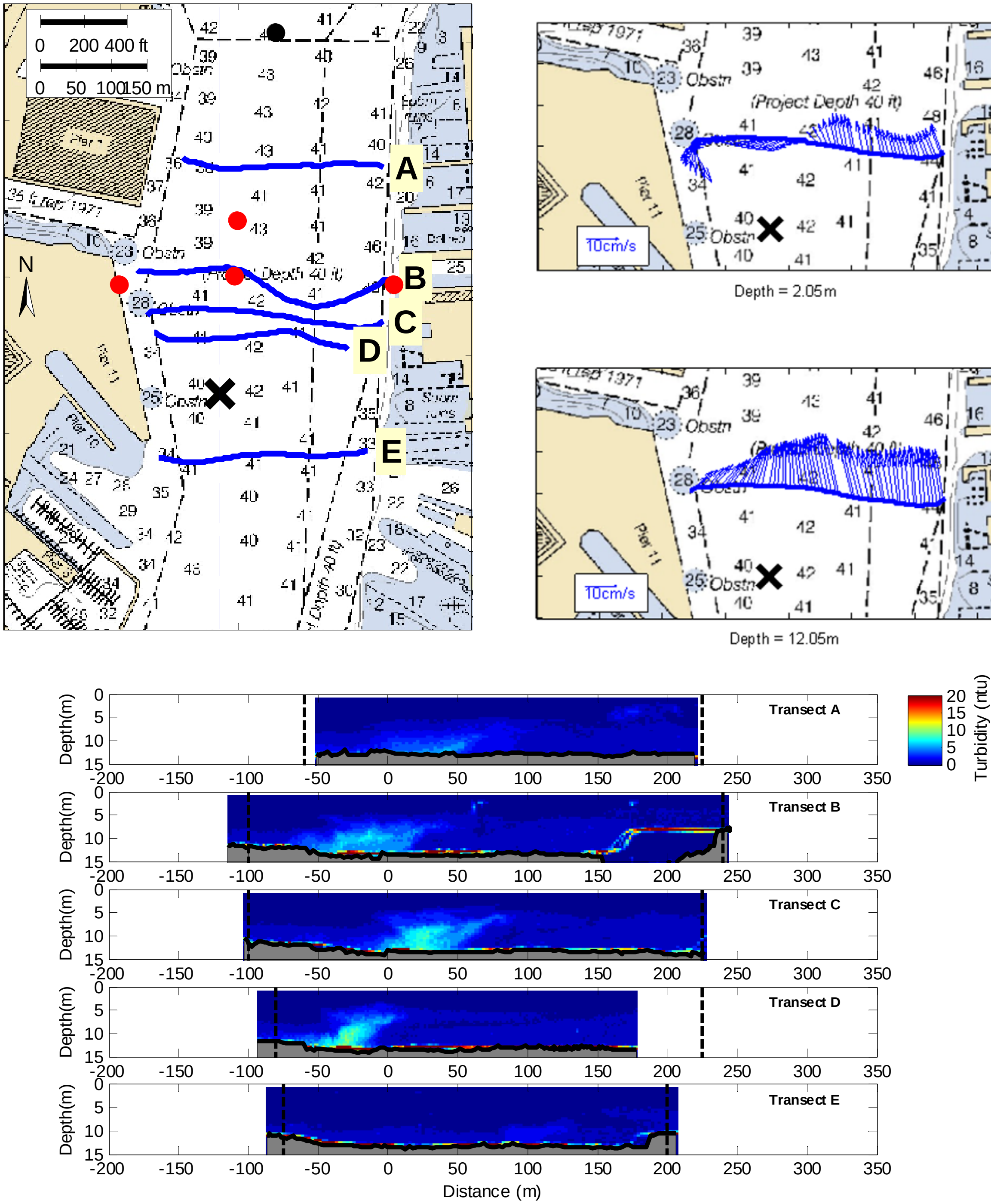


Figure 20. Dredge Plume Observations during First Low Slack in the Northern MSC.

The upper left panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The upper right panels present near-surface and near-bottom velocities measured with ADCP at Transect C. The lower panel presents vertical slices of calibrated turbidity above background measured with ADCP along each vessel transect (dashed lines represent the approximate channel boundaries).

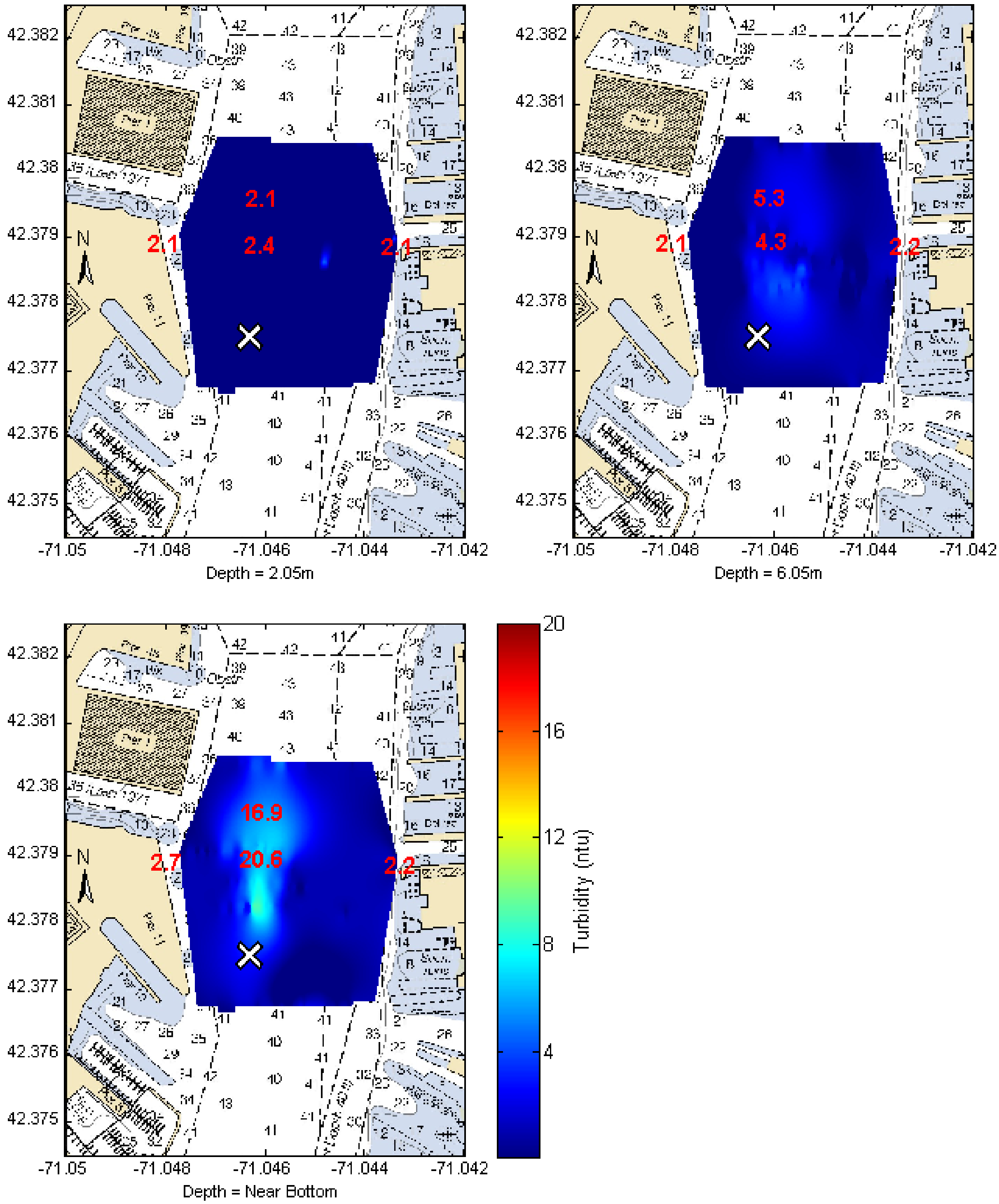


Figure 20 (continued). Dredge Plume Observations during First Low Slack in the Northern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper left), mid-depth (upper right), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths.

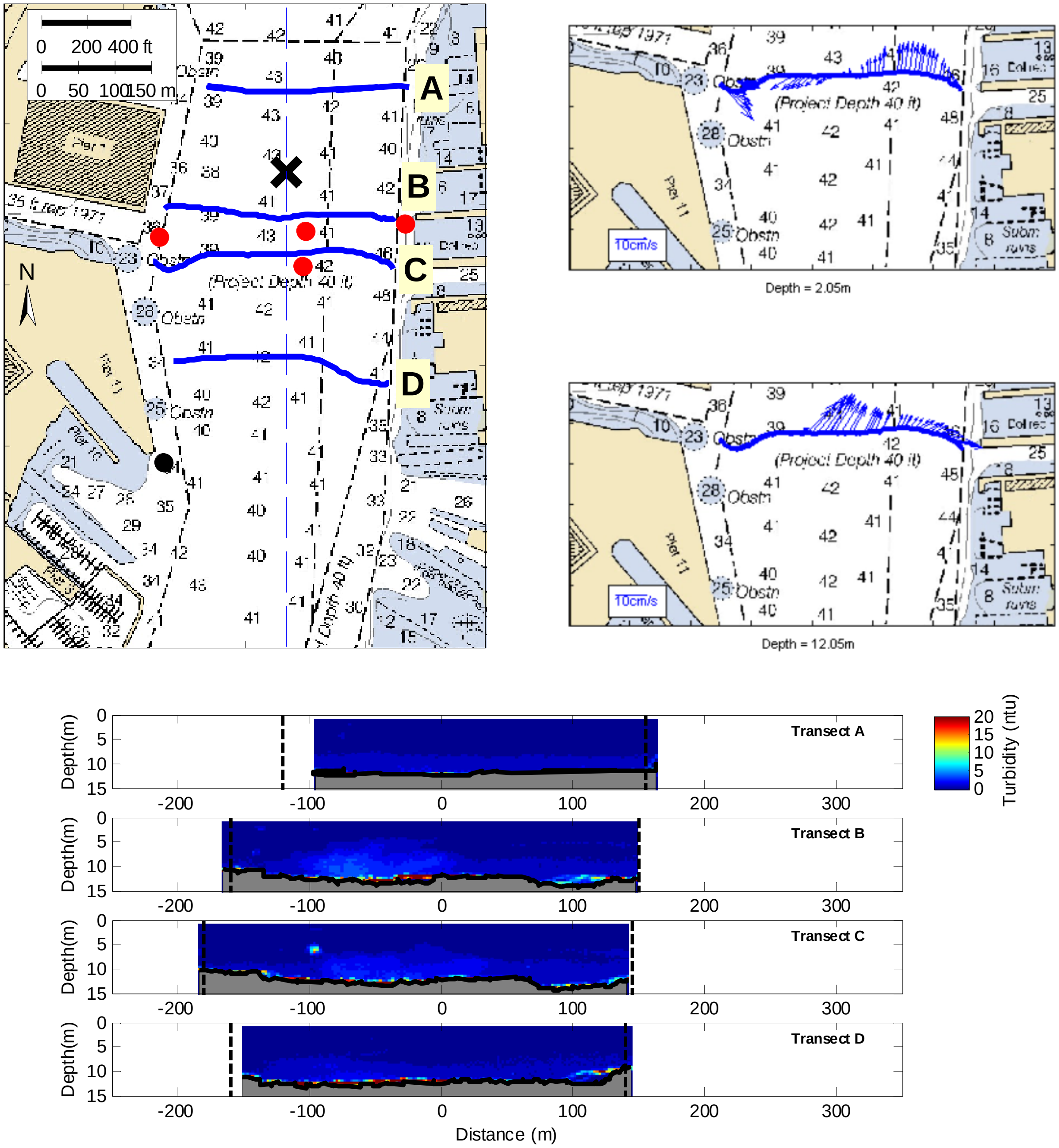


Figure 21. Dredge Plume Observations during Second Low Slack in the Northern MSC.

The upper left panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The upper right panels present near-surface and near-bottom velocities measured with ADCP at Transect C. The lower panel presents vertical slices of calibrated turbidity above background measured with ADCP along each vessel transect (dashed lines represent the approximate channel boundaries).

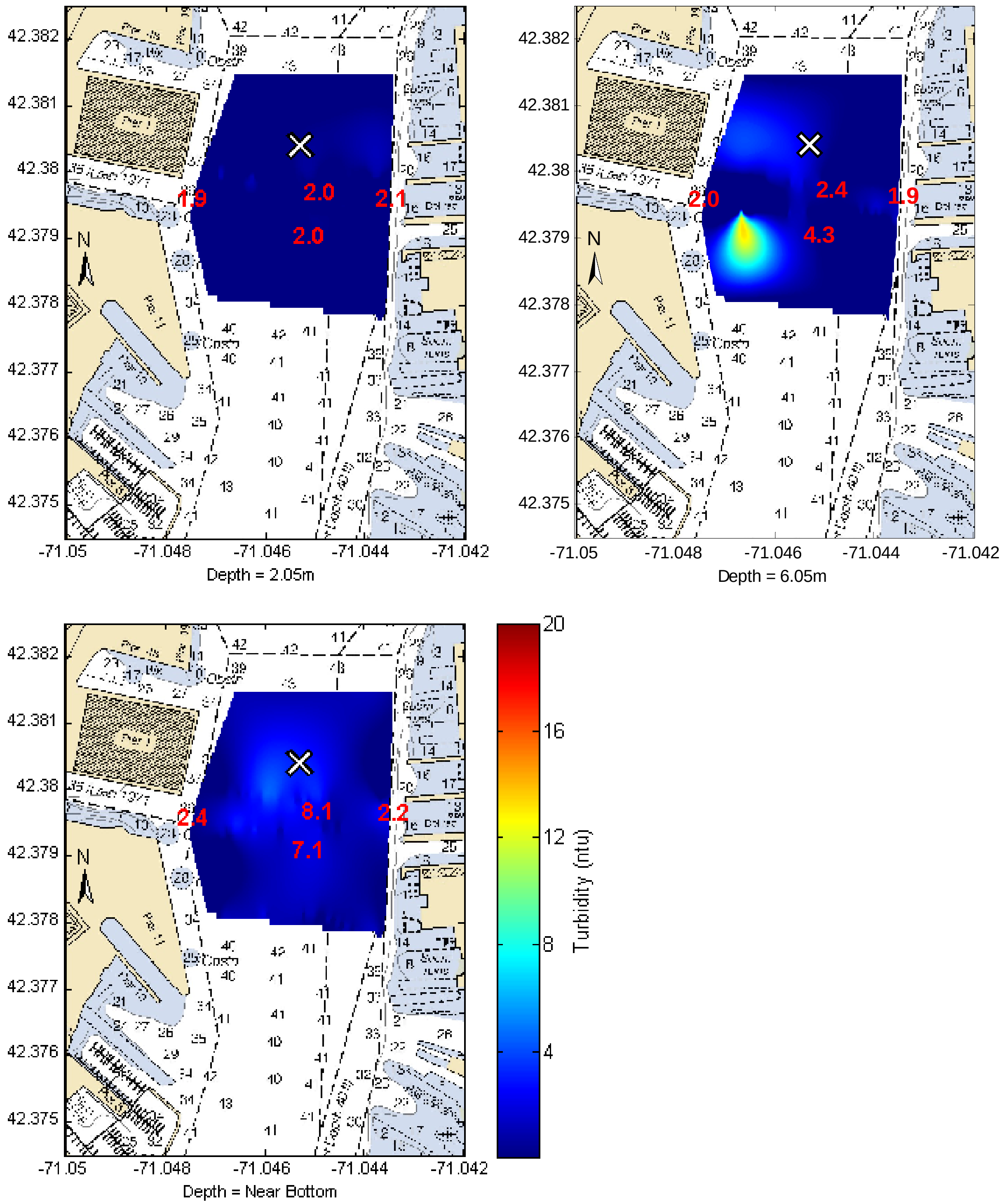


Figure 21 (continued). Dredge Plume Observations during Second Low Slack in the Northern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper left), mid-depth (upper right), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths. The "hot-spot" visible on the mid-depth contour is due to a school of fish.

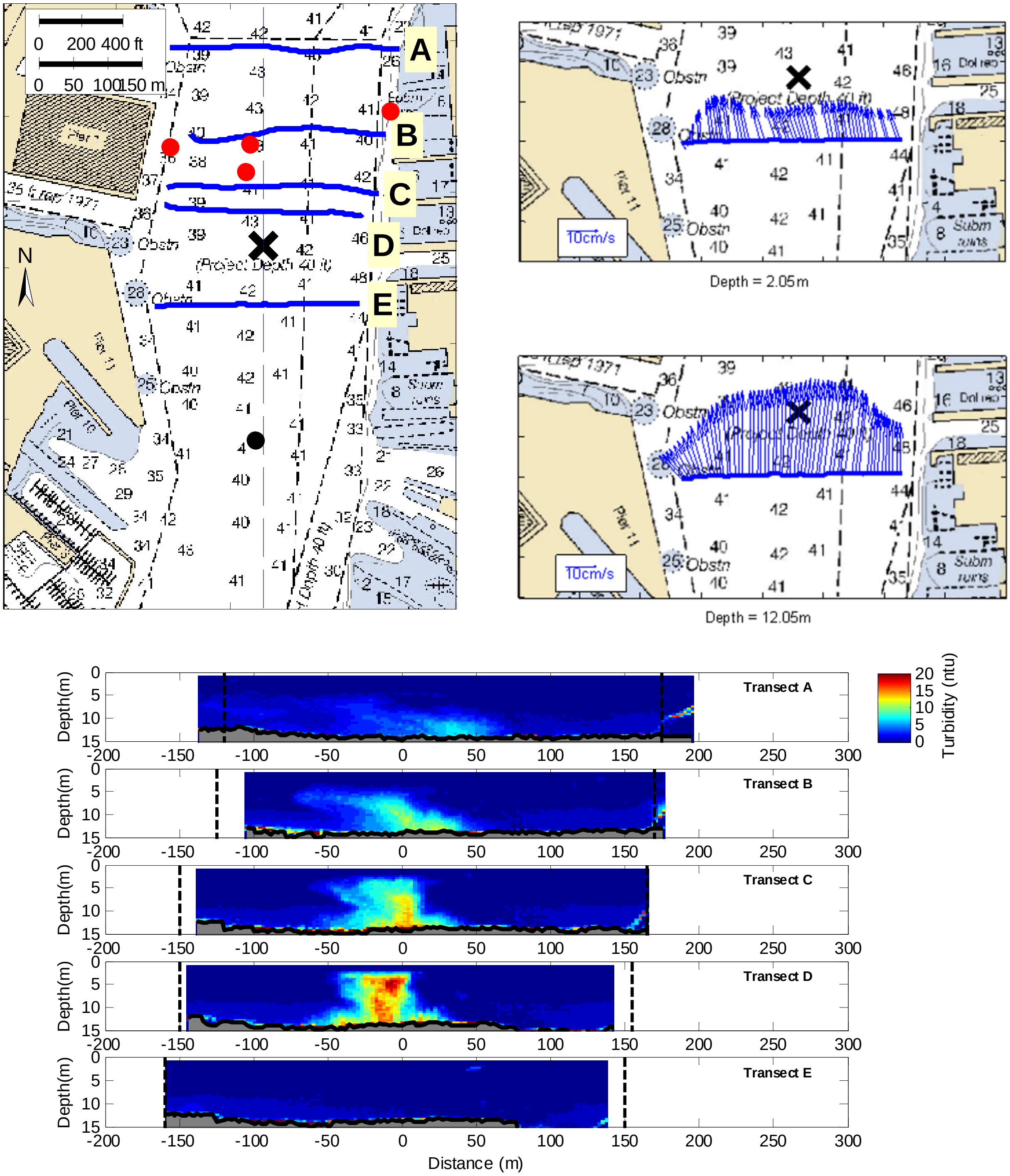


Figure 22. Dredge Plume Observations during First Max Flood in the Northern MSC.

The upper left panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The upper right panels present near-surface and near-bottom velocities measured with ADCP at Transect E. The lower panel presents vertical slices of calibrated turbidity above background measured with ADCP along each vessel transect (dashed lines represent the approximate channel boundaries).

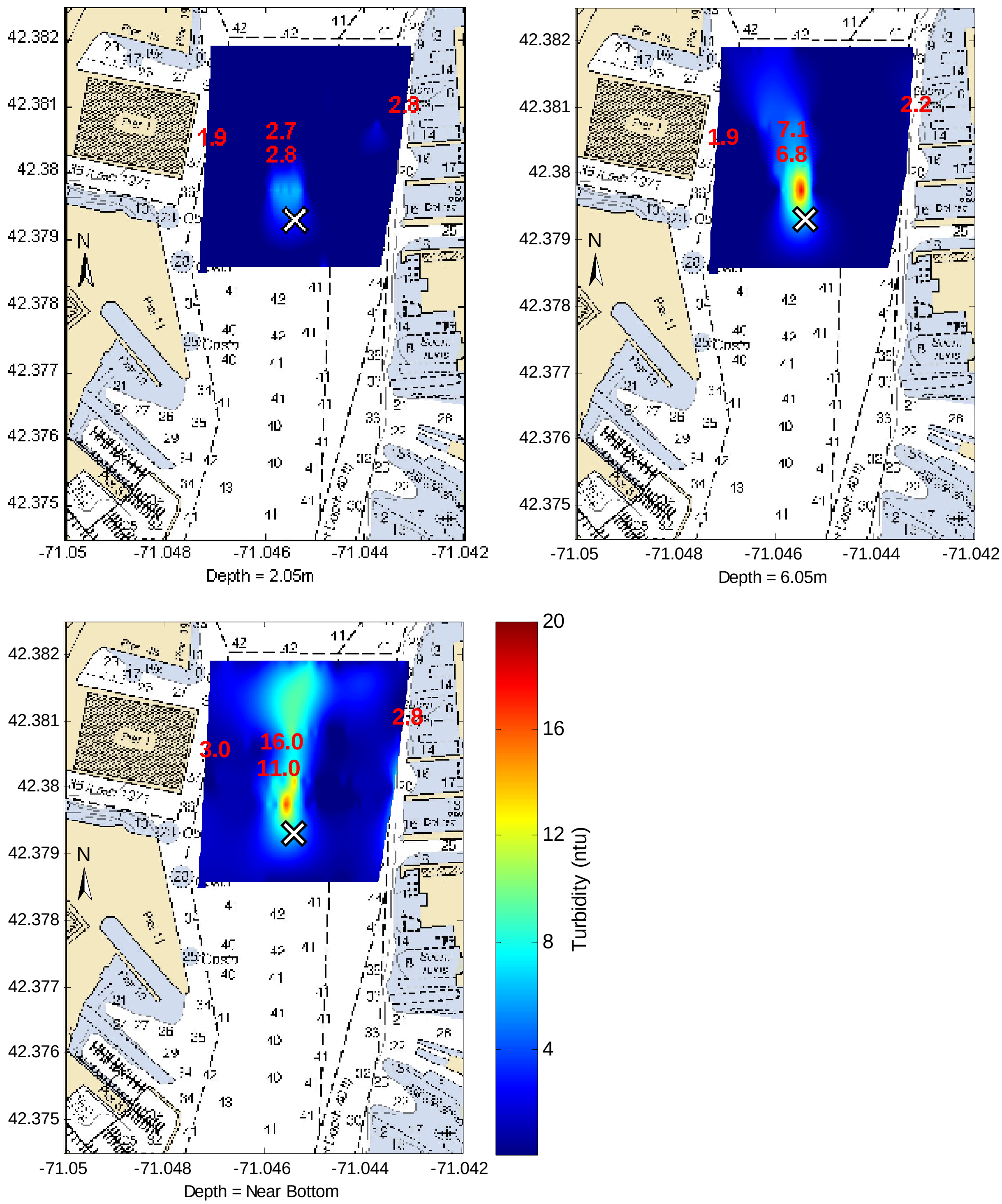


Figure 22 (continued). Dredge Plume Observations during First Max Flood in the Northern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper left), mid-depth (upper right), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths.

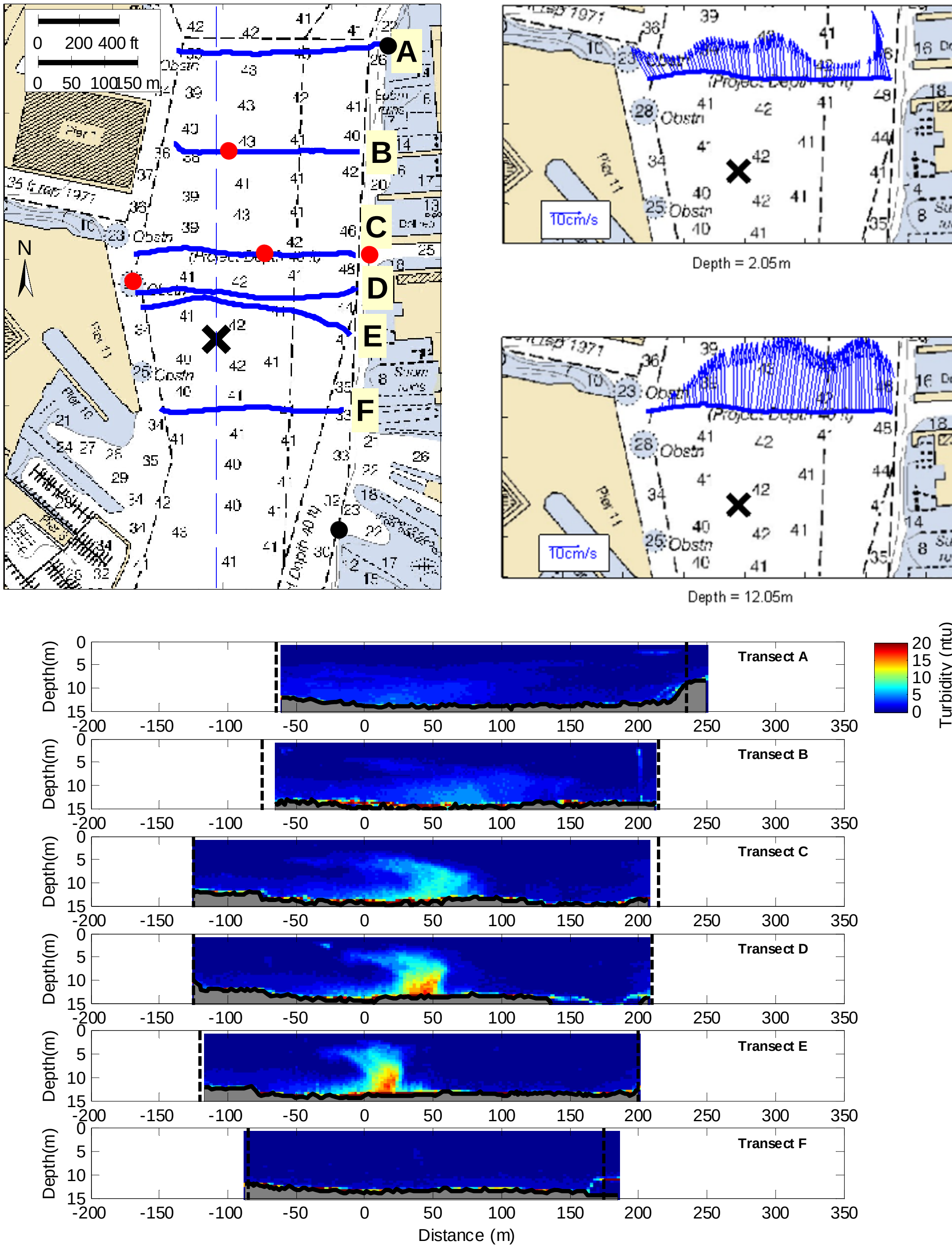


Figure 23. Dredge Plume Observations during Second Max Flood in the Northern MSC.

The upper left panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The upper right panels present near-surface and near-bottom velocities measured with ADCP at Transect C. The lower panel presents vertical slices of calibrated turbidity above background measured with ADCP along each vessel transect (dashed lines represent the approximate channel boundaries).

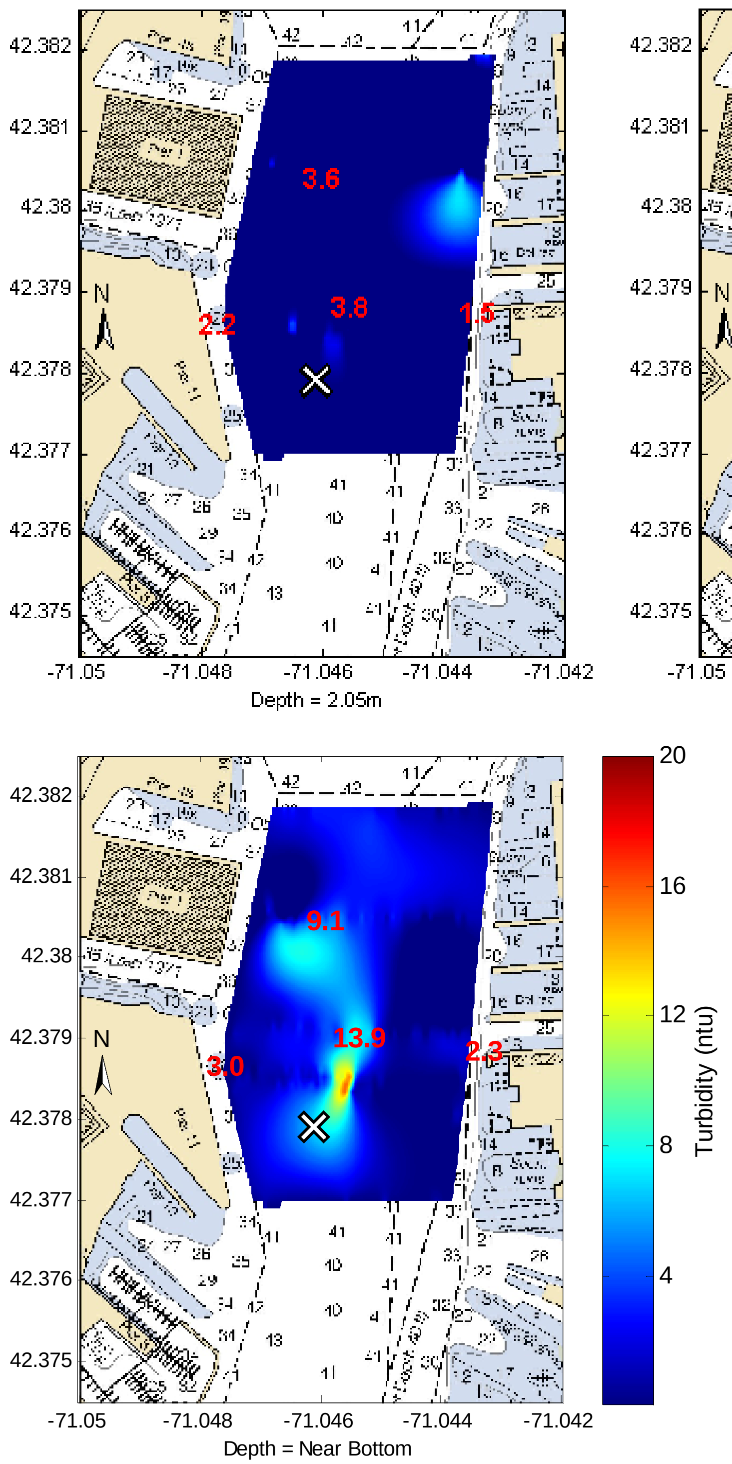


Figure 23 (continued). Dredge Plume Observations during Second Max Flood in the Northern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper left), mid-depth (upper right), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths.

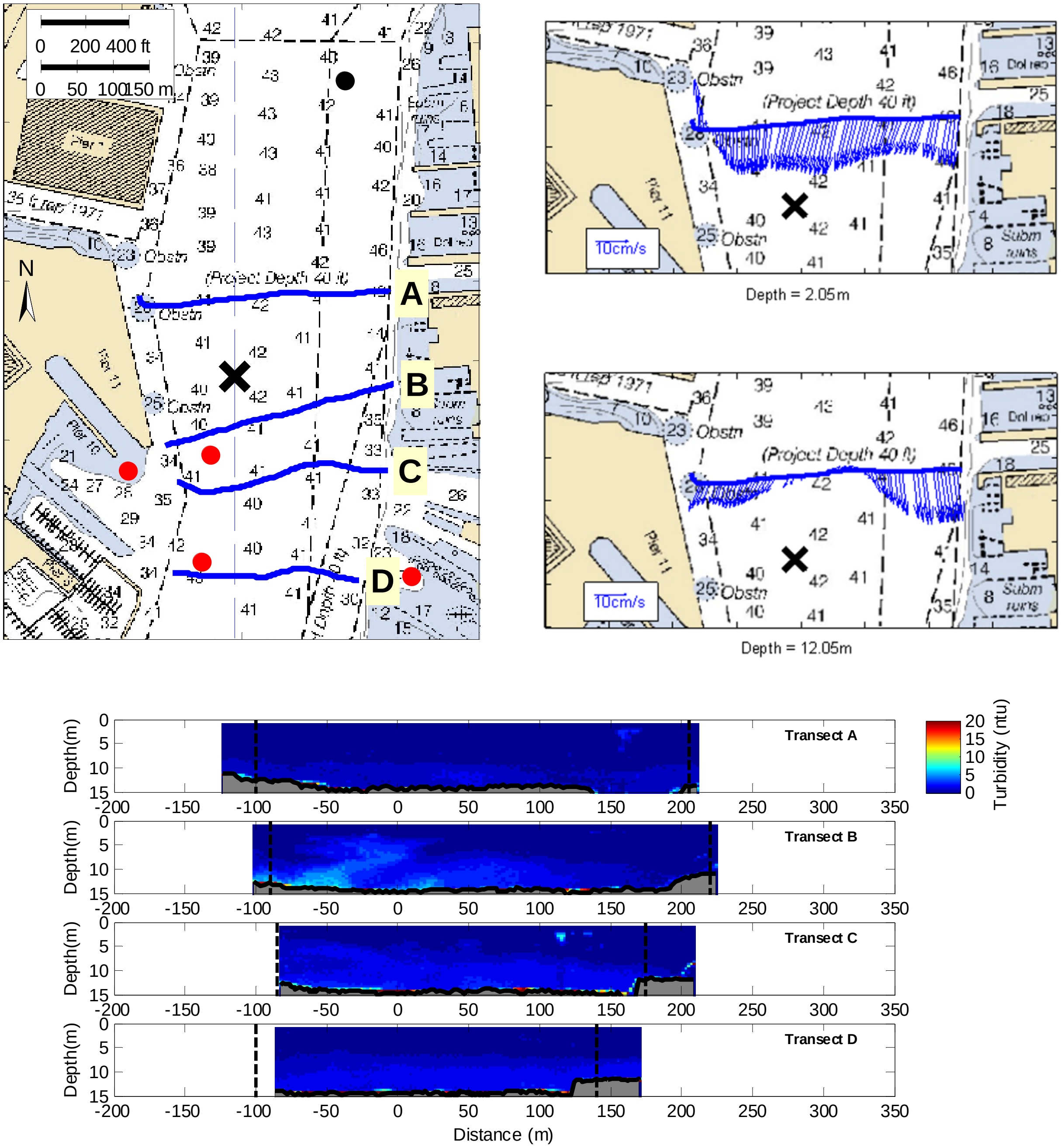


Figure 24. Dredge Plume Observations during First High Slack in the Northern MSC.

The upper left panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The upper right panels present near-surface and near-bottom velocities measured with ADCP at Transect A. The lower panel presents vertical slices of calibrated turbidity above background measured with ADCP along each vessel transect (dashed lines represent the approximate channel boundaries).

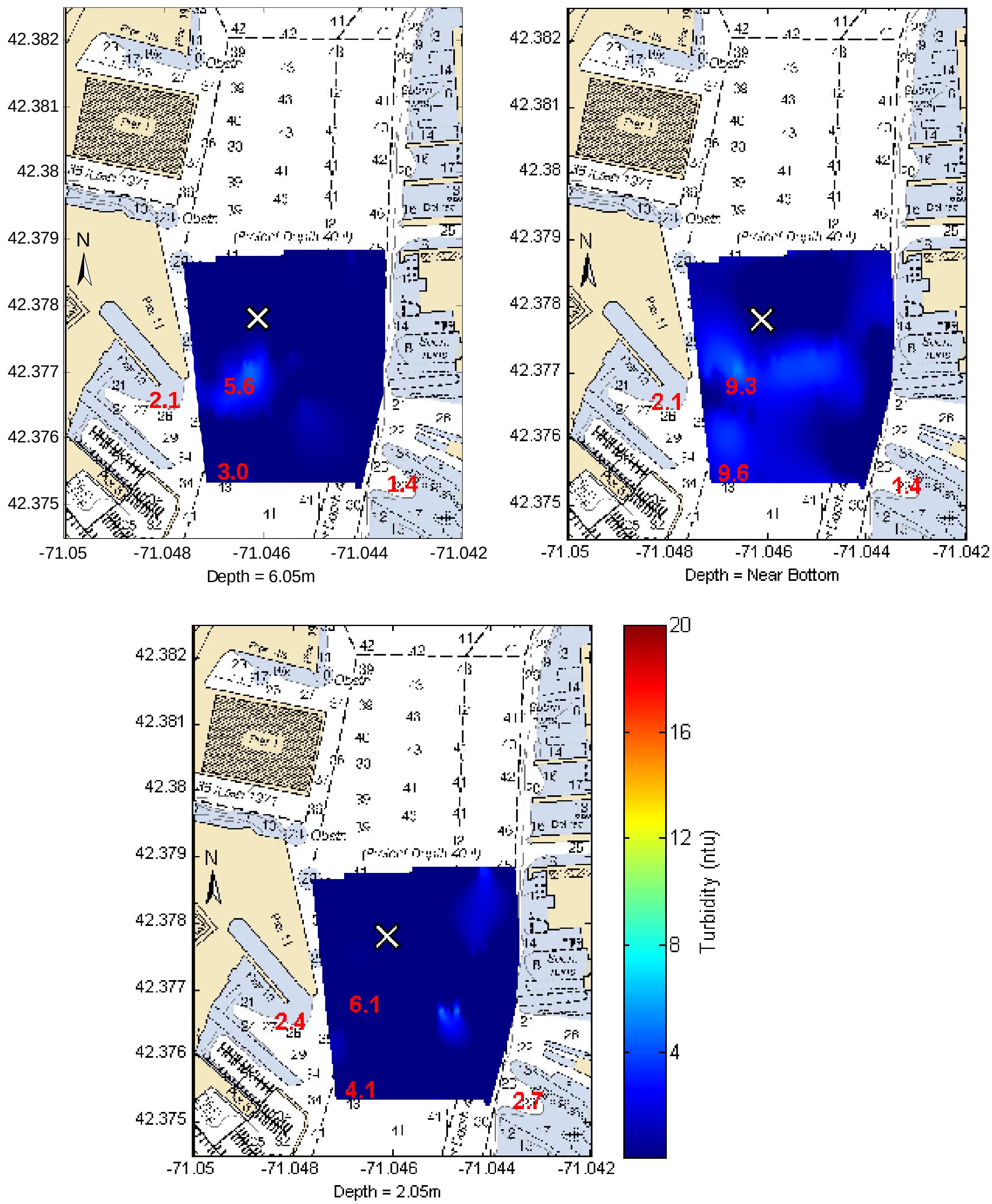


Figure 24 (continued). Dredge Plume Observations during First High Slack in the Northern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper left), mid-depth (upper right), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths.

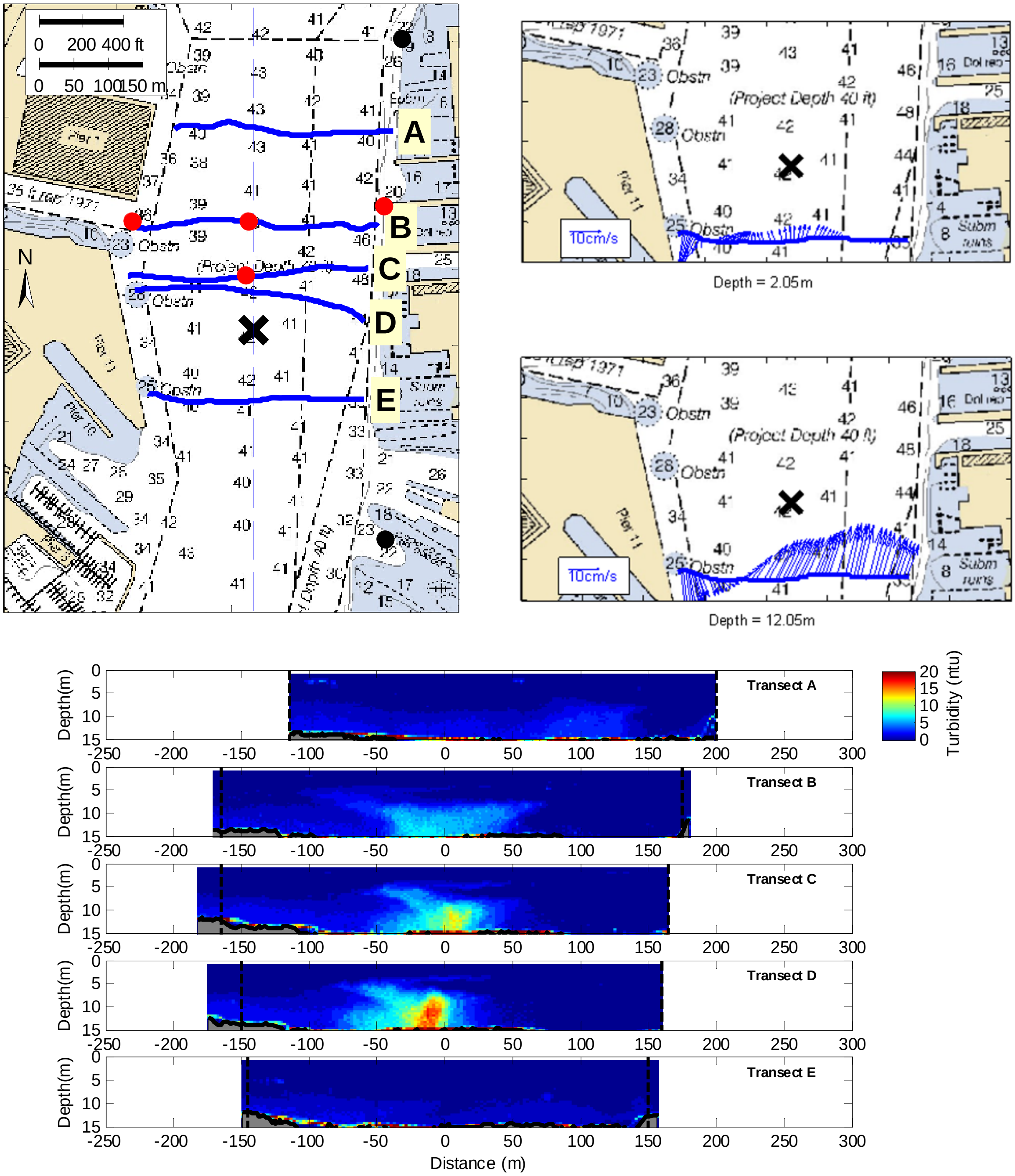


Figure 25. Dredge Plume Observations during Second High Slack in the Northern MSC.

The upper left panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The upper right panels present near-surface and near-bottom velocities measured with ADCP at Transect E. The lower panel presents vertical slices of calibrated turbidity above background measured with ADCP along each vessel transect (dashed lines represent the approximate channel boundaries).

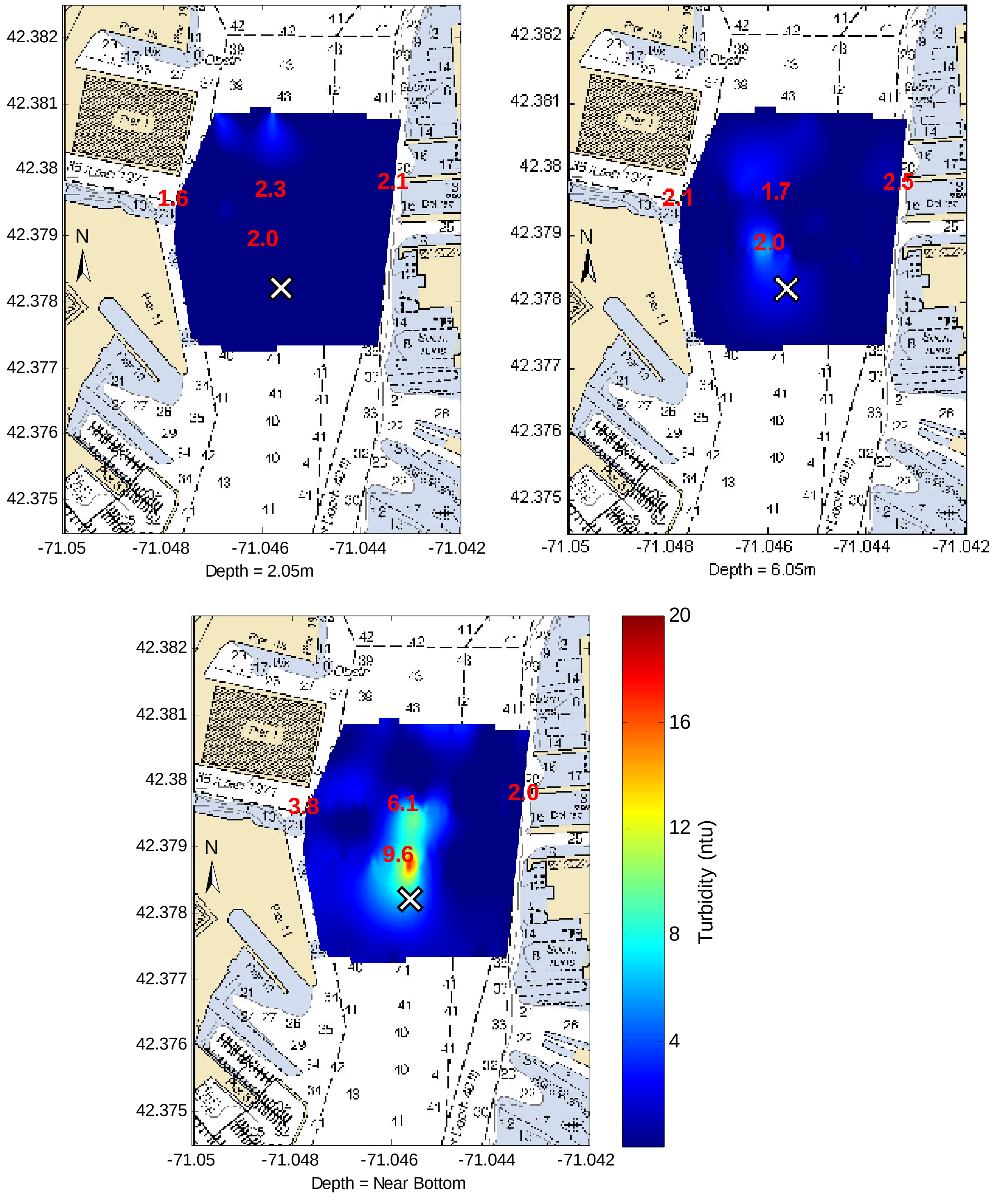


Figure 25 (continued). Dredge Plume Observations during Second High Slack in the Northern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper left), mid-depth (upper right), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths.

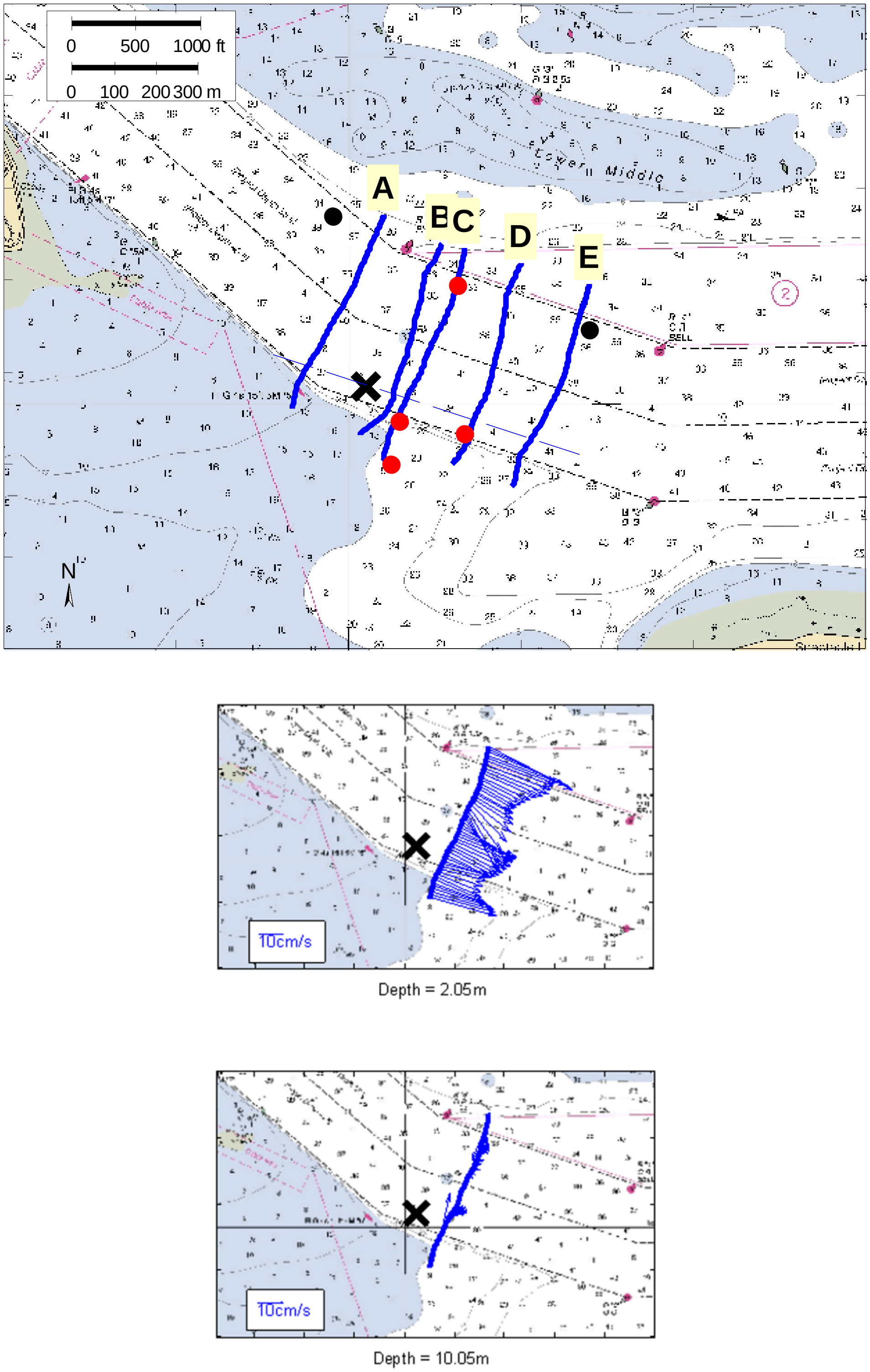


Figure 26. Dredge Plume Observations during First Max Ebb in the Southern MSC.

The upper panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge (‘x’). The lower two panels present near-surface and near-bottom velocities measured with ADCP at Transect C.

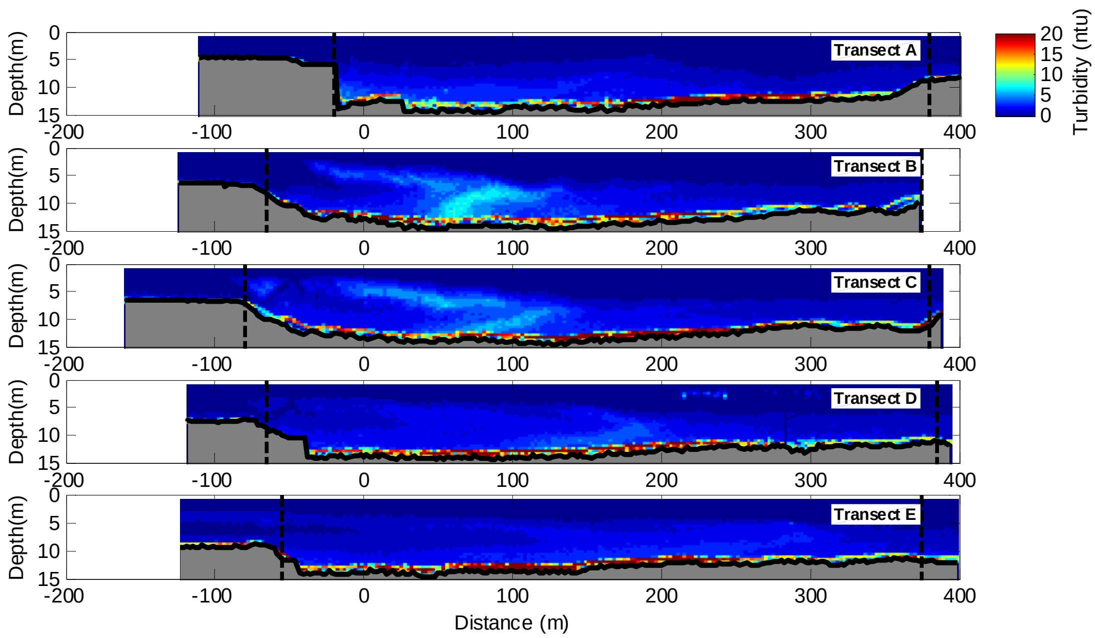


Figure 26 (continued). Dredge Plume Observations during First Max Ebb in the Southern MSC. Presented are vertical slices of calibrated turbidity (above background) measured with ADCP along each vessel transect. The approximate location of the channel boundaries are shown as dashed lines.

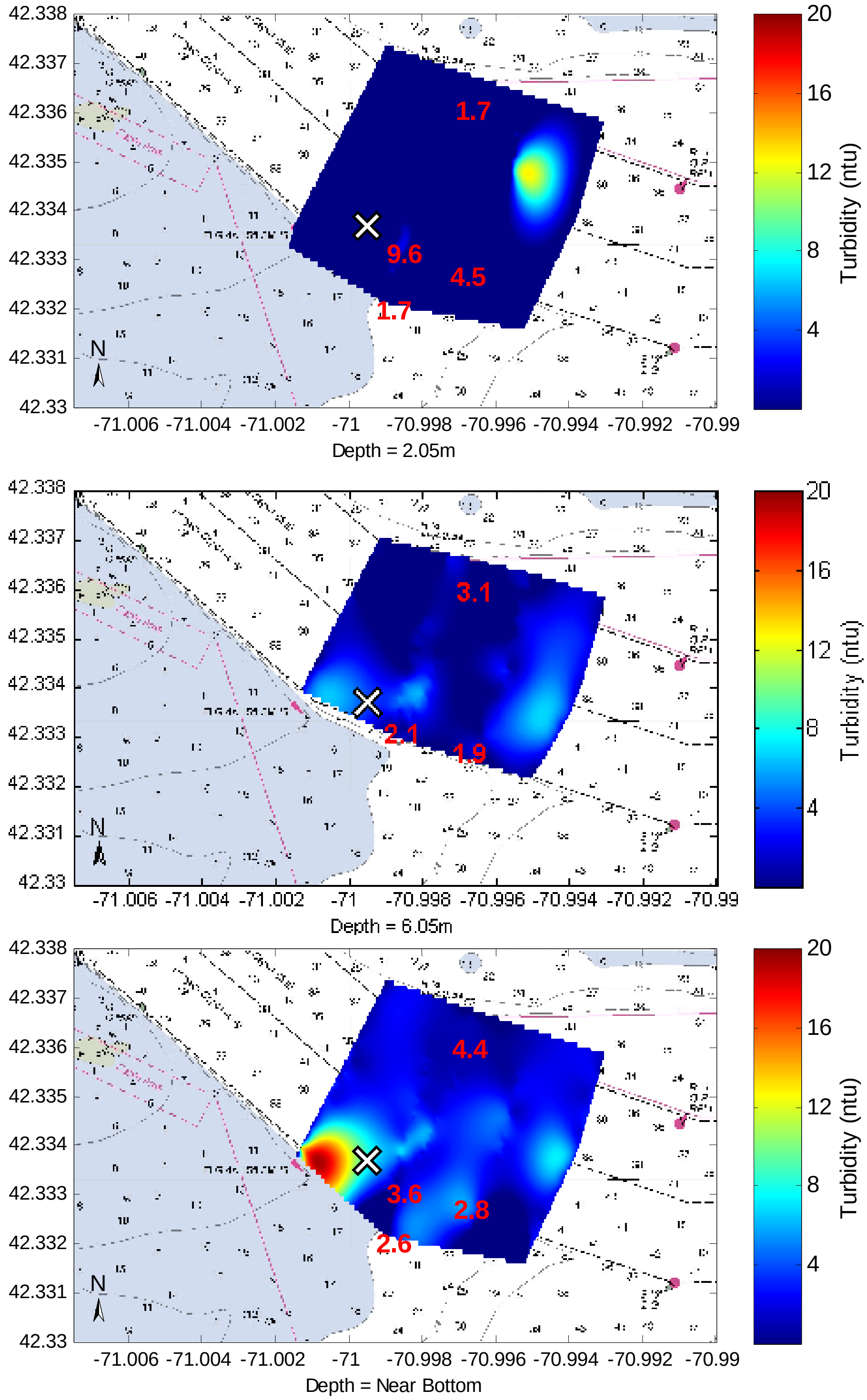
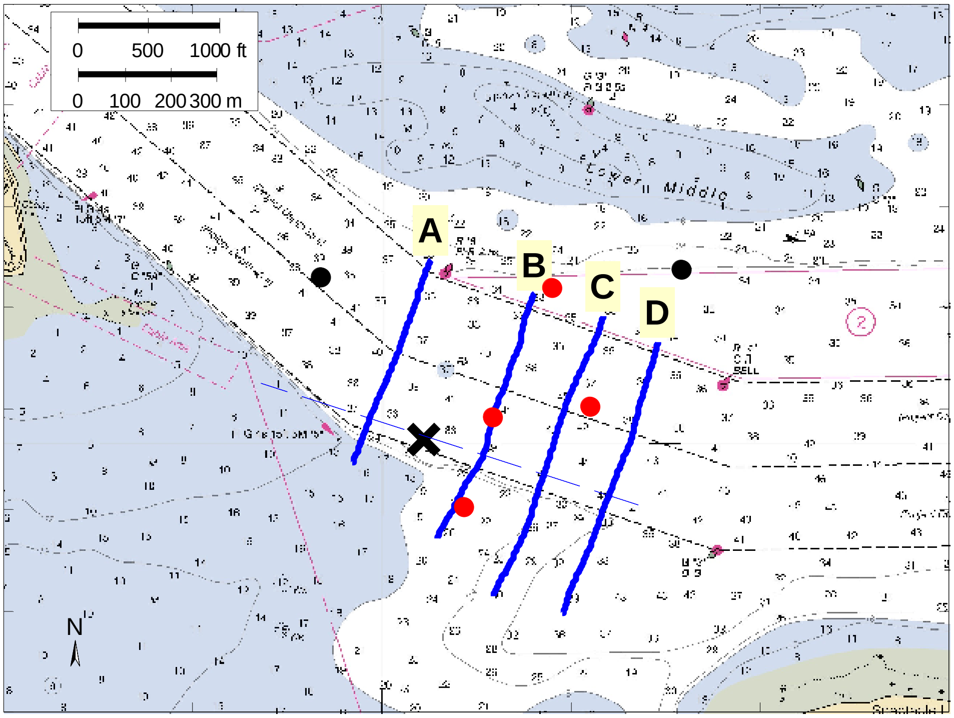
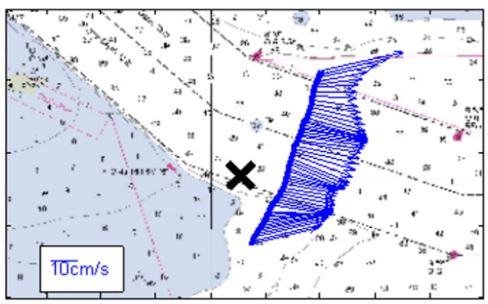
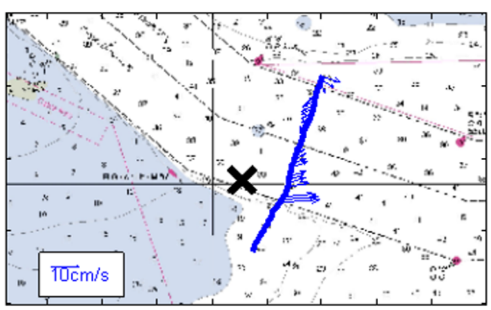


Figure 26 (continued). Dredge Plume Observations during First Max Ebb in the Southern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper), mid-depth (middle), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths. The "hot-spots" visible on the near-surface and near-bottom contours are due to a school of fish and bottom echoes resulting from the sharp depth change, respectively.





Depth = 2.05m



Depth = 10.05m

Figure 27. Dredge Plume Observations during Second Max Ebb in the Southern MSC.

The upper panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The lower two panels present near-surface and near-bottom velocities measured with ADCP at Transect B.

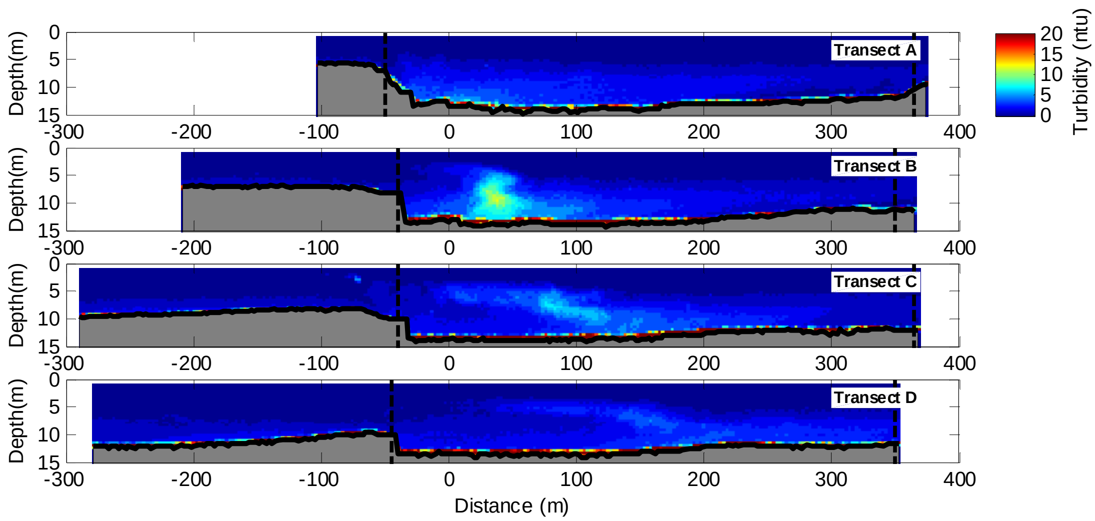


Figure 27 (continued). Dredge Plume Observations during Second Max Ebb in the Southern MSC. Presented are vertical slices of calibrated turbidity (above background) measured with ADCP along each vessel transect. The approximate location of the channel boundaries are shown as dashed lines.

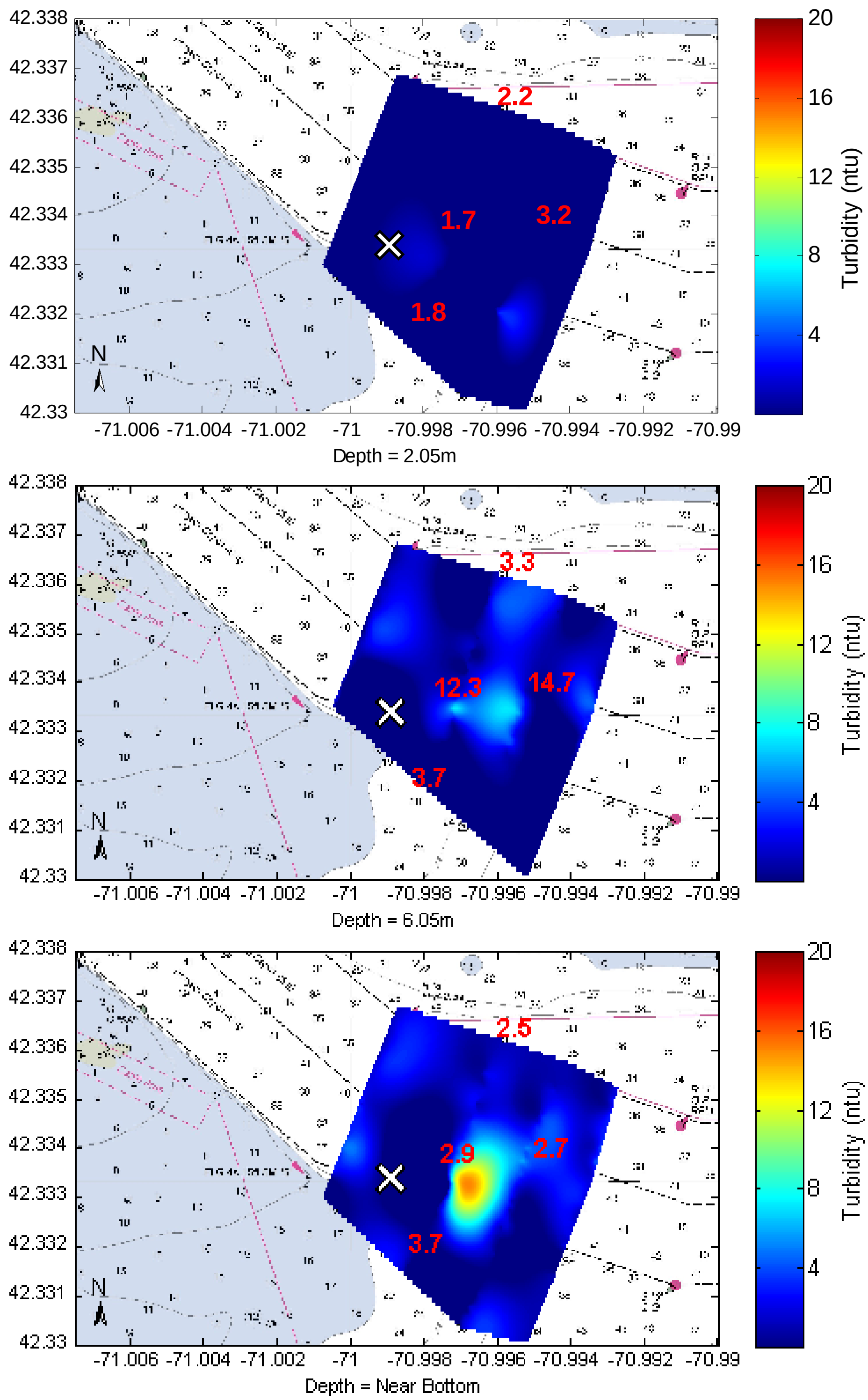


Figure 27 (continued). Dredge Plume Observations during Second Max Ebb in the Southern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper), mid-depth (middle), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths.

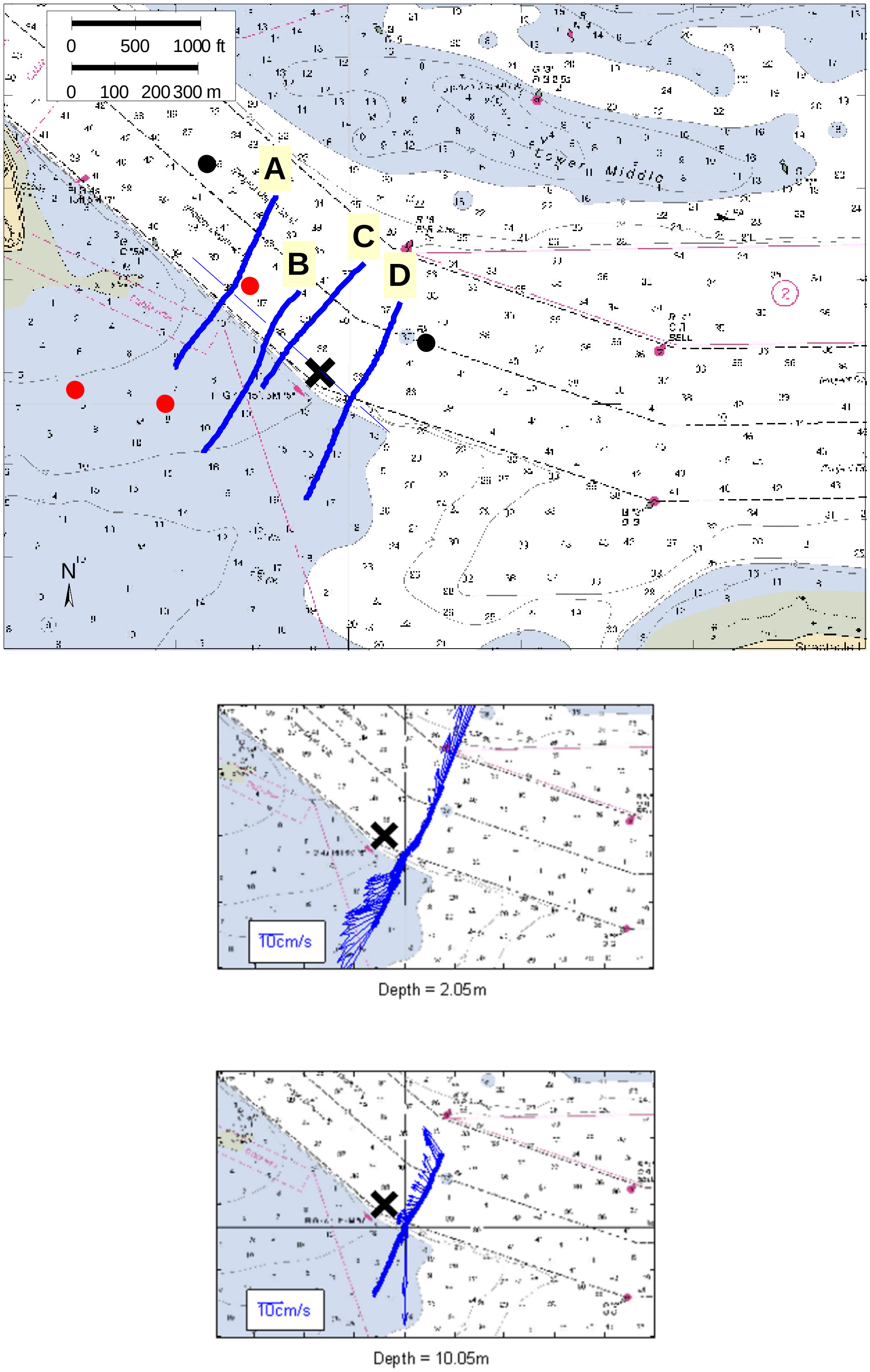


Figure 28. Dredge Plume Observations during First Low Slack in the Southern MSC.

The upper panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The lower two panels present near-surface and near-bottom velocities measured with ADCP at Transect D.

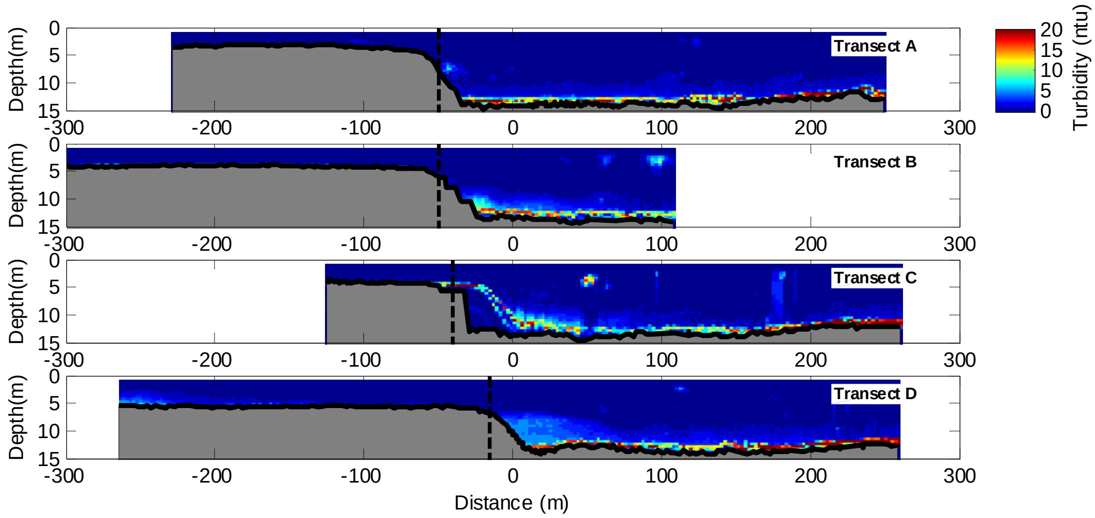


Figure 28 (continued). Dredge Plume Observations during First Low Slack in the Southern MSC. Presented are vertical slices of calibrated turbidity (above background) measured with ADCP along each vessel transect. The approximate location of the channel boundaries are shown as dashed lines.

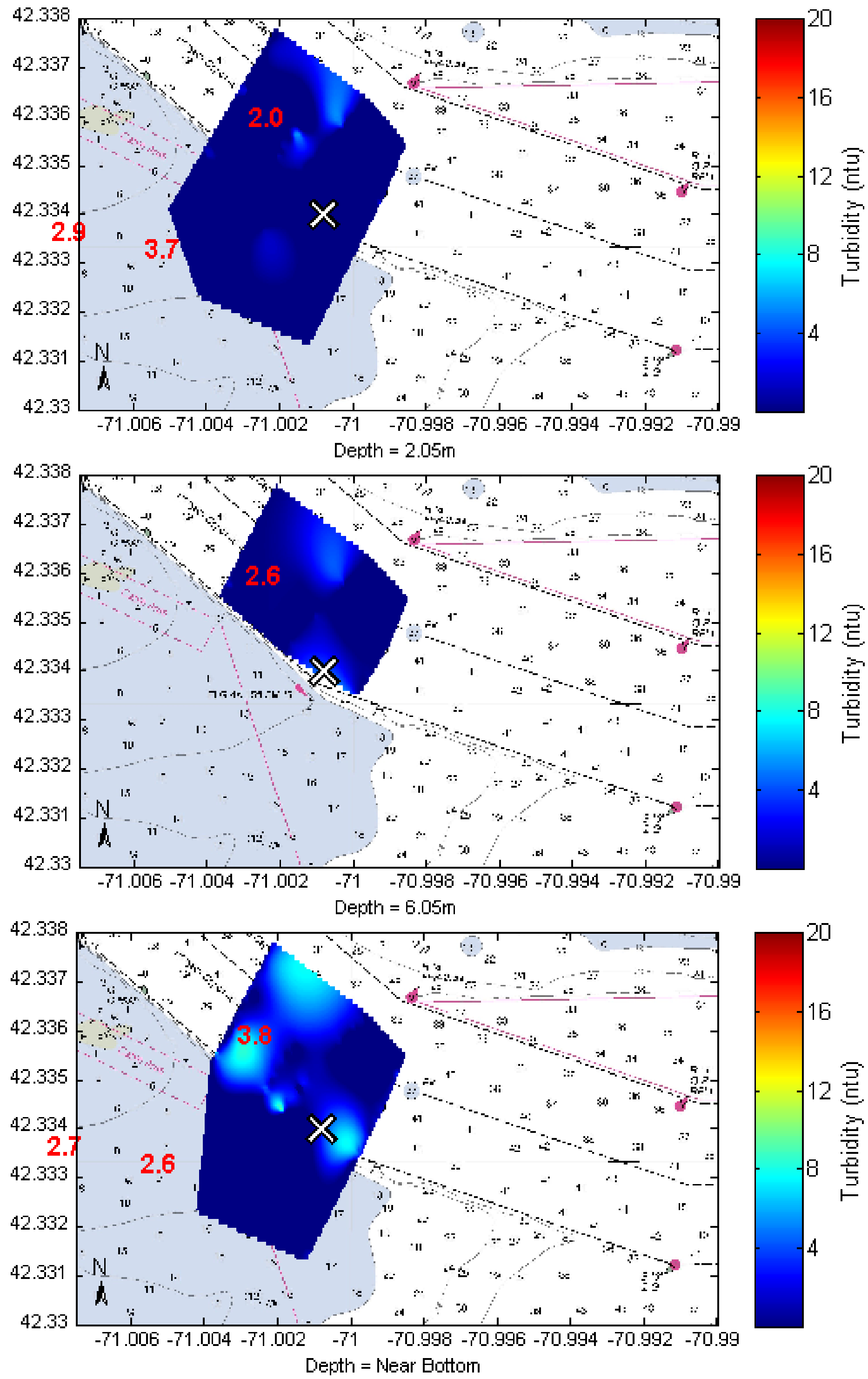


Figure 28 (continued). Dredge Plume Observations during First Low Slack in the Southern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper), mid-depth (middle), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths.

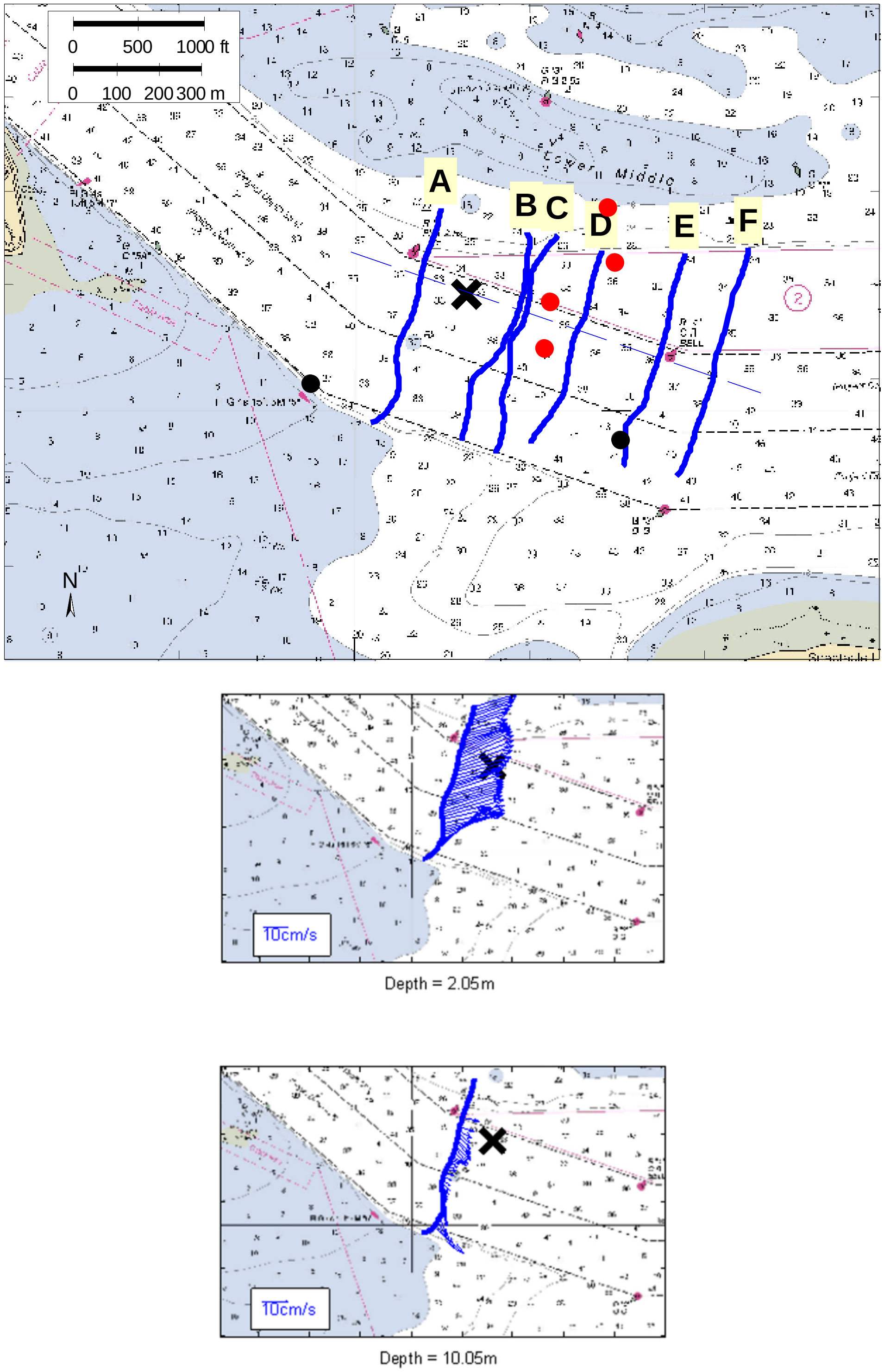


Figure 29. Dredge Plume Observations during Second Low Slack in the Southern MSC.

The upper panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The lower two panels present near-surface and near-bottom velocities measured with ADCP at Transect A.

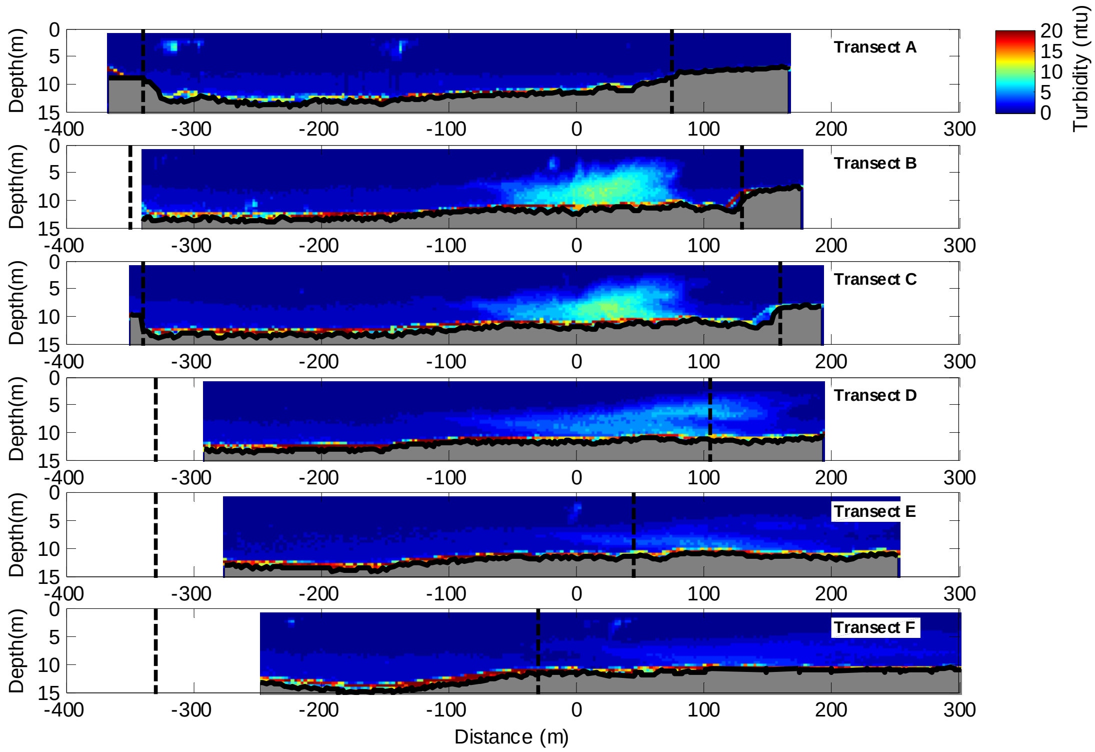


Figure 29 (continued). Dredge Plume Observations during Second Low Slack in the Southern MSC. Presented are vertical slices of calibrated turbidity (above background) measured with ADCP along each vessel transect. The approximate location of the channel boundaries are shown as dashed lines.

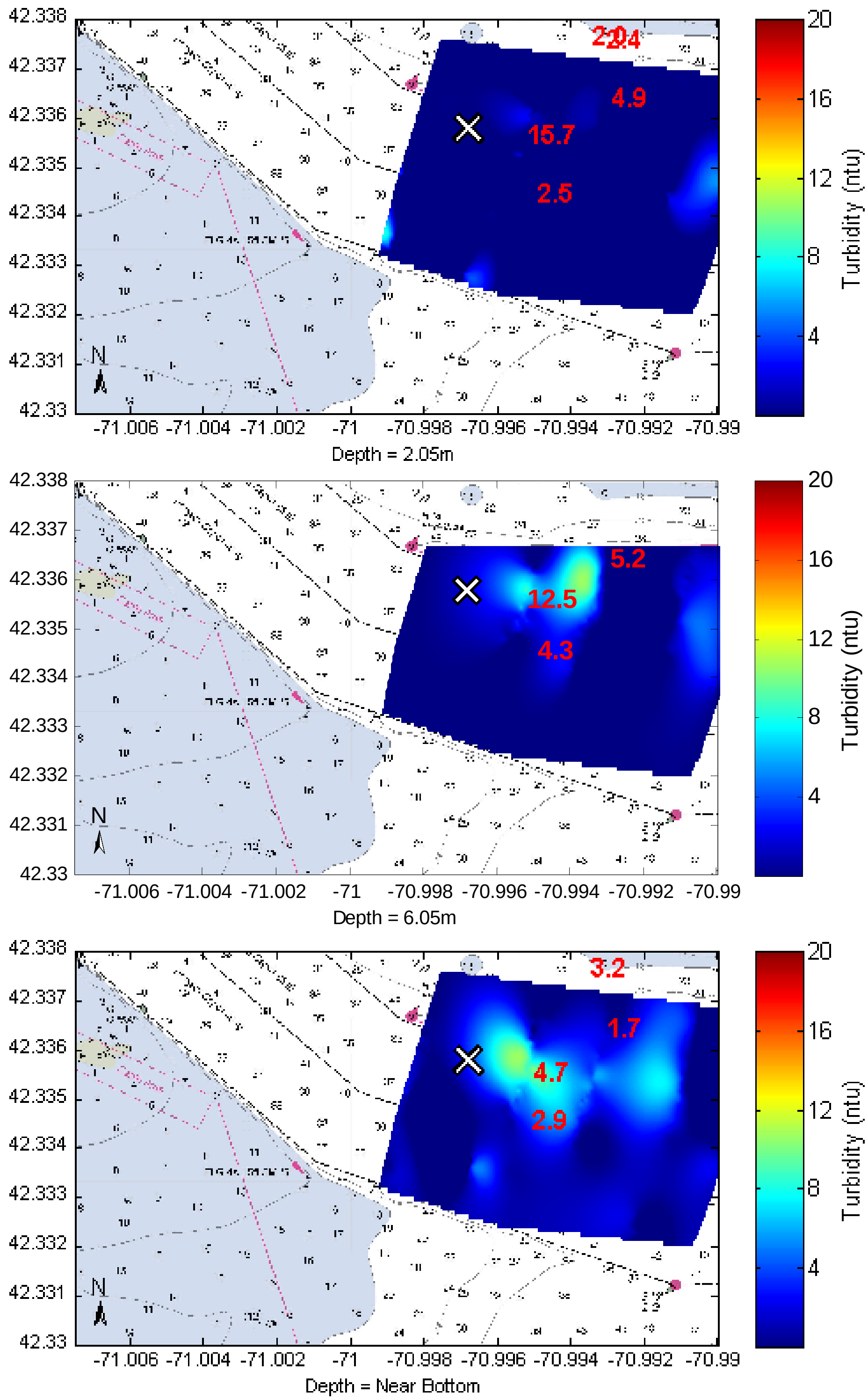


Figure 29 (continued). Dredge Plume Observations during Second Low Slack in the Southern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper), mid-depth (middle), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths.

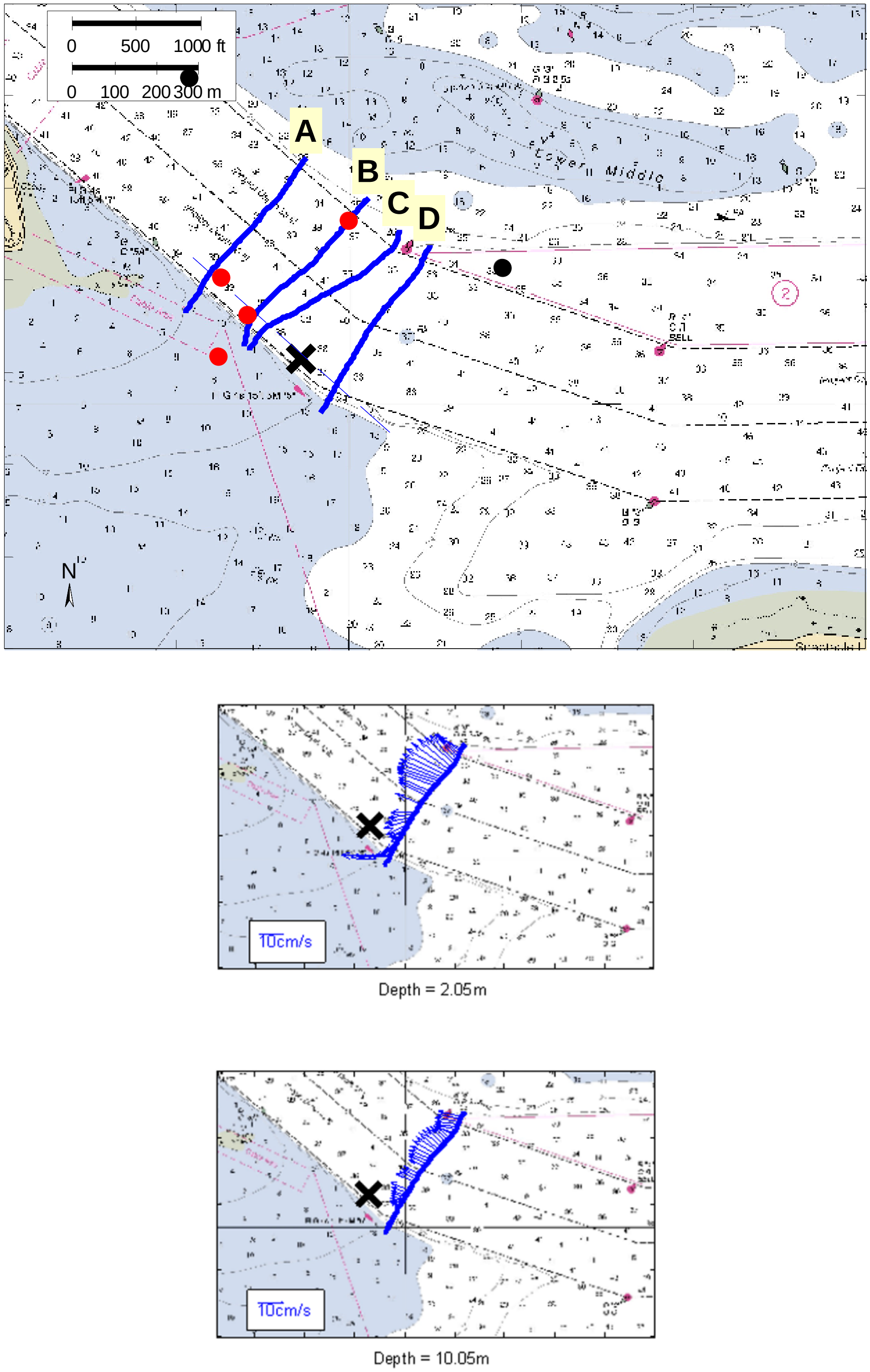


Figure 30. Dredge Plume Observations during First Max Flood in the Southern MSC.

The upper panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge (‘x’). The lower two panels present near-surface and near-bottom velocities measured with ADCP at Transect D.

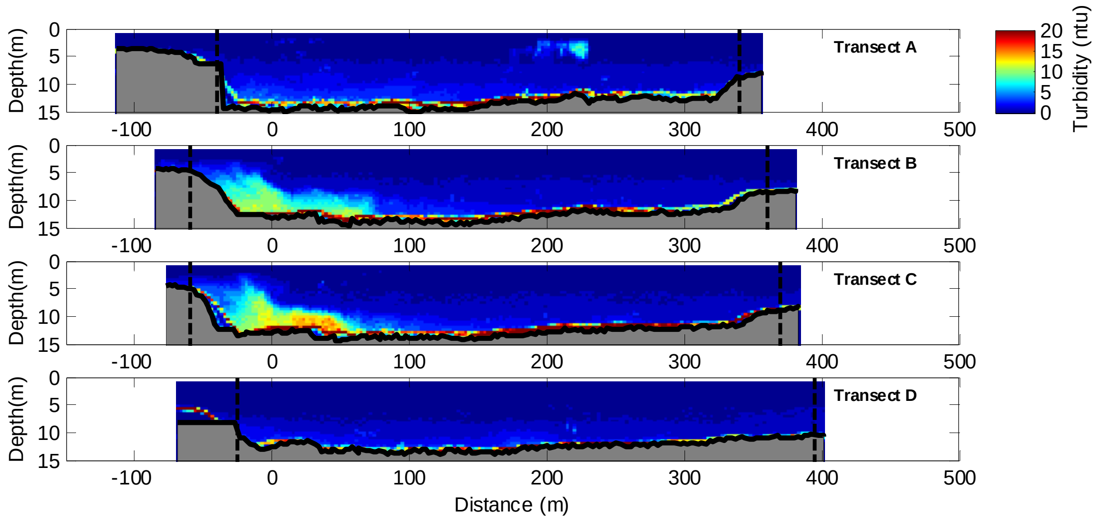


Figure 30 (continued). Dredge Plume Observations during First Max Flood in the Southern MSC. Presented are vertical slices of calibrated turbidity (above background) measured with ADCP along each vessel transect. The approximate location of the channel boundaries are shown as dashed lines.

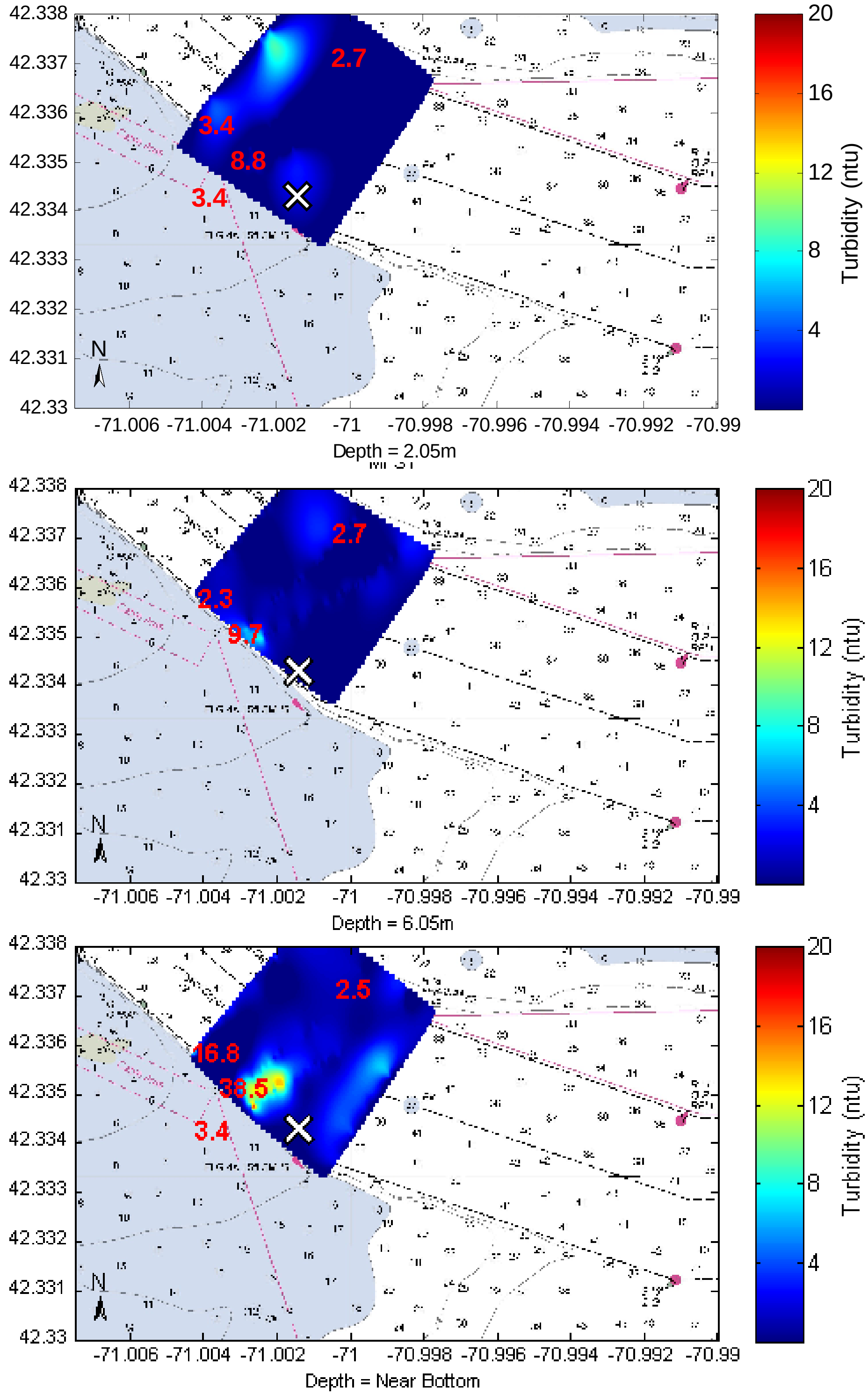


Figure 30 (continued). Dredge Plume Observations during First Max Flood in the Southern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper), mid-depth (middle), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths. The "hot-spot" visible on the near-surface contour is due to an unrelated echo there, probably a school of fish.

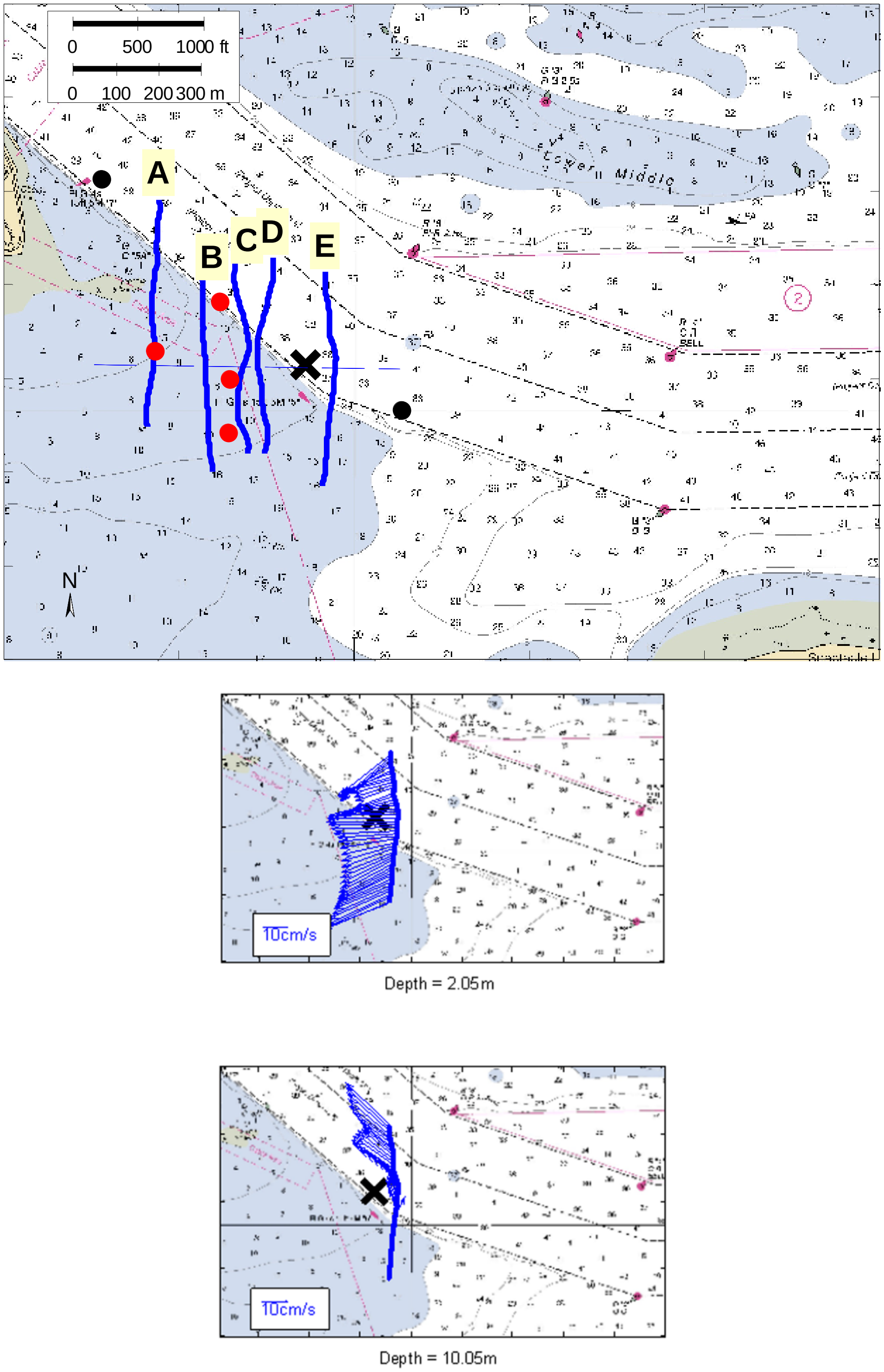


Figure 31. Dredge Plume Observations during Second Max Flood in the Southern MSC.

The upper panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The lower two panels present near-surface and near-bottom velocities measured with ADCP at Transect E.

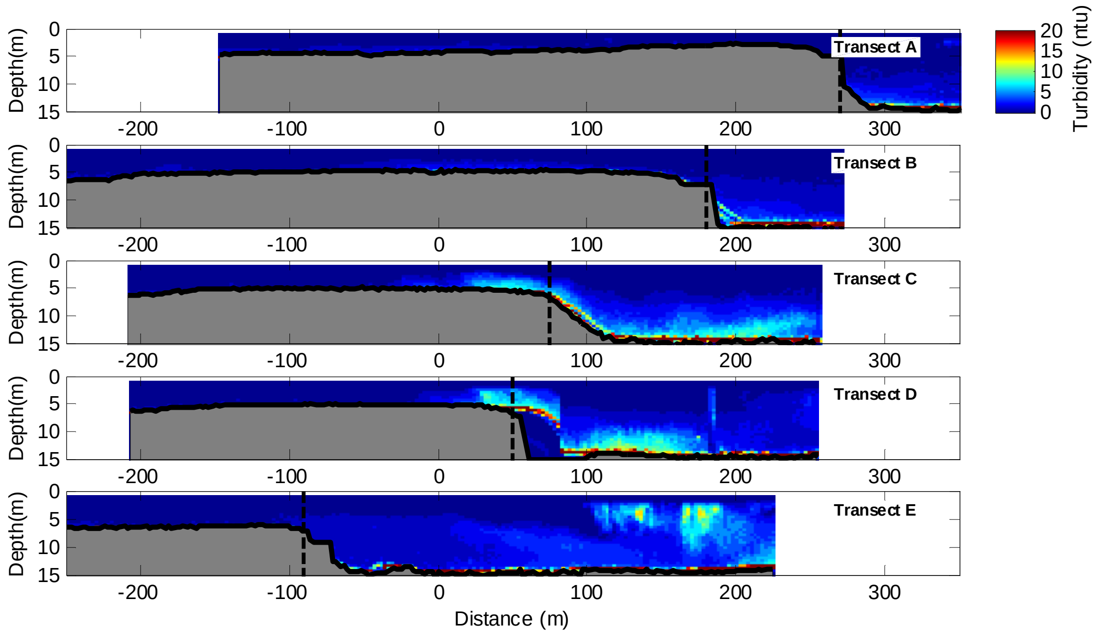


Figure 31 (continued). Dredge Plume Observations during Second Max Flood in the Southern MSC. Presented are vertical slices of calibrated turbidity (above background) measured with ADCP along each vessel transect. The approximate location of the channel boundaries are shown as dashed lines.

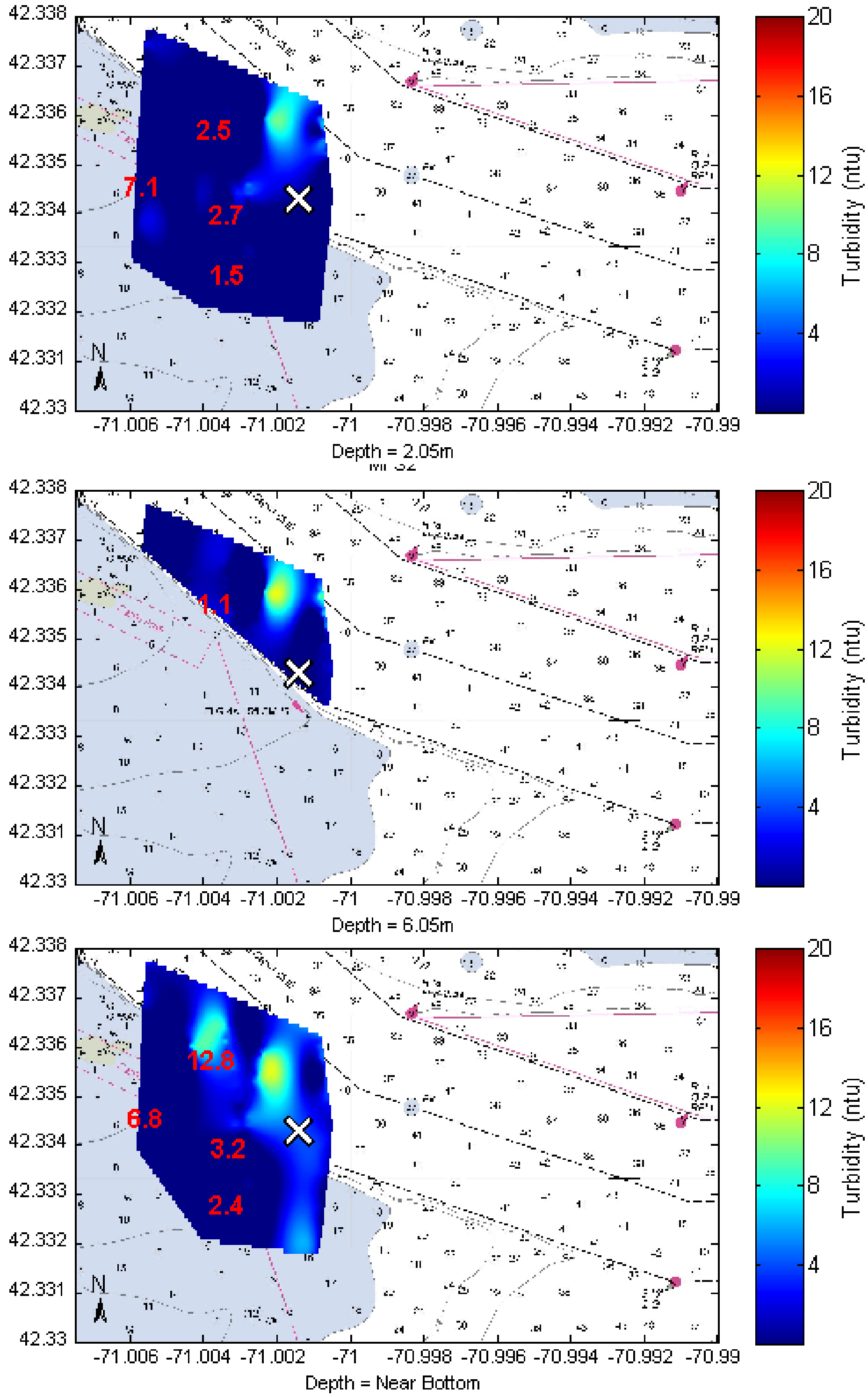


Figure 31 (continued). Dredge Plume Observations during Second Max Flood in the Southern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper), mid-depth (middle), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths.

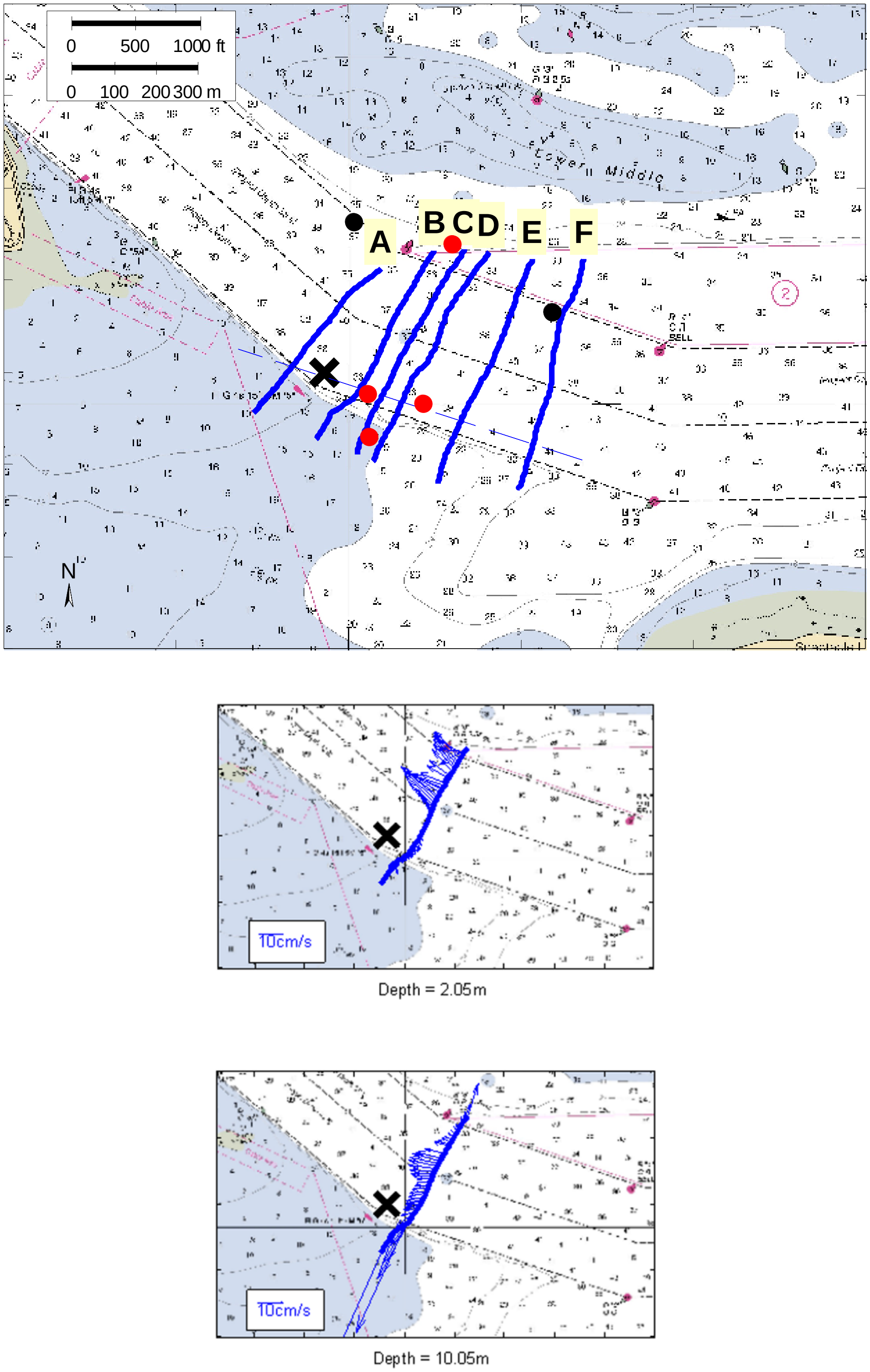


Figure 32. Dredge Plume Observations during First High Slack in the Southern MSC.

The upper panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge (‘x’). The lower two panels present near-surface and near-bottom velocities measured with ADCP at Transect B.

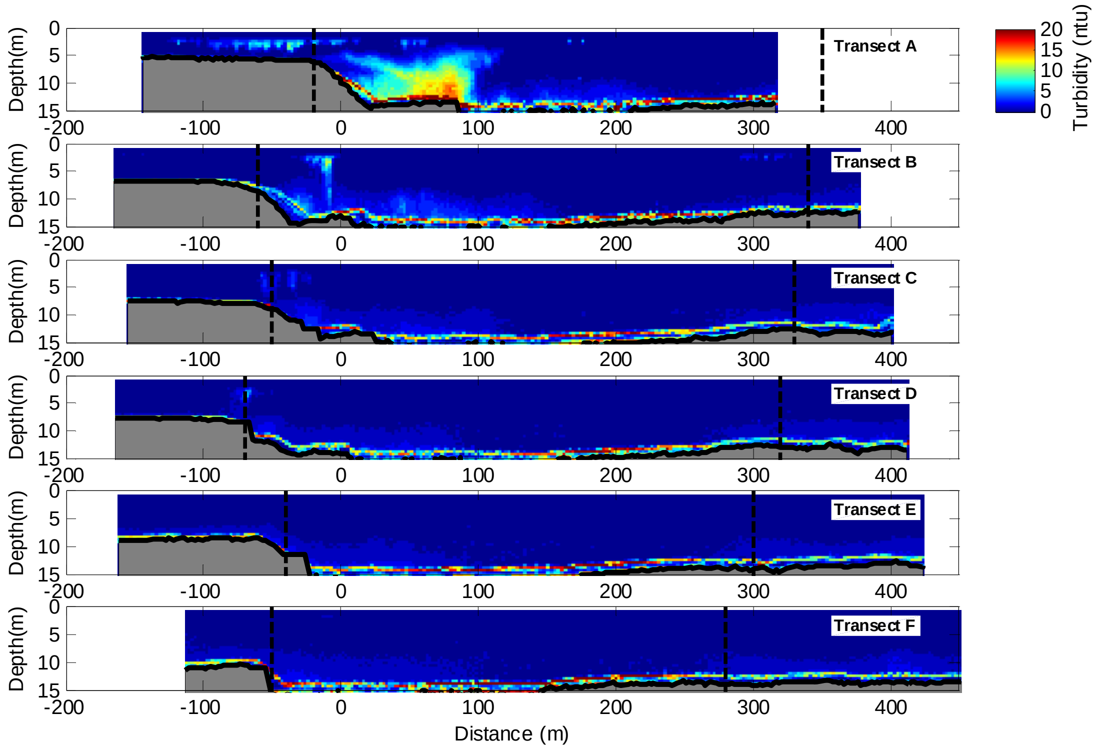


Figure 32 (continued). Dredge Plume Observations during First High Slack in the Southern MSC. Presented are vertical slices of calibrated turbidity (above background) measured with ADCP along each vessel transect. The approximate location of the channel boundaries are shown as dashed lines.

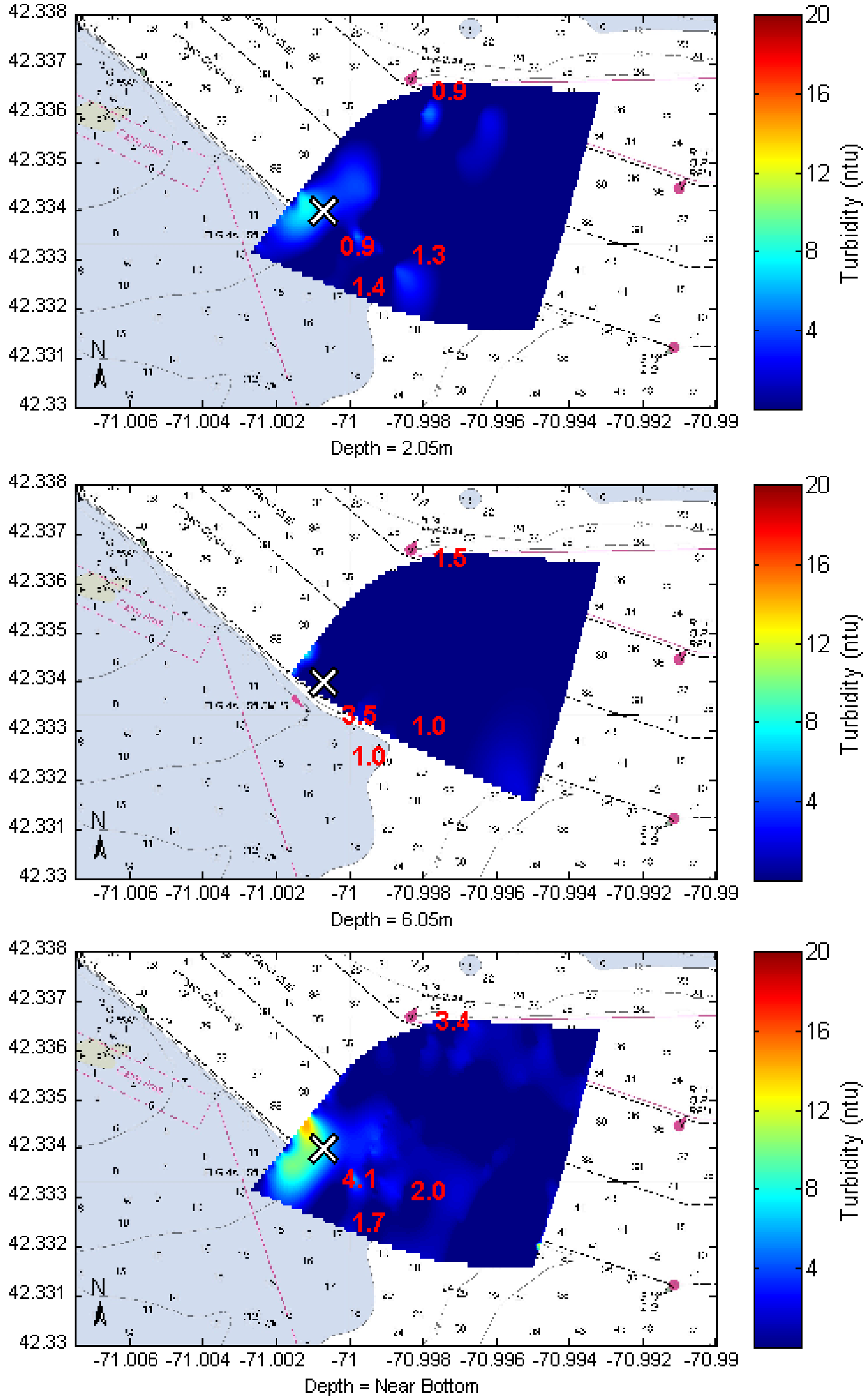


Figure 32 (continued). Dredge Plume Observations during First High Slack in the Southern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper), mid-depth (middle), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths.

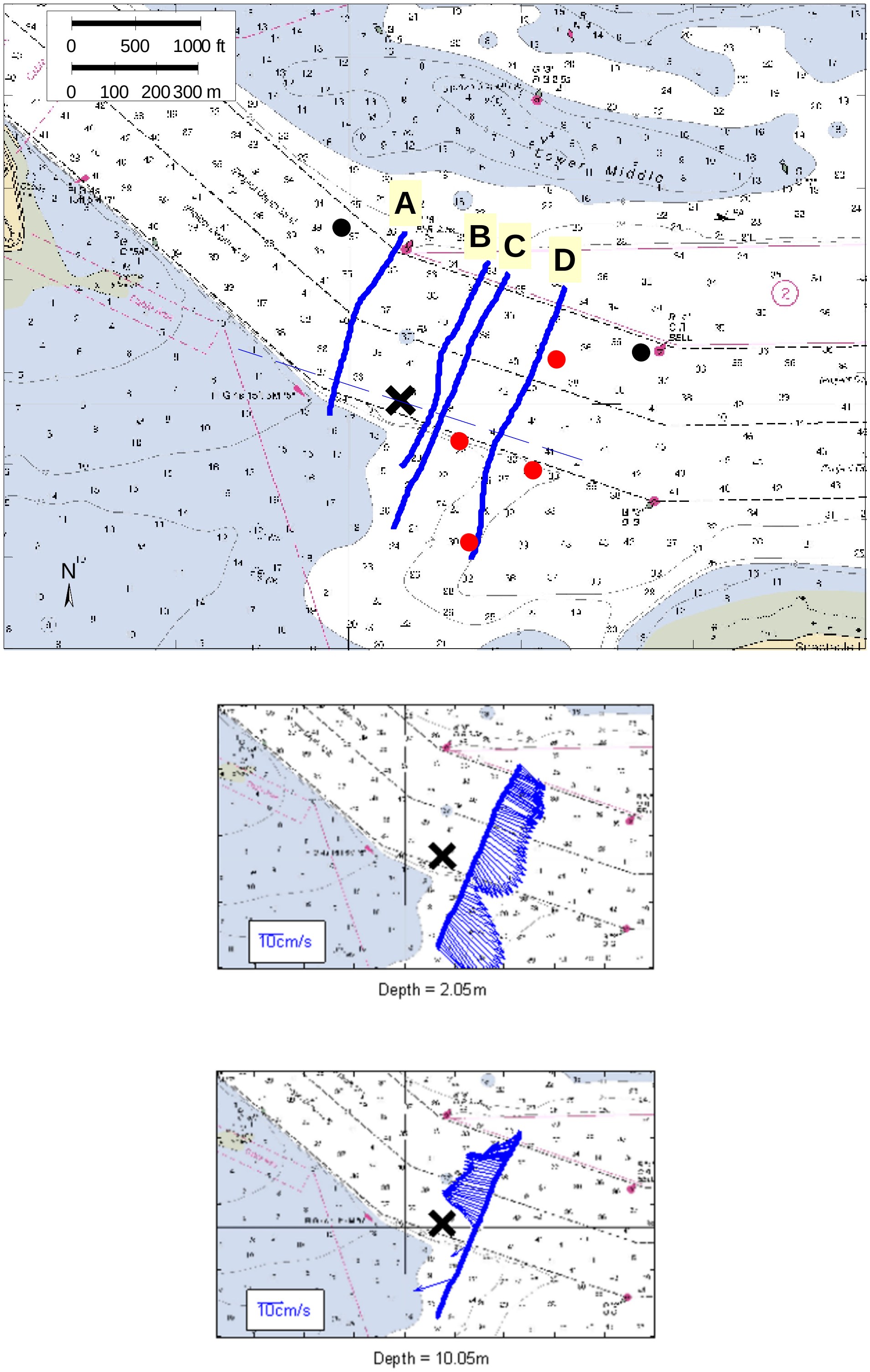


Figure 33. Dredge Observations during Second High Slack in the Southern MSC.

The upper panel shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge (‘x’). The lower two panels present near-surface and near-bottom velocities measured with ADCP at Transect C.

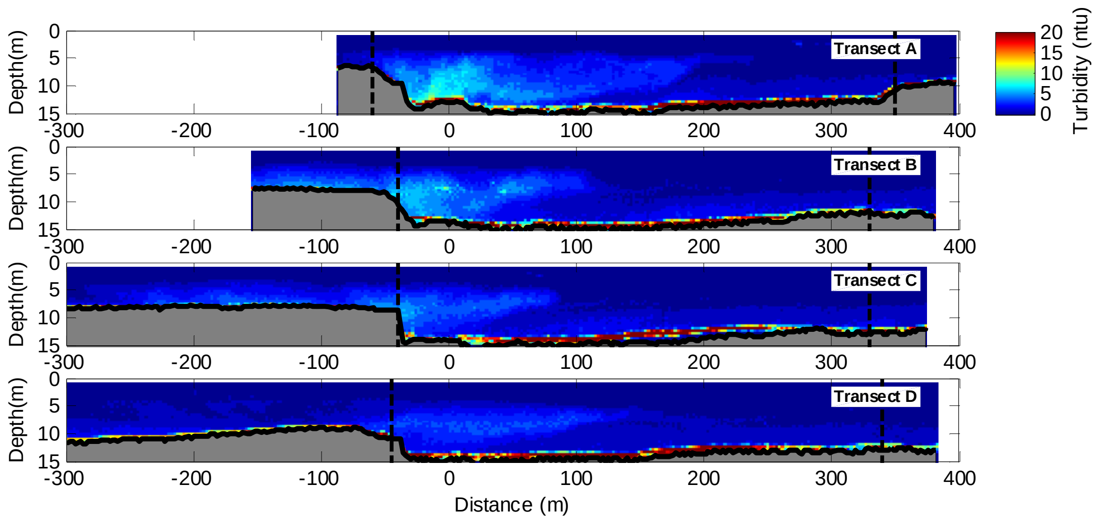


Figure 33 (continued). Dredge Plume Observations during Second High Slack in the Southern MSC. Presented are vertical slices of calibrated turbidity (above background) measured with ADCP along each vessel transect. The approximate location of the channel boundaries are shown as dashed lines.

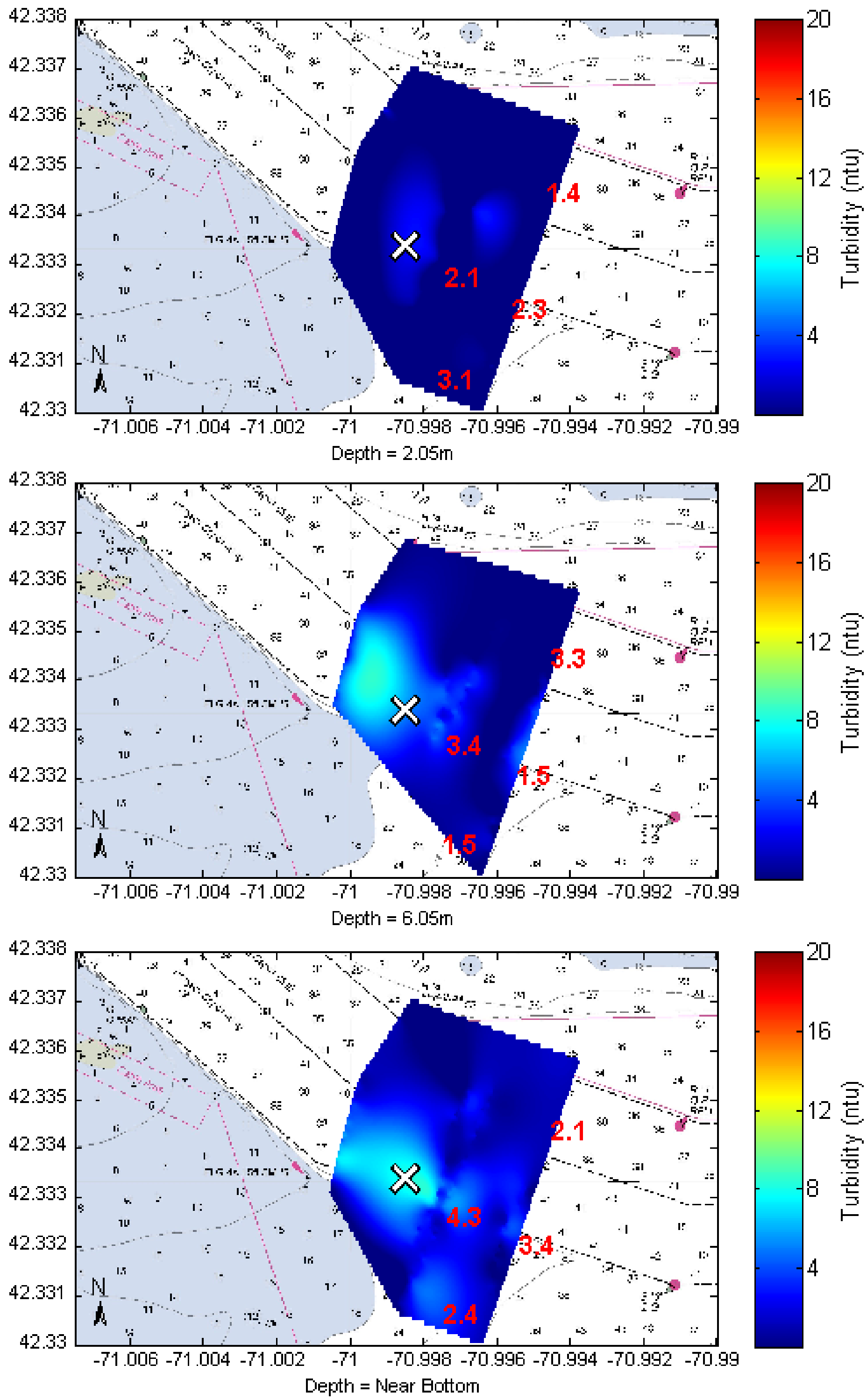


Figure 33 (continued). Dredge Plume Observations during Second High Slack in the Southern MSC. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (upper), mid-depth (middle), and near-bottom (lower). The red numbers indicate the turbidity in NTU measure by OBS during vertical profiles at the same depths.

3.2 Disposal Operation Plumes

3.2.1 General Conditions

As described in Section 3.1.1, tidal currents dominate the movement of water and any suspended sediment in Boston Harbor. Peak tidal flows are generally less that 25cm/s (0.5 kts) in the Mystic River estuary near the CAD cell (Eldridge, 2008). The CAD cell is located at the edge of the confluence of the Mystic and Chelsea Rivers with its eastern boundary located at the point where the Mystic River begins a nearly 90° bend to the south into the confluence. This results in a flow pattern which is complicated by cross channel shear flows resulting from the acceleration of the flow around the river bend.

The Mystic River feeds into Boston Harbor and provides a seasonally varying freshwater inflow. The freshwater currents in the Mystic River are weaker than the tidal currents except occasionally during large rain events. Water column density stratification was observed in vertical profiles during all disposal surveys but was weakest during the late October survey (Figure 34). This pattern was driven by the amount of rain in the Mystic River watershed in the week or two before each survey. The importance of water column stratification's effect on tidal currents through the estuarine circulation it drives was described in Section 3.1.1.

Weather conditions during the study period were mild (Table 3) and no evidence of wind driven circulation was observed.

Table 3. Weather conditions from NOAA Hindcast for Boston Harbor During Disposal Operations Monitoring.

Date	Temperature (°C)	Wind Speed and Direction
7/1/2008	19.1 to 21.9°C	Southwest 0 – 5kts becoming south
10/3/2008	11.2 to 16.5°C	Southwest 5 – 10kts
10/27/2008	11.9 to 12.8°C	Southwest 5 – 10kts becoming northeast 0 – 5kts
10/28/2008	9.3 to 12.0°C	Northeast 5 – 10kts becoming south 10 – 15kts

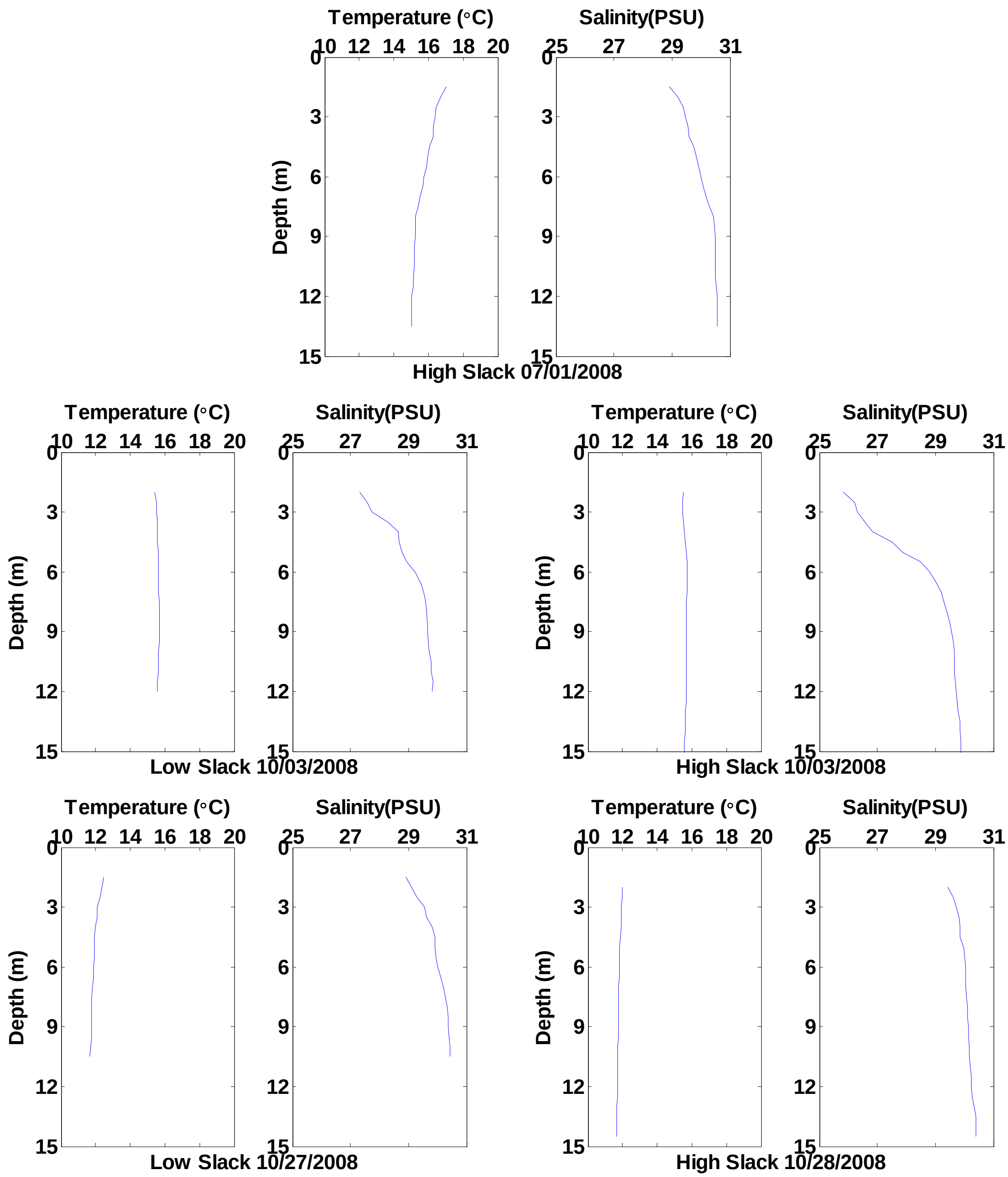


Figure 34. Water Column Stratification as Measured by Vertical Profiles of Temperature and Salinity during Disposal Monitoring near the Mystic River CAD cell (early July, early October, and late October).

3.2.2 Background Turbidity

When possible, background samples were collected at least 1000 ft (300 m) up-current or 1500 ft (450 m) down-current of the CAD cell. The measured background levels where quite low and relatively consistent whether up- or down-current. Figure 35 presents the calibrated turbidity from OBS profiles and laboratory TSS at reference locations during all five disposal monitoring surveys. With the exception of one profile with elevated near-bottom turbidity and suspended sediment[3], the background turbidity was approximately 2 – 5 NTU and the background TSS was approximately 6 – 15 mg/L. The black lines in Figure 35 represent the depth average of the background profiles not exhibiting a near-bottom peak. With a range of background values observed, a conservative approach was taken; the minimum of the average vertical profile was selected (2 NTU and 6 mg/L) as the background value and used throughout the following analysis.

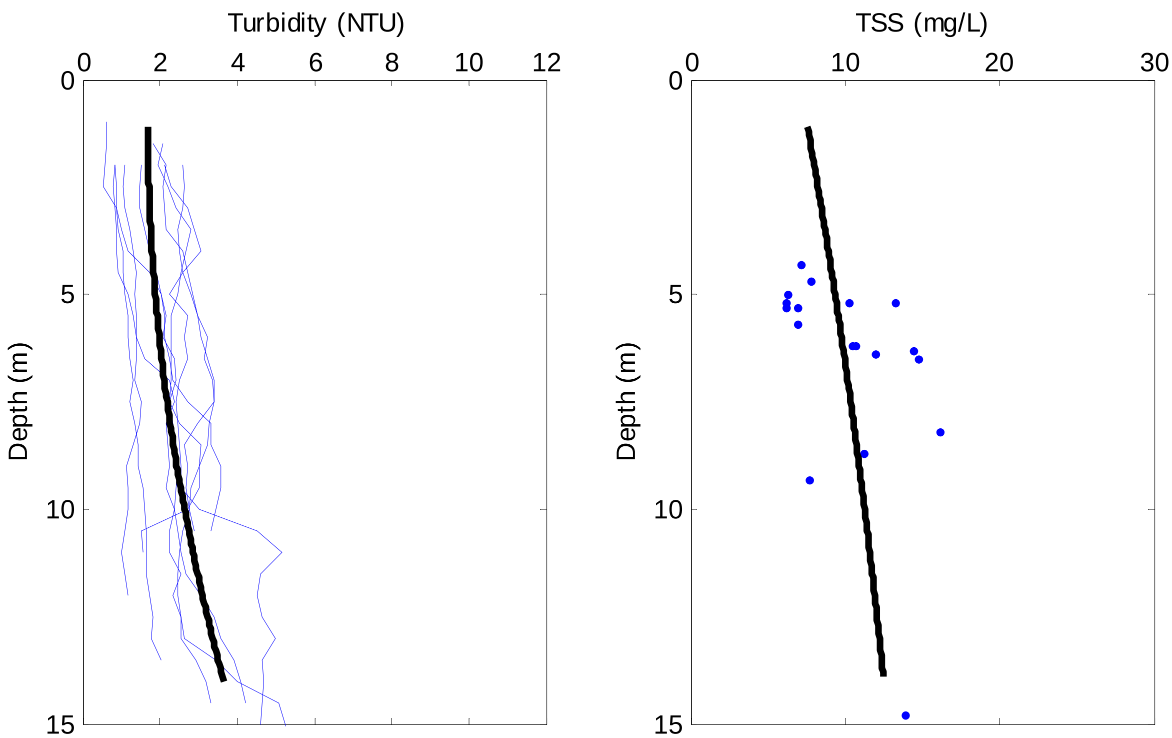


Figure 35. Ambient Turbidity and TSS during all Background Vertical Profiles.

Presented are data from all 10 background profiles (blue) and the 2nd order polynomial fit (black) of those 9 profiles without elevated near-bottom turbidity.

[3] Reference (background) profiles with elevated near-bottom turbidity were all collected at in-channel reference locations while nearby dredging operations were ongoing. No such elevated near-bottom turbidity was observed at reference stations located outside the navigation channel or when dredging operations were suspended. This suggested the possible presence of a dredging related near-bottom turbidity signal at the in-channel reference stations. After this observation was noted (7/1/2008), reference stations were chosen outside the navigation channel where conditions were likely more representative of background.

3.2.3 Disposal Plume Turbidity and Suspended Sediment

Five disposal plumes were monitored in and around the Mystic River CAD cell during five slack tides on four separate days. In the series of figures that follow, current velocity and suspended sediment measurements collected during the plume surveys are presented. Each figure presents results from a single disposal survey. Included in each figure is a series of panels presenting the locations of measurements, current velocity, and vertical and plan-view contours of observed turbidity. The location panel shows the CAD cell boundaries, the approximate location of the dredge barge at the time of release, the locations of cross-channel vessel transects, and the locations of vertical profile stations. The vessel transects are labeled and are referred to in a later panel. Two panels present the current velocity measured near surface and near bottom along one transect. The velocity is represented as arrows with lengths proportional to the speed of the current and direction representing the direction of current flow. The next panel presents vertical contours of calibrated turbidity in NTU (above background) along each vessel transects. The contours are labeled with the transect letter and are oriented in chronological order showing the approximate time since release and the approximate location of the channel boundaries are shown as dashed lines. The last series of panels present three plan-view contours of estimated turbidity near-surface, mid-depth, and near-bottom. The near-surface and mid-depth contours represent turbidity at constant depths below the surface, while the near-bottom contours represents turbidity at a constant height above the bottom. Also shown in these panels are the turbidity values measured by OBS during vertical profiles for the same depths. The full vertical profiles of turbidity and other parameters are available in the Survey Reports (Battelle, 2009a and Battelle, 2009b).

Vertical and plan-view contours of suspended sediment concentration in mg/L above background have also been developed. These figures were derived from the same set of ADCP acoustic backscatter data using the suspended sediment concentration calibration curve presented previously and so appear similar to the turbidity contour figures. They are presented separately in Appendix A of this report. In the following sections, TSS values from Appendix A will be referenced alongside corresponding turbidity values.

Unlike plumes resulting from dredging operations, which are steady state or quasi-steady, plumes resulting from dredged material placement are transient in nature. During dredging operations, data from consecutive transects over an area can be combined into turbidity contours which represent a synoptic or quasi-synoptic view, as long as the total time of all transects is short relative to a tidal cycle (typically 1.5 hour). But in a transient situation, such as a disposal release, contours from multiple transects do not represent a synoptic snapshot and the time after release of each transect must be considered.

3.2.3.1 Disposal Plume during July 1, 2008 High Slack at the Mystic River CAD Cell

On July 1, 2008, a disposal plume was surveyed during a dredged material release from a split hull scow at the Mystic River CAD cell during the late morning high slack window. The monitoring occurred during the first week of disposal into the cell. The material placed into the CAD cell was dredged from the surface layer of a proposed new CAD cell, which was being prepared for future use and is located in the Federal navigation Main Ship channel just south of the confluence. Figure 36 documents the suspended sediment plume observed in the water column after the release. The currents were weak and variable (< 10 cm/s) with a slight horizontal shear flowing weakly to the west in the northern half of the channel and weakly to the east in the southern half. With little current to transport and disperse the suspended sediment, the disposal plume stayed close to the point of release, transported primarily by its own momentum.

The currents observed before the disposal release were weak and variable, but flowed primarily to the east. The following transects were run:

- Transect A, 1 min after release, 350 ft (110 m) east of release
- Transect B, 3 min after release, 350 ft (110 m) east of release
- Transect C, 6 min after release, 500 ft (150 m) east of release
- Transect D, 19 min after release, through release point, plume observed
- Transect E, 32 min after release, 300 ft (90 m) west of release, plume observed
- Transect F, 43 min after release, 800 ft (250 m) east of observed.

The first three transects (A, B and C) were run to the east of the release point with the third starting six minutes after release. None of these transects showed any evidence of the plume. The fourth transect (D) was then run through the approximate point of release 19 min after release. (Transect D appears in Figure 36, Panel 1 approximately 100 ft (30 m) west of the 'x' but given the size of the scow this is effectively within the release footprint.) The plume is visible along Transect D (Panel 4) approximately 400 ft (120 m) wide at 45 NTU above background (130 mg/L). Transect E was then run just another 150 ft (45 m) west of D where some evidence of the plume was visible (30 NTU; 85 mg/L). Running additional transects to the west was not possible because of the presence of an LNG tanker offloading at the terminal just west of the CAD cell.

With the plume dissipating rapidly vertical profiles were performed along a line approximately 500 ft (150 m) west of the release point (still within the CAD cell) in order to capture physical samples at the approximate plume centroid before plume dissipated entirely. Peak turbidity observed during vertical profiles was approximately 10 NTU above background. It is important to note again that the plan-view contours (Panels 5-7) do not represent a synoptic view, however, they do present evidence of the limited movement of the plume away from the release point. Evidence of the plume greater than 15 NTU above background is limited to an area within approximately 330 ft (100 m) of the release point and the plume was not observed 500 ft downdrift of the CAD cell boundary.

3.2.3.2 Disposal Plume during October 3, 2008 Low Slack at the Mystic River CAD Cell

On October 3, 2008, two disposal plumes were surveyed during a period when the cell had been filled to at least 50% of design capacity. The first disposal release occurred during the morning low slack window. The material placed into the CAD cell had been dredged from the upper Reserved Channel. Figure 37 documents the suspended sediment plume observed in the water column after the release.

A series of ten cross-channel transects executed over a period of approximately 75 minutes are presented in Figure 37, and summarized below:

- Transect A, 1 min after release, 300 ft (90 m) east of release
- Transect B, 5 min after release, 500 ft (150 m) west of release
- Transect C, 9 min after release, 700 ft (215 m) west of release
- Transect D, 12 min after release, 300 ft (90 m) east of release, weak plume observed

- Transect E, 15 min after release, 500 ft (150 m) west of release, plume observed
- Transect F, 26 min after release, 500 ft (150 m) west of release, plume observed
- Transect G, 37 min after release, 500 ft (150 m) west of release, plume observed
- Transect H, 40 min after release, 750 ft (230 m) west of release, weak plume observed
- Transect I, 1 hour 5 min after release, 500 ft (150 m) west of release, plume observed
- Transect J, 1 hour 11 min after release, 200 ft (60 m) west of release, weak plume observed.

The transect locations are shown in the first two Panels of Figure 37. The current is nearly 20 cm/s westward near-surface and slack near-bottom (Panels 3 and 4). The disposal plume observed was weak with turbidity concentrations never exceeding 25 NTU (70 mg/L) near-bottom (transect I) and 15 NTU (40 mg/L) throughout the rest of the water column (Panel 5) (transects E, F, G, and I). The first five transects were performed within about 15 min of the time of release. The plan-view contours from the first five transect (Panel 6) show limited movement of the plume away from the release point with the plume largely remaining between the east and west boundaries of the CAD cell. After the first five transects, vertical profiles were preformed west of the release point. Peak turbidity observed during vertical profiles was approximately 40 NTU above background. After vertical profiles were complete, five additional transects were performed between approximately 26 and 71 minutes after release. They show the dissipation of the plume with turbidity levels low but above background mid-depth and 22 NTU (60 mg/L) near-bottom along a line through the point of release 65 min after release. The remaining panels in Figure 37 show the plan-view contours of the estimated turbidity from the first five and last five transects separately. They reinforce the view that the plume concentration was weak and its movement was limited. The densest part of the plume did not cross the line 500 ft downdrift of CAD cell boundary.

3.2.3.3 Disposal Plume during October 3, 2008 High Slack at the Mystic River CAD Cell

On October 3, 2008 a second disposal plume was surveyed during the afternoon high slack window. The material placed into the CAD cell had been dredged from the upper Reserved Channel. Figure 38 documents the suspended sediment plume observed in the water column after the release. The currents are weak and variable with a weak eastward current near-surface and a weak westward current near-bottom particularly in the northern part of the channel.

A series of six cross-channel transects are presented in Figure 38. In an attempt to locate and map the plume in the weak and variable tidal currents, transects were run alternately east, west, and through the point of release, as summarized below:

- Transect A, 2 min after release, 300 ft (90 m) east of release
- Transect B, 9 min after release, 500 ft (150 m) west of release, plume observed
- Transect C, 13 min after release, 500 ft (150 m) east of the CAD cell boundary, plume observed
- Transect D, 16 min after release, through release point, plume observed
- Transect E, 32 min after release, through release point, plume observed
- Transect F, 36 min after release, 500 ft (150 m) west of release, plume observed.

The plume spread east (transects A and C) and west (transects B and F) from the point of release (as seen in the vertical turbidity contours [Panel 4]) with the strongest plume signal visible near the point of release. Peak turbidity observed with calibrated ADCP approached 45 NTU (130 mg/L) above background at Transect B 500 ft (150 m) west of the release point. With the release located near the CAD cell's eastern boundary, the decision was made to perform vertical profiles along a line approximately 500 ft (150 m) east of the CAD cell's eastern boundary approximately along transect C. Peak turbidity observed during vertical profiles was approximately 12 NTU above background. It is important to note again that the plan-view contours (Panels 5 to 7) do not represent a synoptic view, however, they do present evidence of the limited movement of the plume away from the release point. With little current to transport and disperse the suspended sediment, the release plume stays close to the point of release transported primarily by its own momentum and did not cross the line 500 ft downdrift of the CAD cell boundary.

3.2.3.4 Disposal Plume during October 27, 2008 Low Slack at the Mystic River CAD Cell

On October 27, 2008 a disposal plume was surveyed during a period when the cell had been filled to at least 90% of design capacity. The disposal release occurred during the midday low slack window. The material placed into the CAD cell had been dredged from the MSC just east of the Reserved Channel. Figure 39 documents the suspended sediment plume observed in the water column after the release. The currents are weak and variable with a weak westward current near-surface and slack current near-bottom.

A series of six cross-channel transects are presented in Figure 39 and summarized below:

- Transect A, 9 min after release, 500 ft (150 m) west of CAD cell boundary
- Transect B, 12 min after release, 600 ft (180 m) west of release, plume observed
- Transect C, 14 min after release, 200 ft (60 m) west of release, plume observed
- Transect D, 17 min after release, 600 ft (180 m) east of release, weak plume observed
- Transect E, 44 min after release, 500 ft (150 m) west of CAD cell boundary, weak plume observed
- Transect F, 50 min after release, 400 ft (120 m) east of release, weak plume observed.

The plume moved relatively quickly westward and out of the CAD cell and dissipated. Transect B, located along the cell's western boundary, shows the strongest indication of the plume with turbidity levels approaching 50 NTU (140 mg/L). Filaments of the plume are also visible at transect C (near the point of release) and transects D and F (to the east of release) all at low concentrations. Turbidity values along transects A (9 min) and F (50 min), co-located along a line approximately 500 ft (150 m) west of the cell boundary, were just above background (< 8 NTU; <20 mg/L).

3.2.3.5 Disposal Plume during October 28, 2008 High Slack at the Mystic River CAD Cell

On October 28, 2008 the final disposal plume survey was performed during the midday high slack window. The material placed into the CAD cell had been dredged from the MSC just east of the Reserved Channel. Figure 40 documents the suspended sediment plume observed in the water column after the release. The currents are weak and variable with a weak eastward current near-surface and slack current near-bottom.

A series of eleven cross-channel transects executed over a period of approximately one hour are presented in Figure 40, Panels 1and 2, and summarized below:

- Transect A, 2 min after release, 100 ft (30 m) east of release
- Transect B, 5 min after release, 400 ft (120 m) east of release, plume observed

- Transect C, 9 min after release, 400 ft (120 m) west of release, plume observed
- Transect D, 12 min after release, 600 ft (180 m) west of release, plume observed
- Transect E, 14 min after release, 400 ft (120 m) west of CAD cell boundary
- Transect F, 42 min after release, 400 ft (120 m) east of release, weak plume observed
- Transect G, 45 min after release, 100 ft (30 m) east of release, plume observed
- Transect H, 47 min after release, 200 ft (60 m) west of release, plume observed
- Transect I, 49 min after release, 400 ft (120 m) west of release, plume observed
- Transect J, 52 min after release, 600 ft (180 m) west of release, weak plume observed
- Transect K, 55 min after release, 400 ft (120 m) west of CAD cell boundary, weak plume observed.

The data show the dissipation of the plume over time. The first five transects were performed within about 15 min of the time of release. During that time, the plume was present with high turbidity (50 NTU; 140 mg/L) throughout the water column near the point of release (Transect C) with filaments of the plume also visible along transects B and D (near the western boundary of the cell) at turbidity levels below 30 NTU (85 mg/L) throughout the water column. After the first five transects, vertical profiles were preformed along a line approximately 500 ft (150 m) west of the release point (Transect I) but inside the cell. Peak turbidity observed during vertical profiles was the highest seen during all surveys at approximately 75 NTU above background at a location on the northern edge of the CAD cell boundary. After vertical profiles were complete, six additional transects were performed between approximately 40 and 60 minutes after release. They show the dissipation of the plume down to near background levels mid-depth and near-surface although near-bottom levels within approximately 300 ft (90 m) of the point of release remained 30 NTU (85 mg/L) above background after 50 min. The plan-view contours in Figure 40 (Panels 6 through 11) again present clear evidence of the limited movement of the plume away from the release point. Turbidity from OBS presented in the plan-view contours shows only approximate match to the color contours because of the heterogeneity of the plume.

As with the previous disposal plumes, the centroid of the plume moved very little and vertical profiles were performed along a line within the CAD cell in order to capture physical samples of the plume before plume dissipated entirely. Turbidity values along transects E (14 min) and K (55 min), both located along a line approximately 500 ft outside the CAD cell's western boundary, were at background and just above background, respectively.

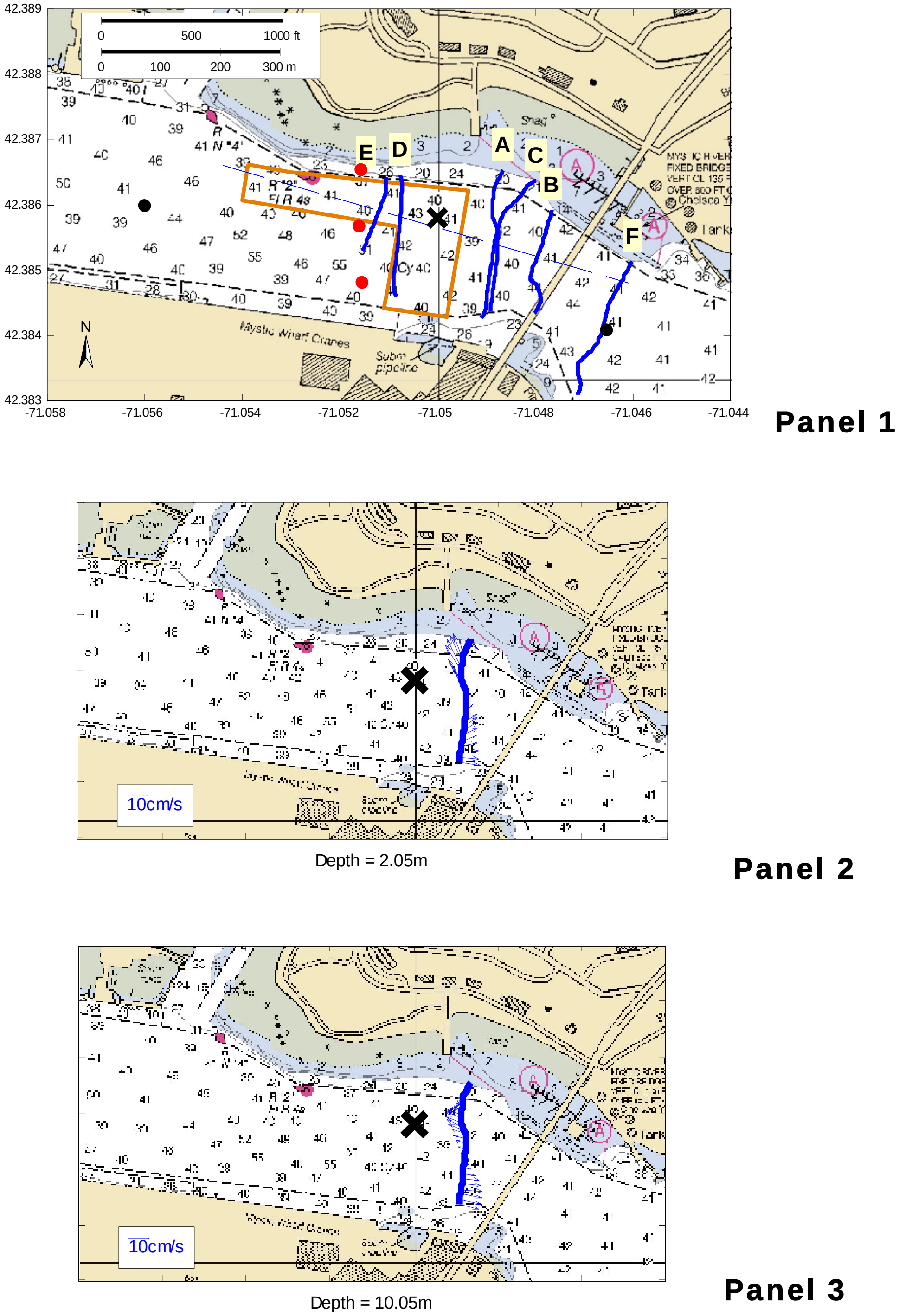
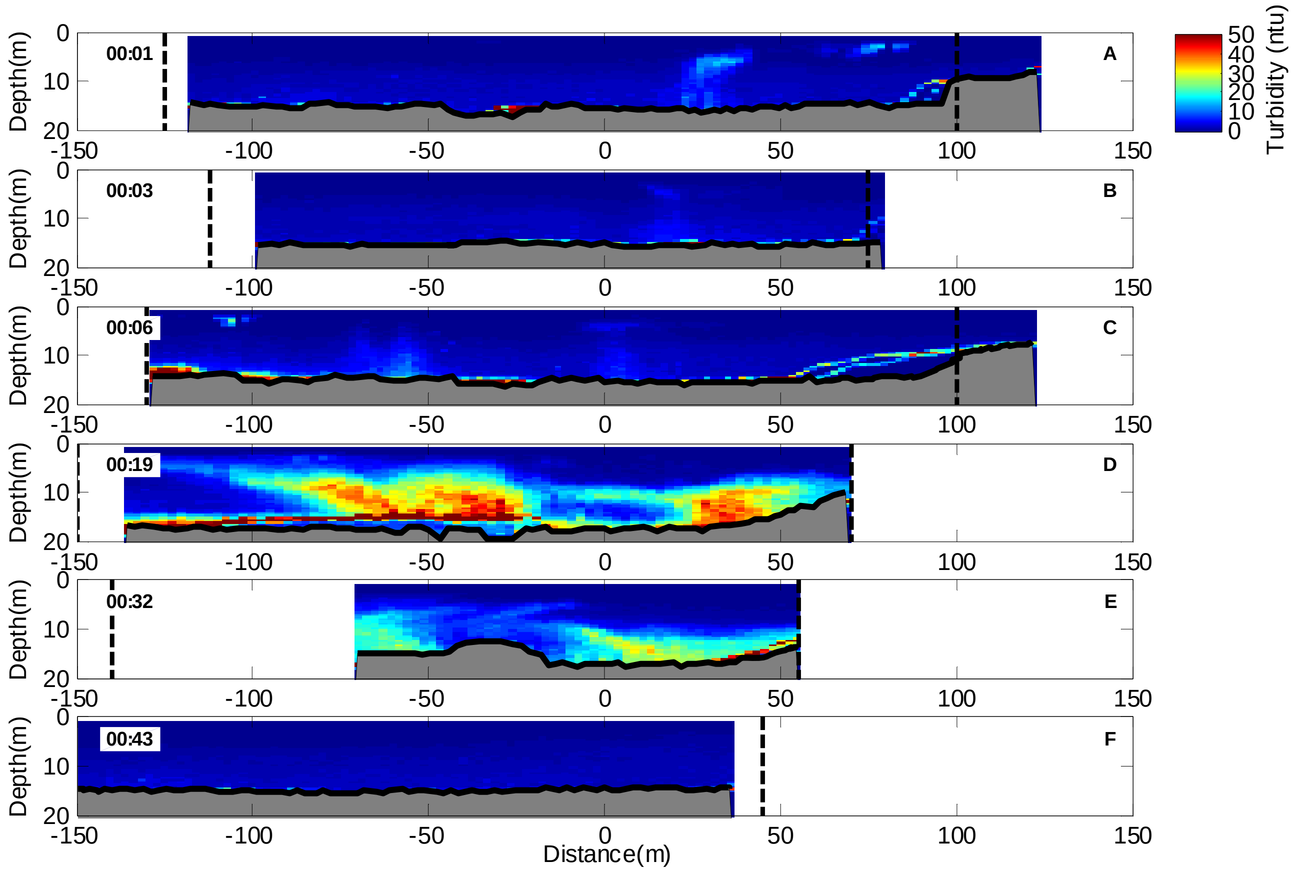


Figure 36. Observations during July 1, 2008 High Slack Disposal into the Mystic River CAD Cell.

The panel 1 shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The panels 2 and 3 present near-surface and near-bottom velocities, respectively, measured with ADCP at Transect A.



Panel 4

Figure 36 (continued). Observations during July 1, 2008 High Slack Disposal into the Mystic River CAD Cell. Panel 4 shows vertical slices of calibrated turbidity (above background) measured with ADCP along each vessel transect. The approximate location of the channel boundaries are shown as dashed lines.

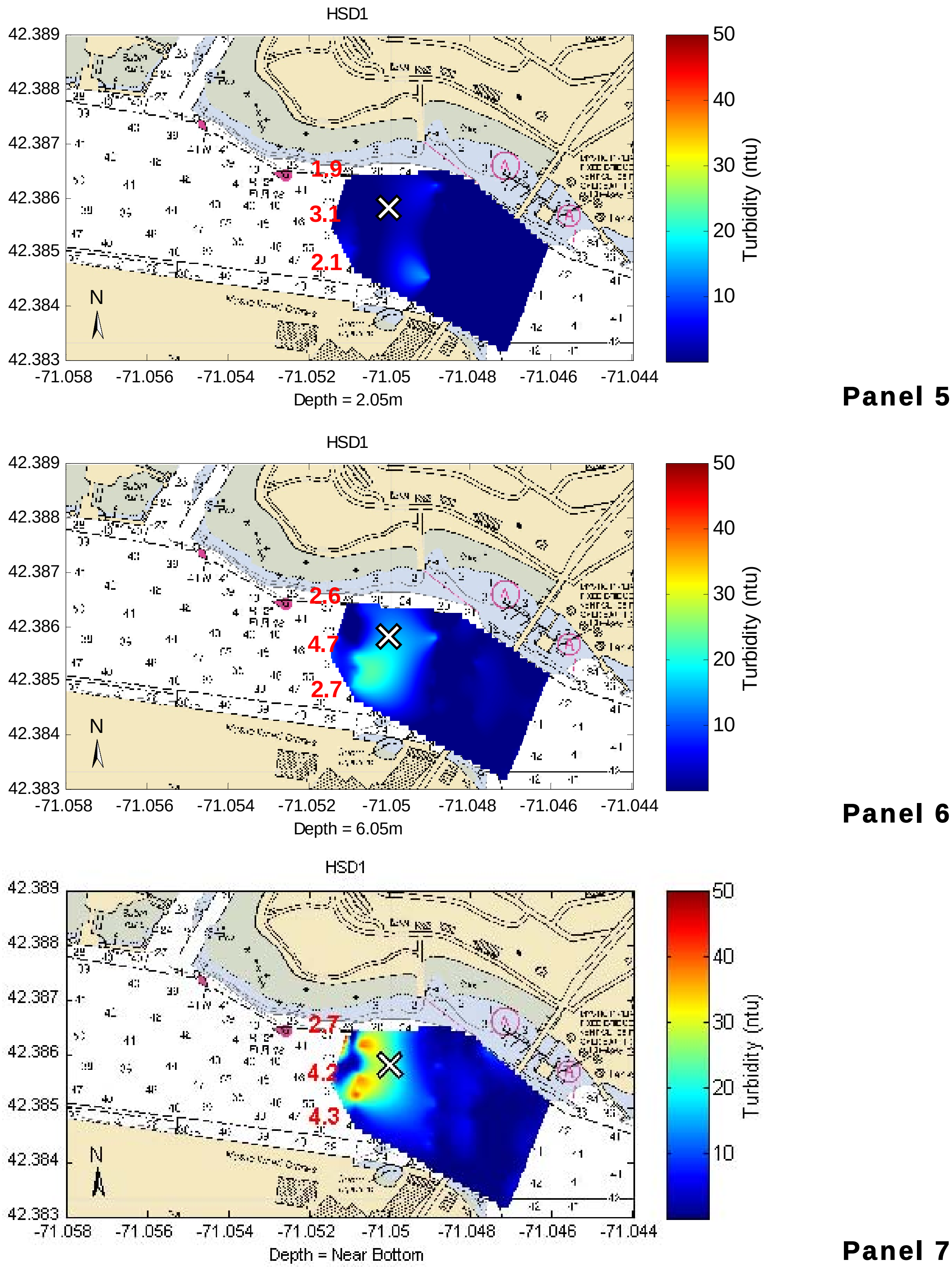
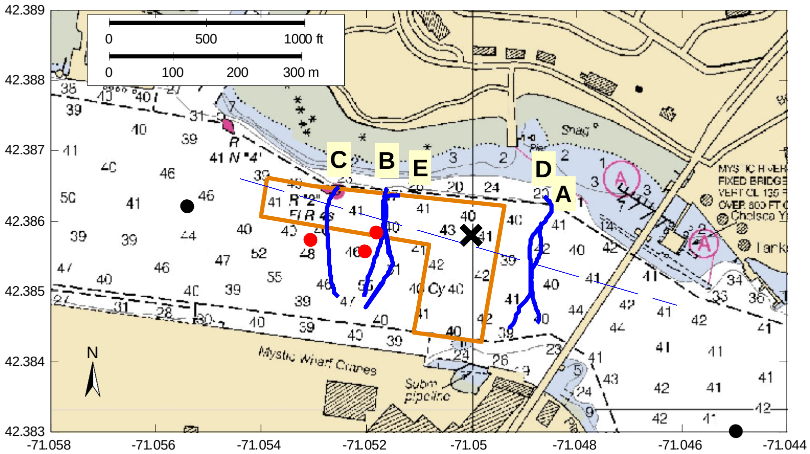
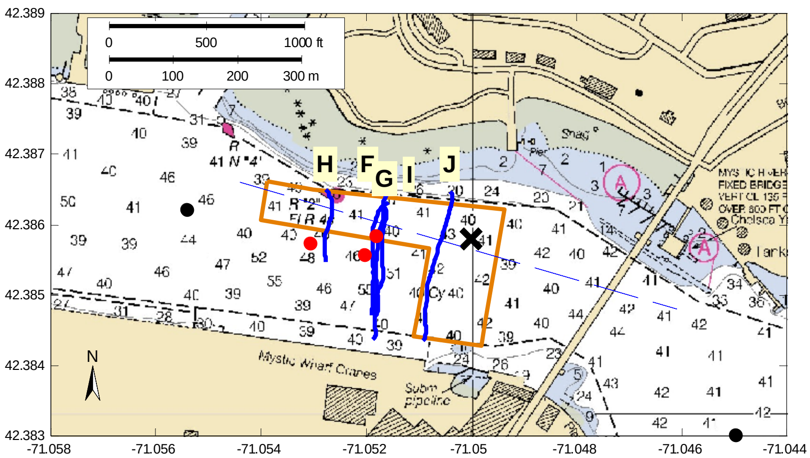


Figure 36 (continued). Observations during July 1, 2008 High Slack Disposal into the Mystic River CAD Cell. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (panel 5), mid-depth (panel 6), and near-bottom (panel 7). Also shown are turbidity in NTU at the same depths from OBS at vertical profile stations, 30-42 min after release.



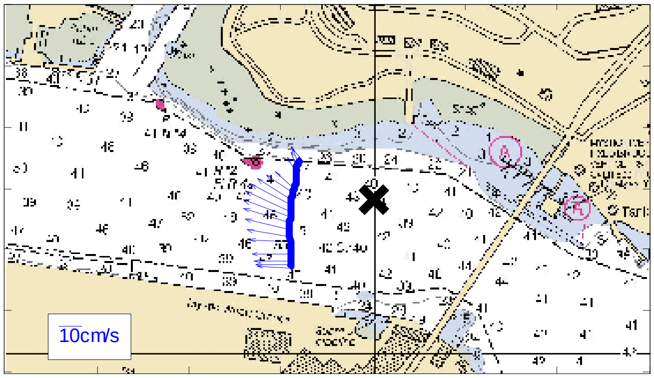
Panel 1



Panel 2

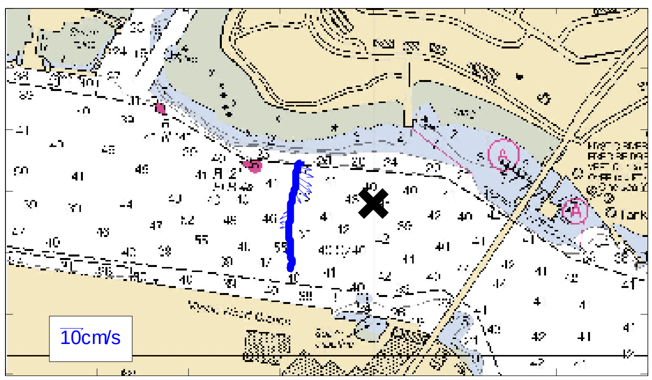
Figure 37. Observations during October 3, 2008 Low Slack Disposal into the Mystic River CAD Cell.

Panels 1 and 2 show vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge (‘x’).



Depth = 2.05m

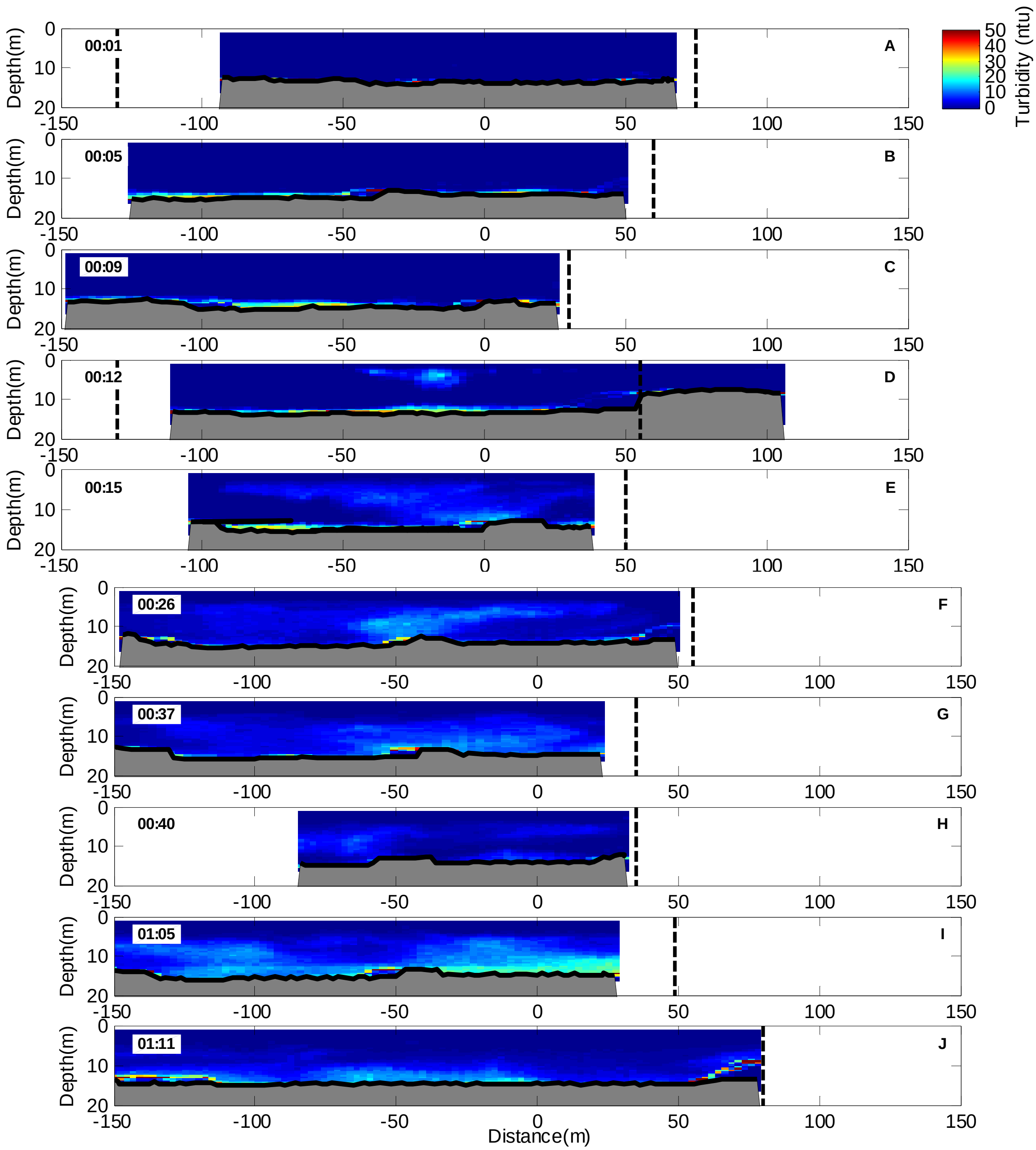
Panel 3



Depth = 10.05m

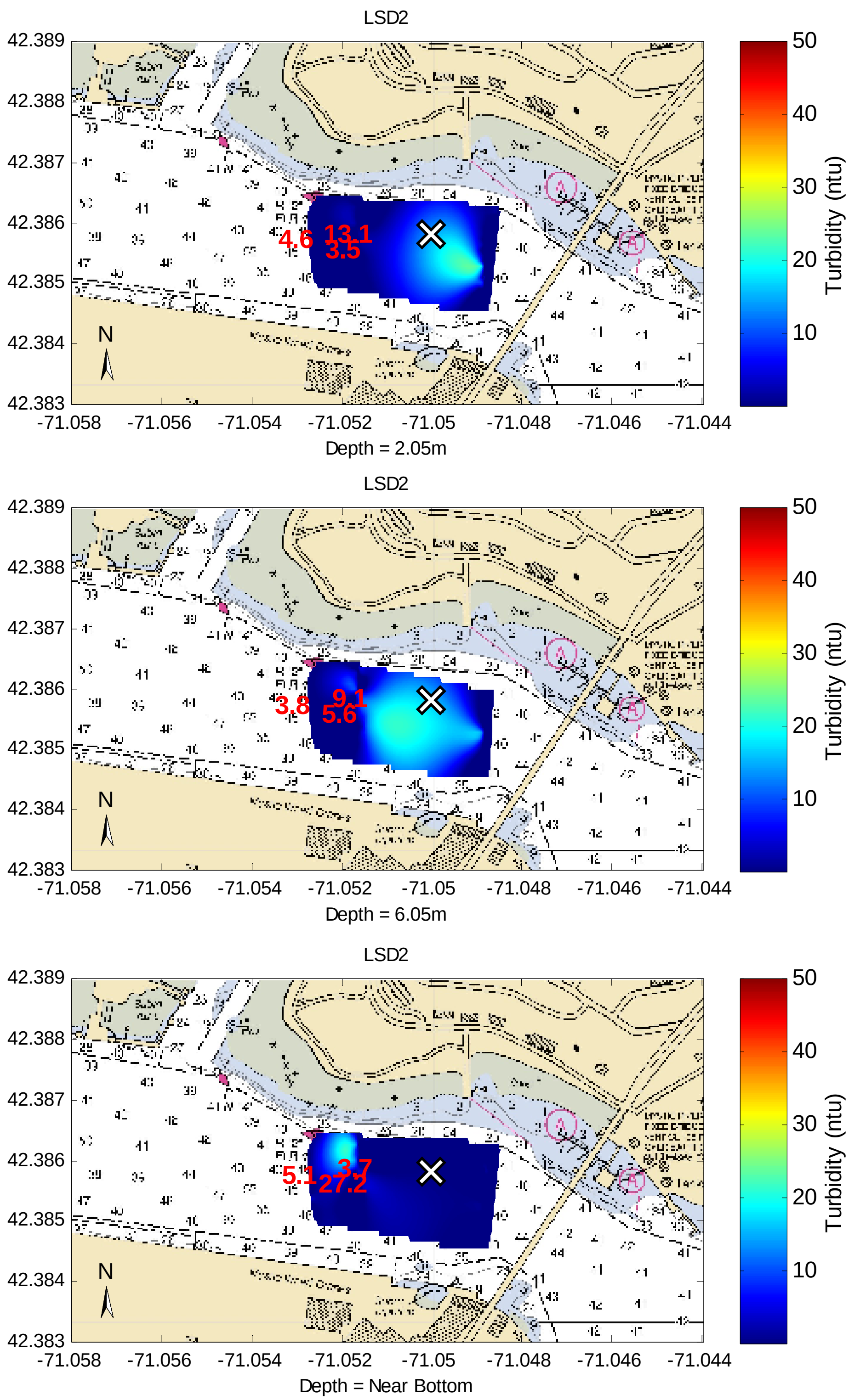
Panel 4

Figure 37 (continued). Observations during October 3, 2008 Low Slack Disposal into the Mystic River CAD Cell. Panels 3 and 4 present near-surface and near-bottom velocities, respectively, measured with ADCP at Transect B.



Panel 5

Figure 37 (continued). Observations during October 3, 2008 Low Slack Disposal into the Mystic River CAD Cell. Panel 5 shows vertical slices of calibrated turbidity (above background) measured with ADCP along each vessel transect. The approximate location of the channel boundaries are shown as dashed lines.

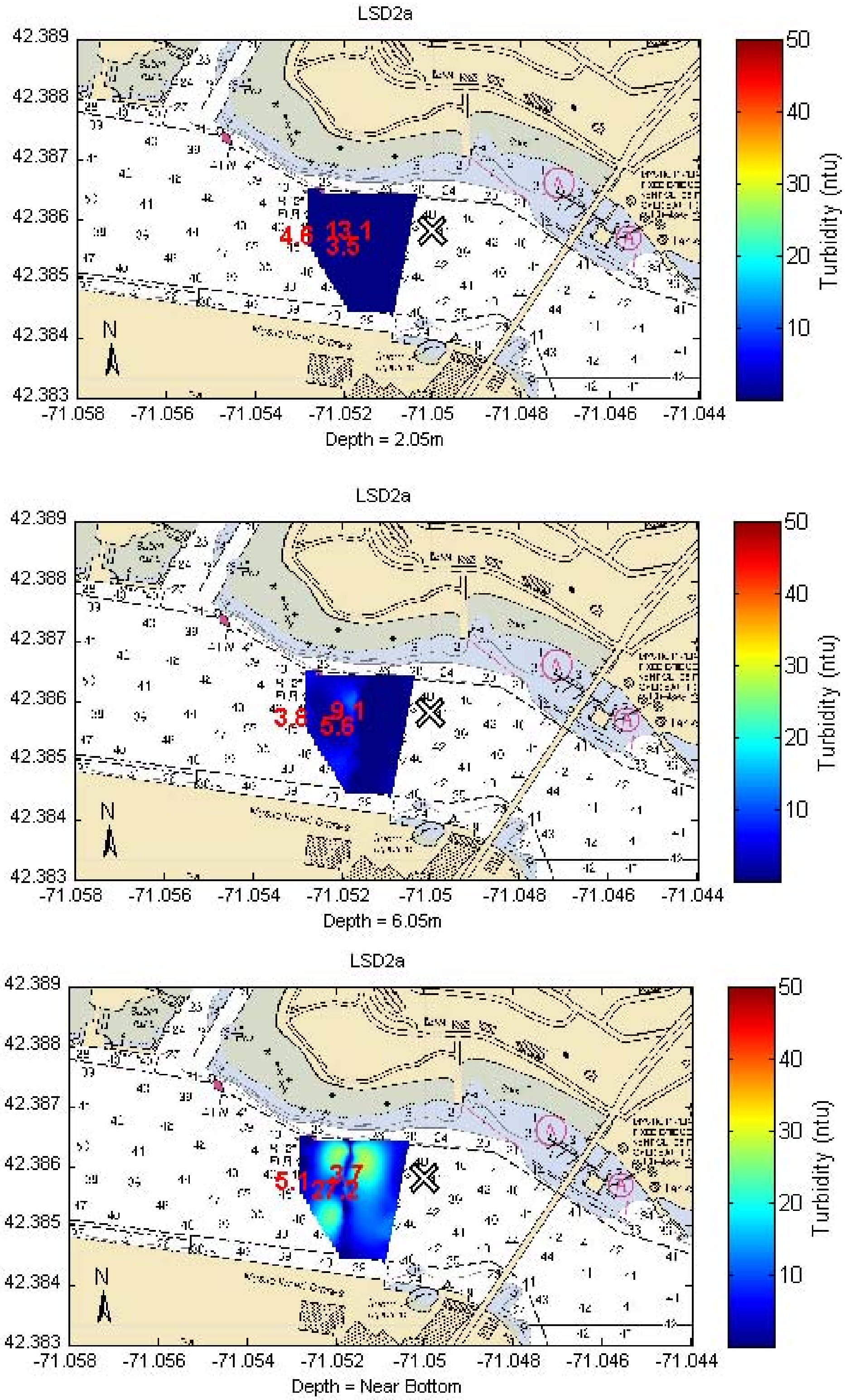


Panel 6

Panel 7

Panel 8

Figure 37 (continued). Observations during October 3, 2008 Low Slack Disposal into the Mystic River CAD Cell. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (panel 6), mid-depth (panel 7), and near-bottom (panel 8) during transects A- E. Also shown are turbidity in NTU at the same depths from OBS at vertical profile stations, 21-43 min after release.

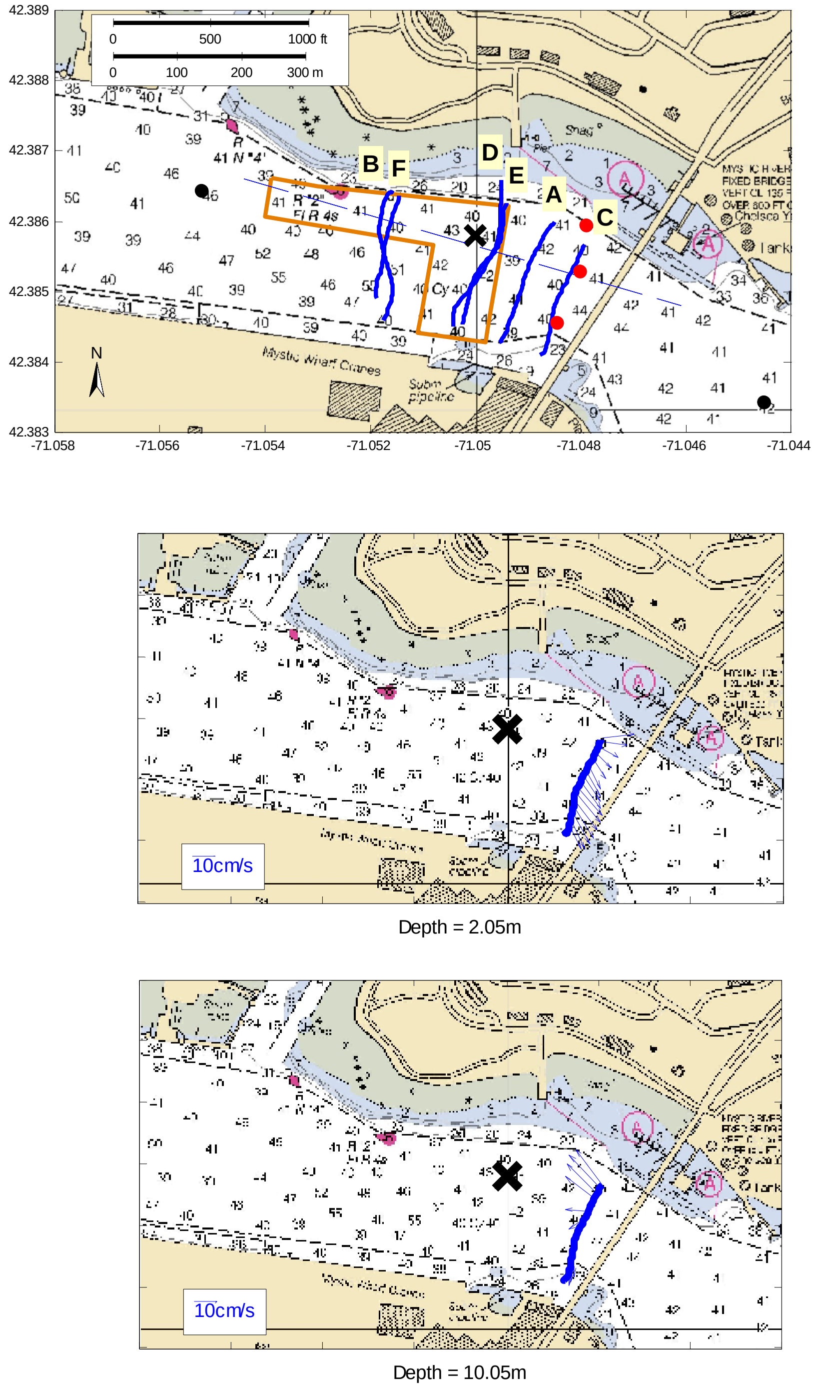


Panel 9

Panel 10

Panel 11

Figure 37 (continued). Observations during October 3, 2008 Low Slack Disposal into the Mystic River CAD Cell. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (panel 9), mid-depth (panel 10), and near-bottom (panel 11) during transects F – J.



Panel 1

Panel 2

Panel 3

Figure 38. Observations during October 3, 2008 High Slack Disposal into the Mystic River CAD Cell.

The panel 1 shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The panels 2 and 3 present near-surface and near-bottom velocities, respectively, measured with ADCP at Transect C

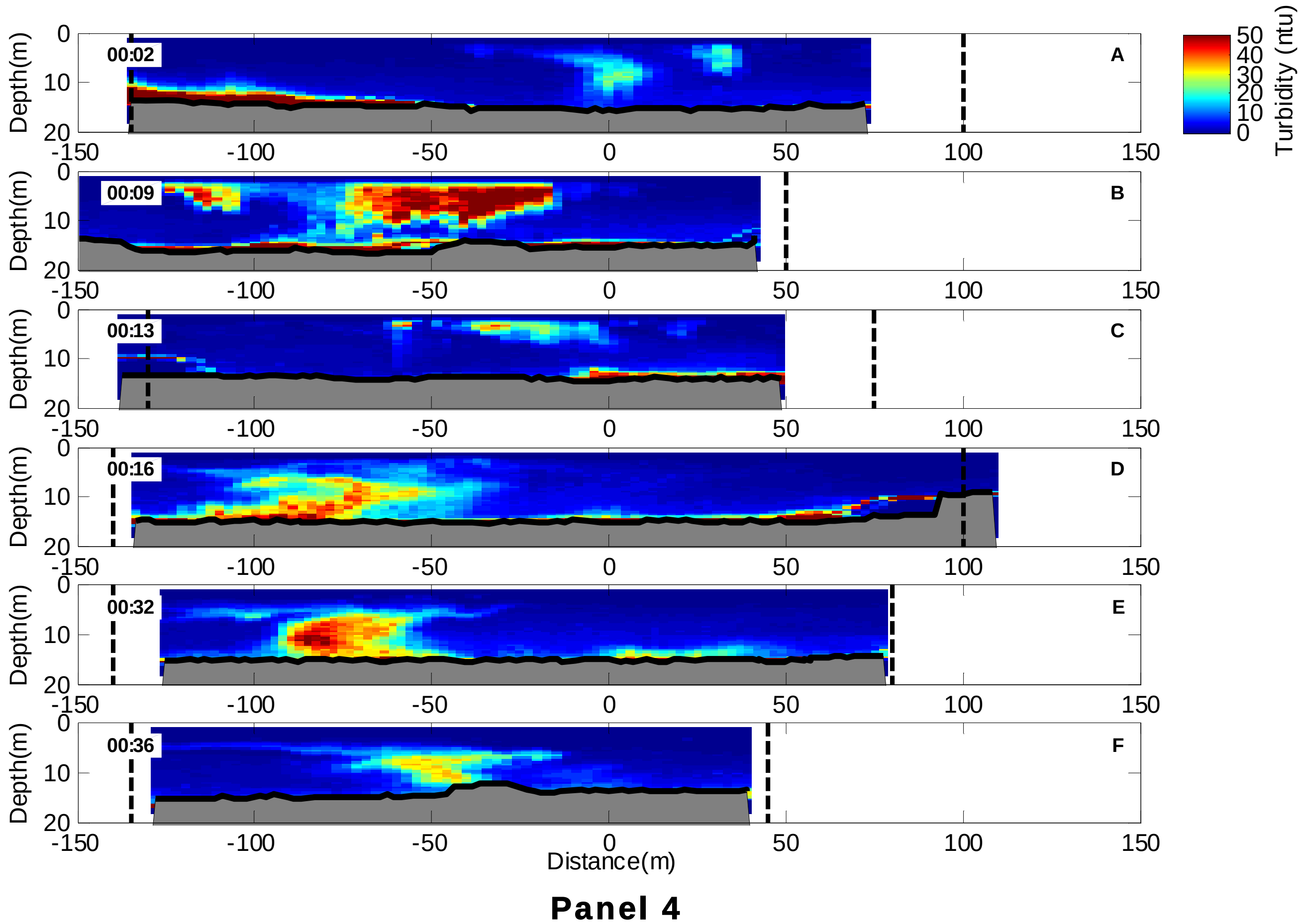
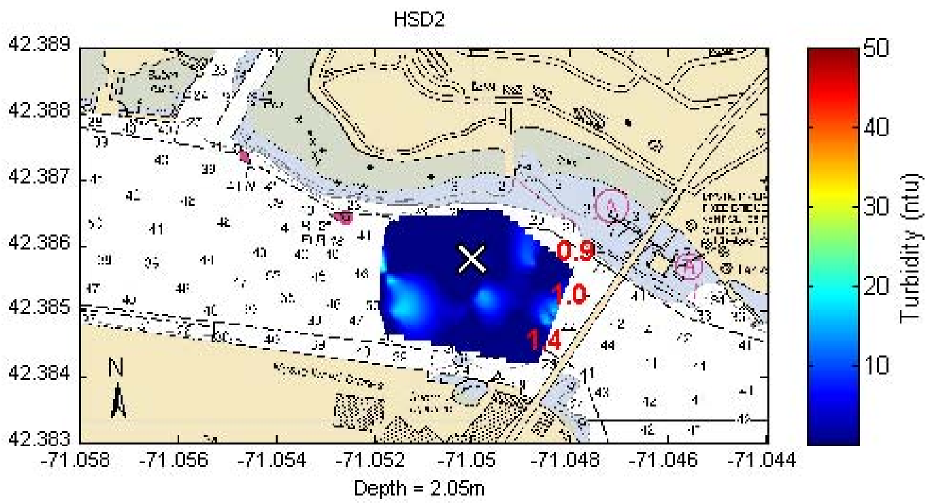
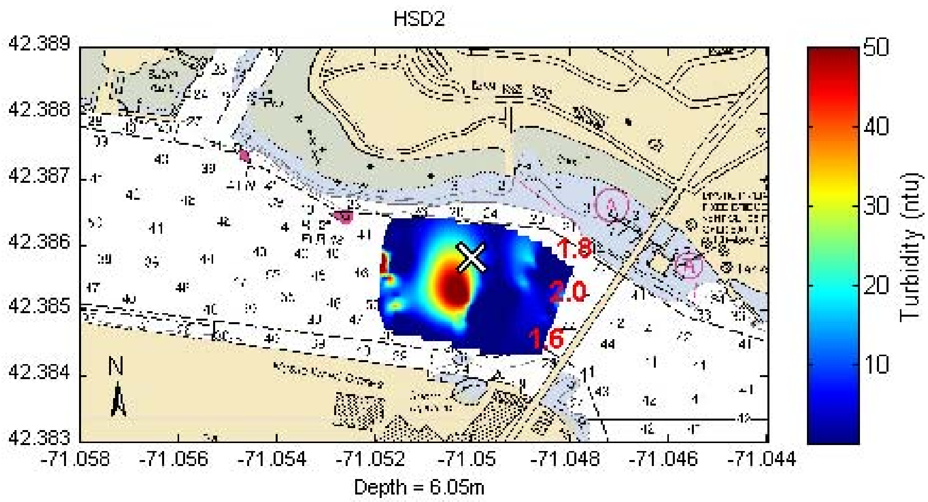


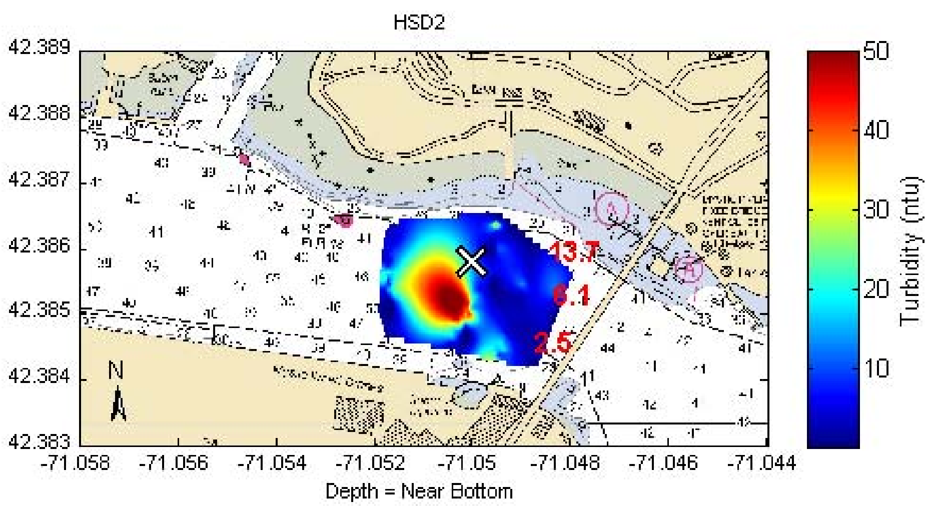
Figure 38 (continued). Observations during October 3, 2008 High Slack Disposal into the Mystic River CAD Cell. Panel 4 shows vertical slices of calibrated turbidity (above background) measured with ADCP along each vessel transect. The approximate location of the channel boundaries are shown as dashed lines.



Panel 5



Panel 6



Panel 7

Figure 38 (continued). Observations during October 3, 2008 High Slack Disposal into the Mystic River CAD Cell. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (panel 5), mid-depth (panel 6), and near-bottom (panel 7). Also shown are turbidity in NTU at the same depths from OBS at vertical profile stations, 23-47 min after release.

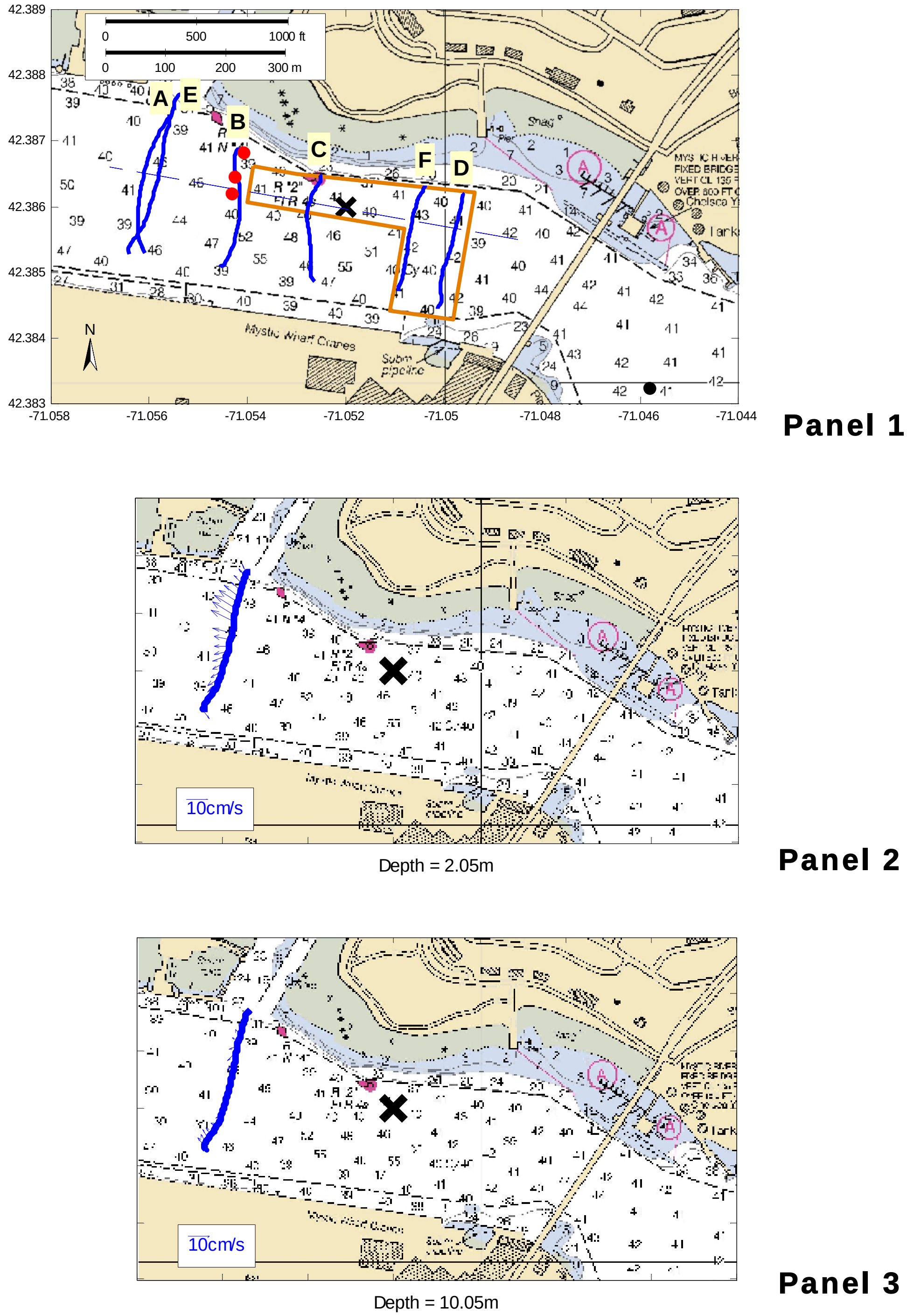


Figure 39. Observations during October 27, 2008 Low Slack Disposal into the Mystic River CAD Cell.

The panel 1 shows vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x'). The panels 2 and 3 present near-surface and near-bottom velocities, respectively, measured with ADCP at Transect A.

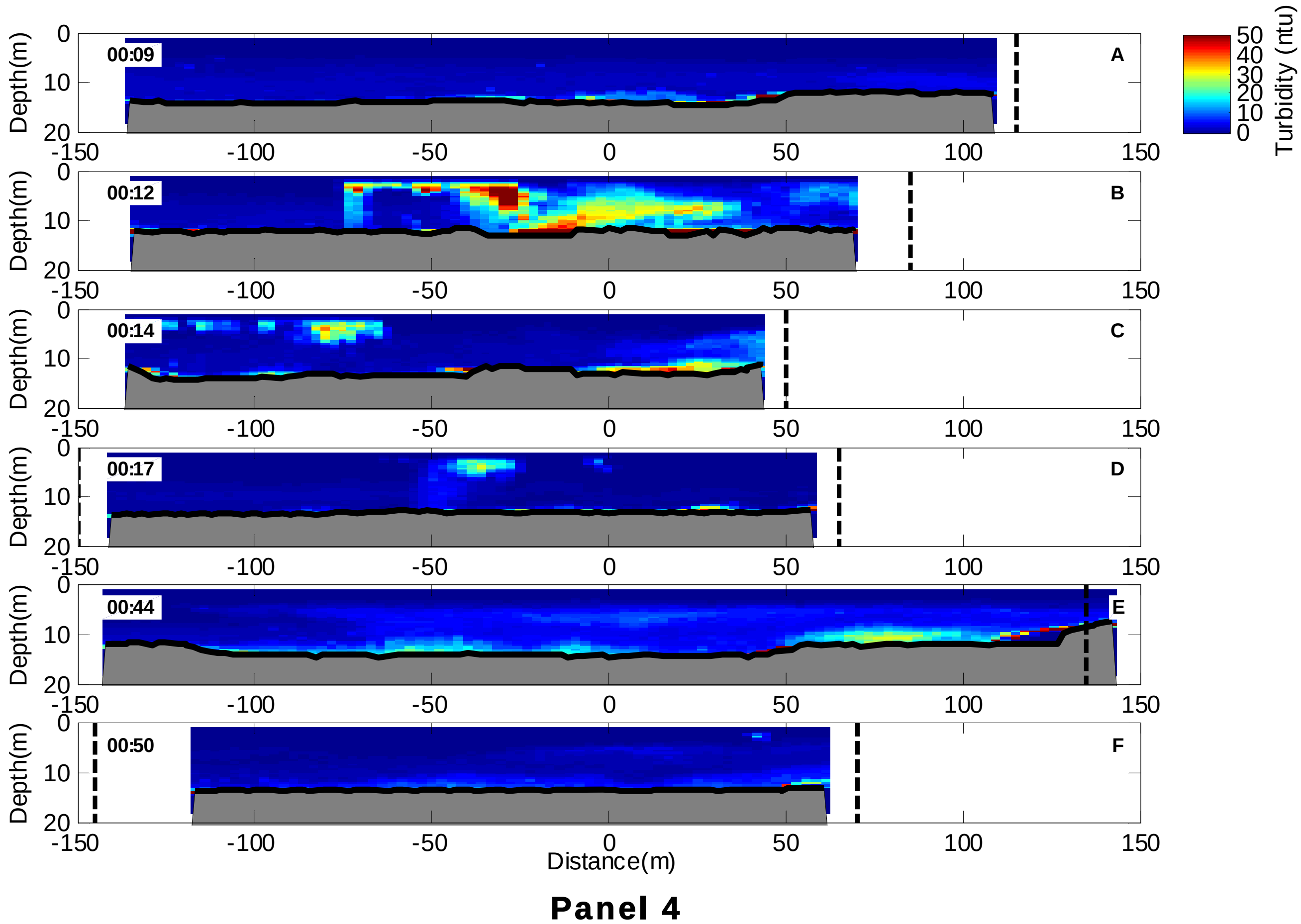
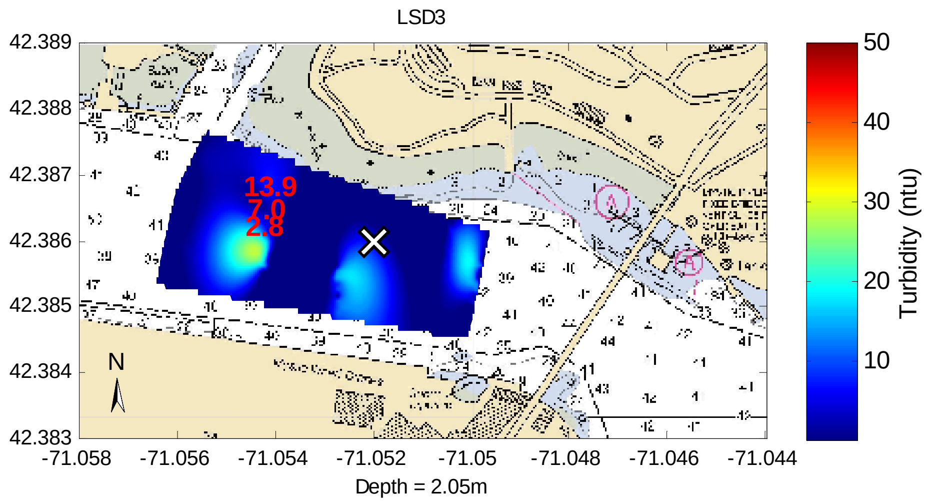
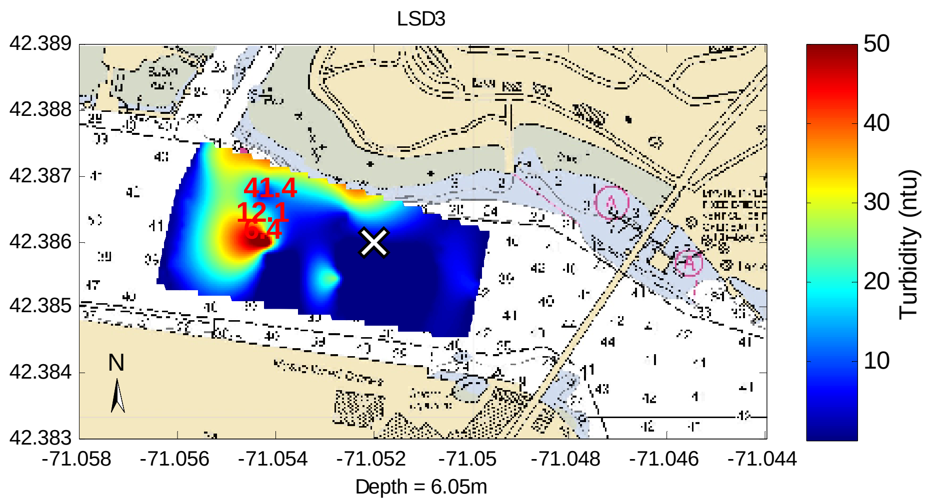


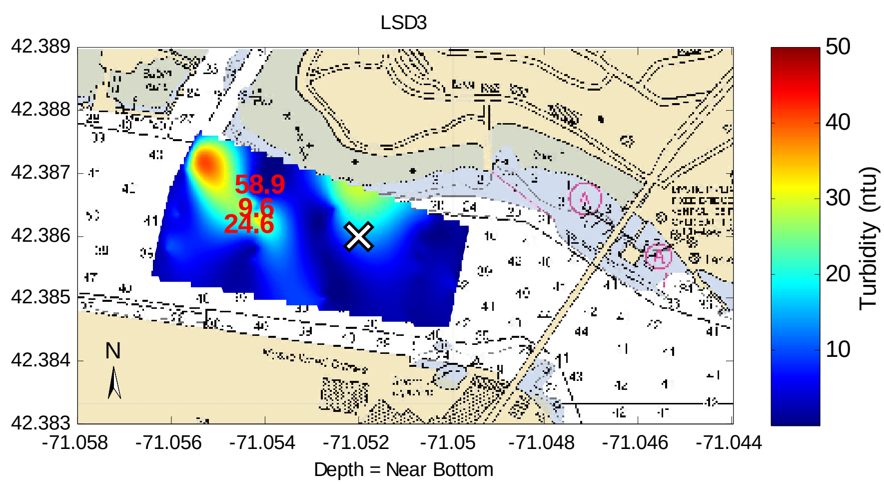
Figure 39 (continued). Observations during October 27, 2008 Low Slack Disposal into the Mystic River CAD Cell. Panel 4 shows vertical slices of calibrated turbidity (above background) measured with ADCP along each vessel transect. The approximate location of the channel boundaries are shown as dashed lines.



Panel 5



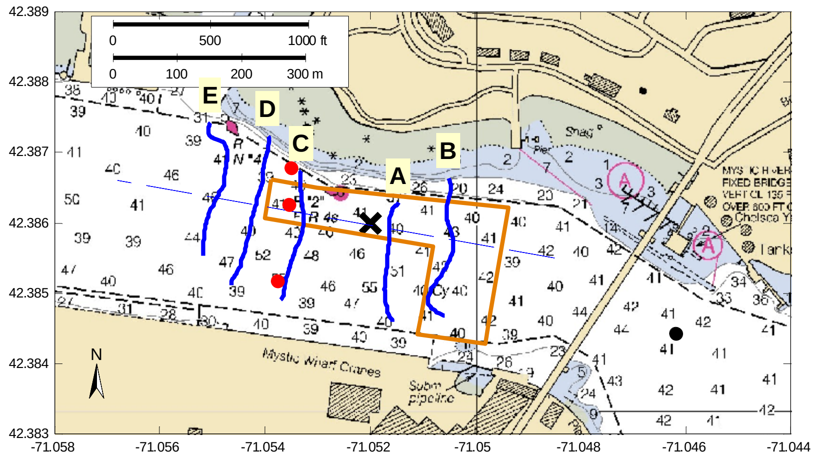
Panel 6



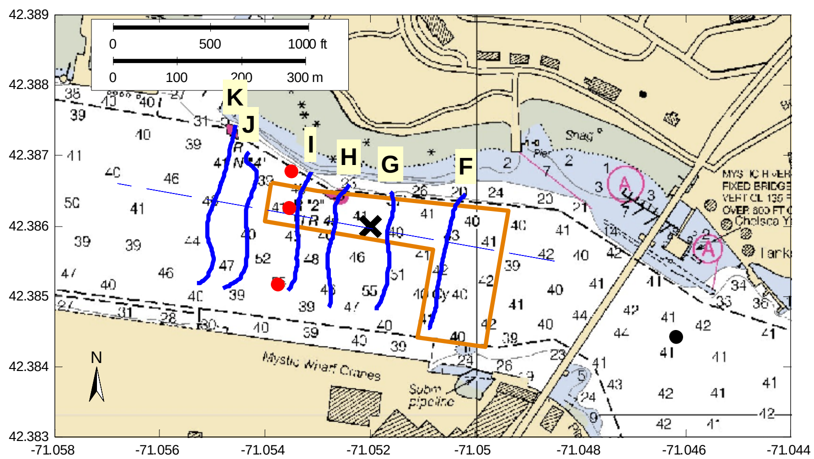
Panel 7

Figure 39 (continued). Observations during October 27, 2008 Low Slack Disposal into the Mystic River CAD Cell.

Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (panel 5), mid-depth (panel 6), and near-bottom (panel 7). Also shown are turbidity in NTU at the same depths from OBS at vertical profile stations, 24-39 min after release.



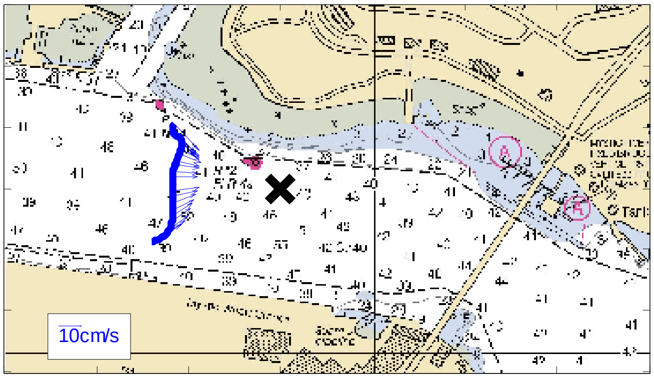
Panel 1



Panel 2

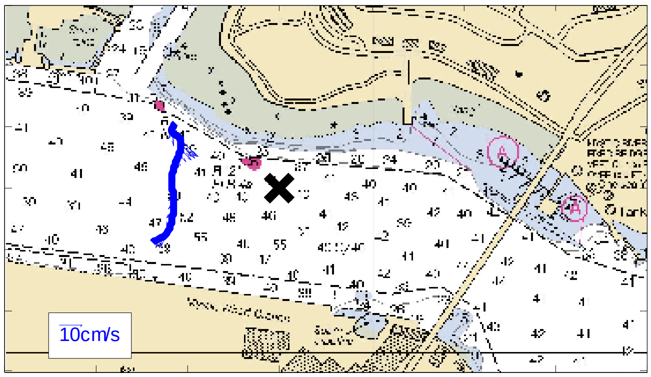
Figure 40. Observations during October 28, 2008 High Slack Disposal into the Mystic River CAD Cell.

Panels 1 and 2 show vessel transects, vertical profile stations (reference = black circle, plume = red circle), and approximate location of the dredge ('x').



Depth = 2.05m

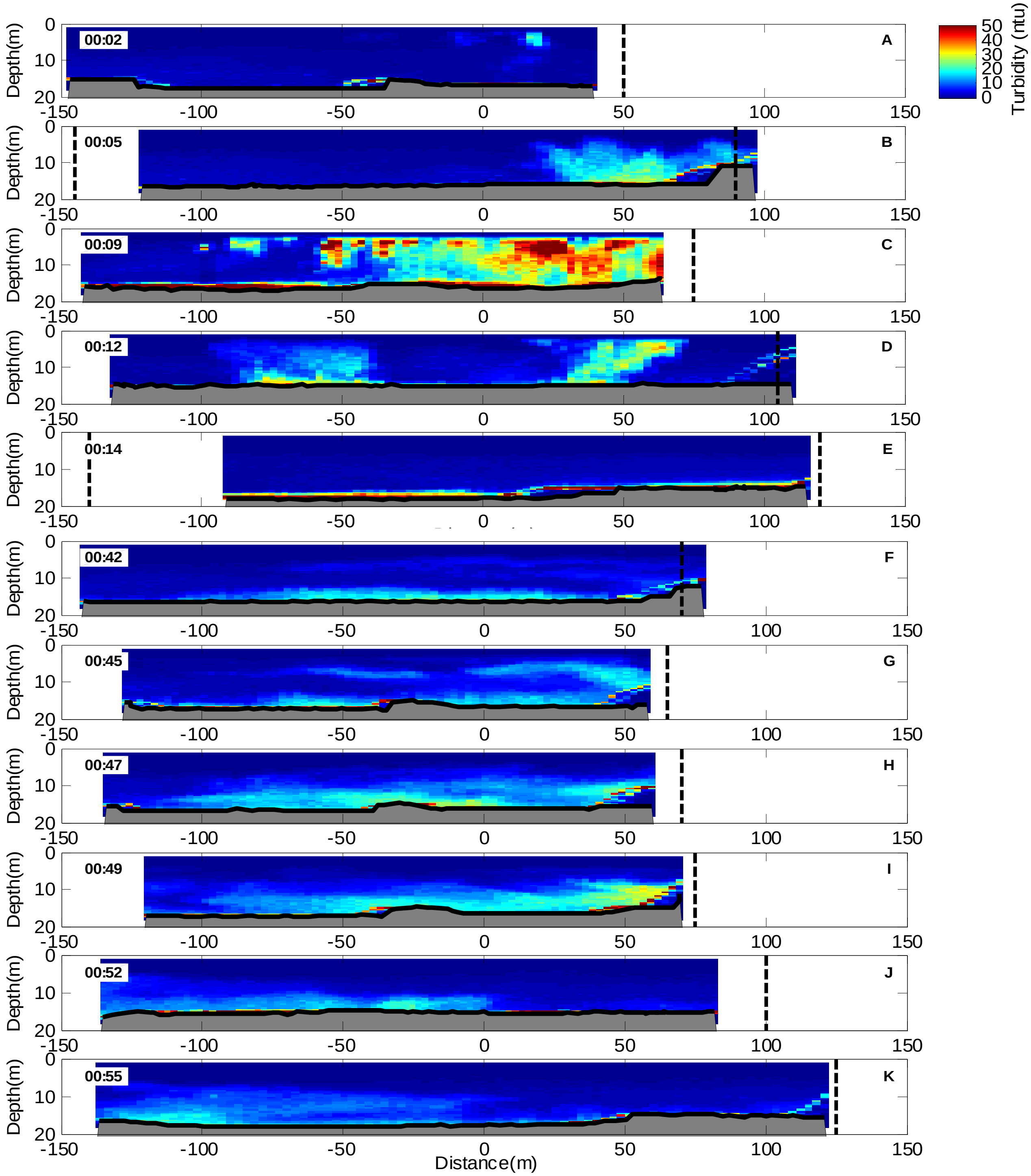
Panel 3



Depth = 10.05m

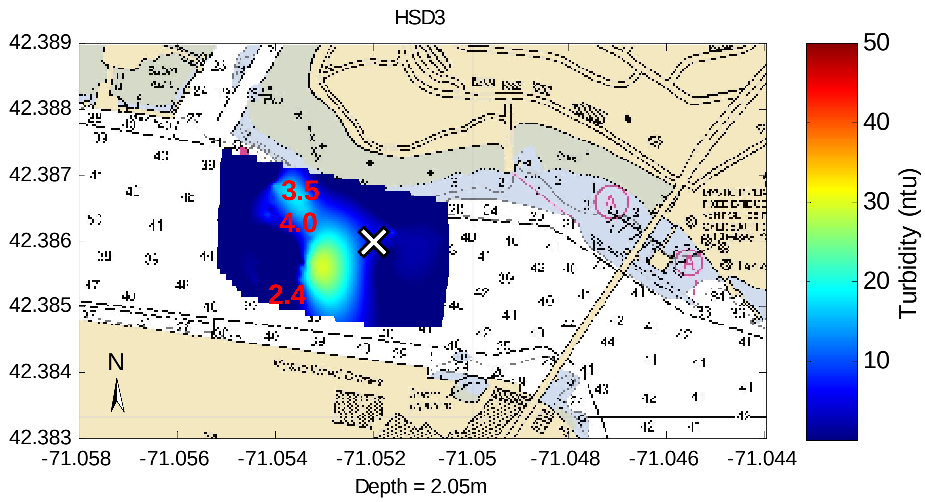
Panel 4

Figure 40 (continued). Observations during October 28, 2008 High Slack Disposal into the Mystic River CAD Cell. Panels 3 and 4 present near-surface and near-bottom velocities, respectively, measured with ADCP at Transect B.

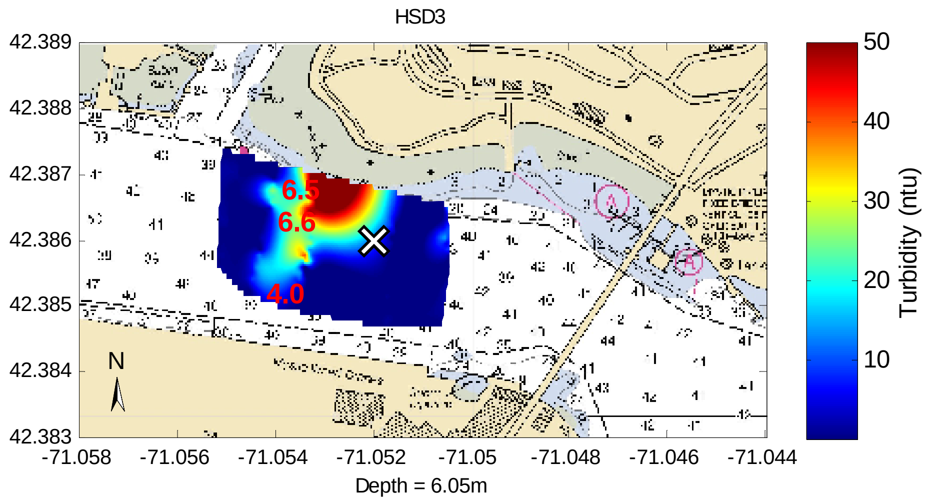


Panel 5

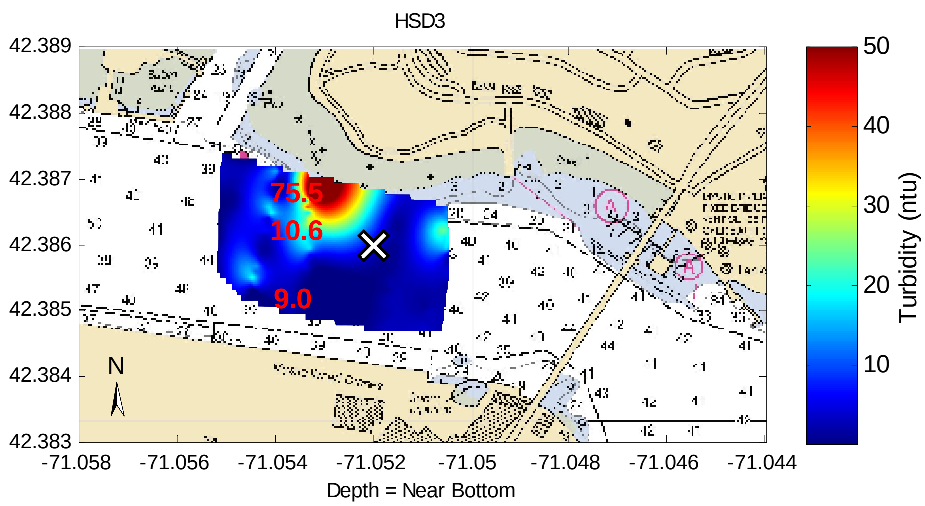
Figure 40 (continued). Observations during October 28, 2008 High Slack Disposal into the Mystic River CAD Cell. Panel 5 shows vertical slices of calibrated turbidity (above background) measured with ADCP along each vessel transect. The approximate location of the channel boundaries are shown as dashed lines.



Panel 6

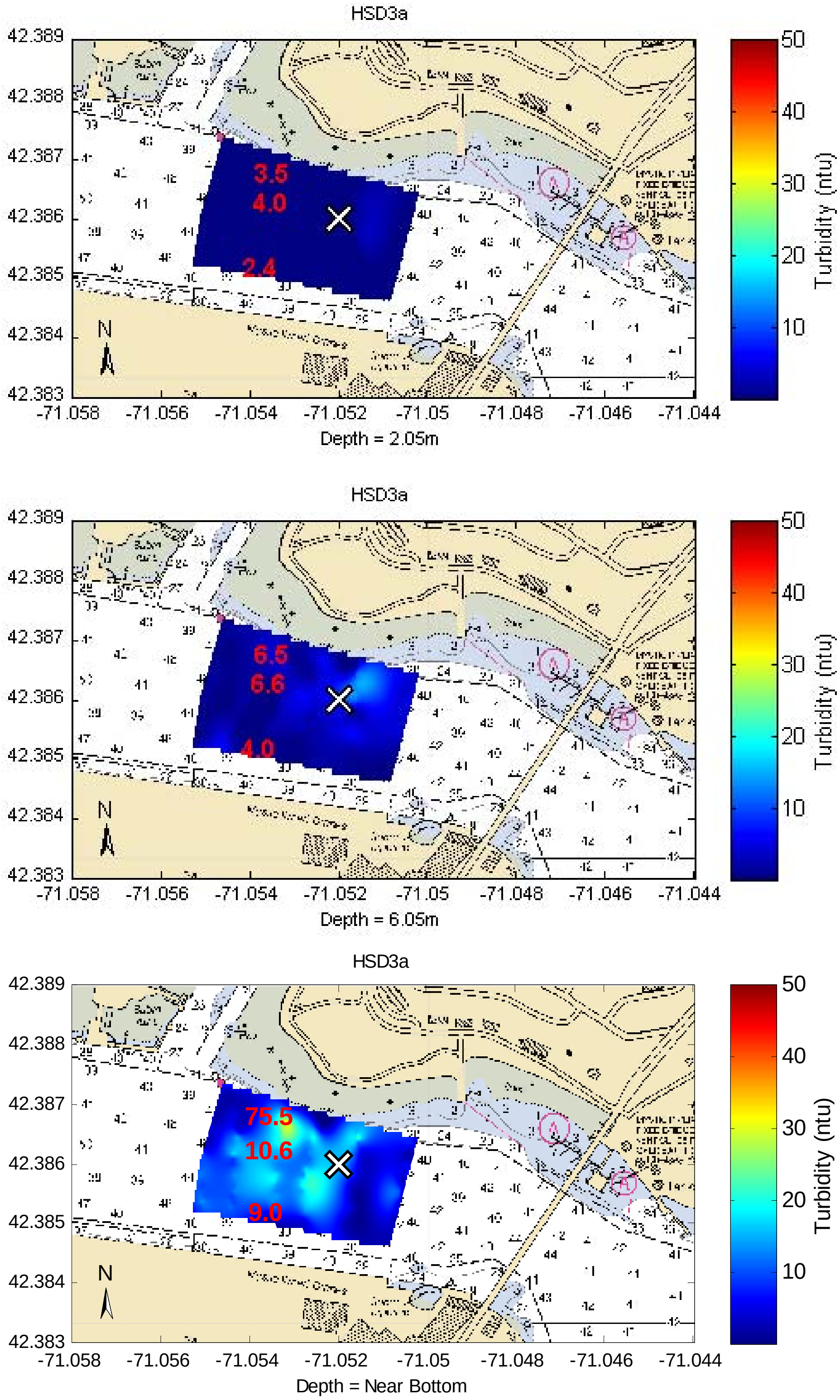


Panel 7



Panel 8

Figure 40 (continued). Observations during October 28, 2008 High Slack Disposal into the Mystic River CAD Cell. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (panel 6), mid-depth (panel 7), and near-bottom (panel 8) during transects A- E. Also shown are turbidity in NTU at the same depths from OBS at vertical profile stations, 20-35 min after release.



Panel 9

Panel 10

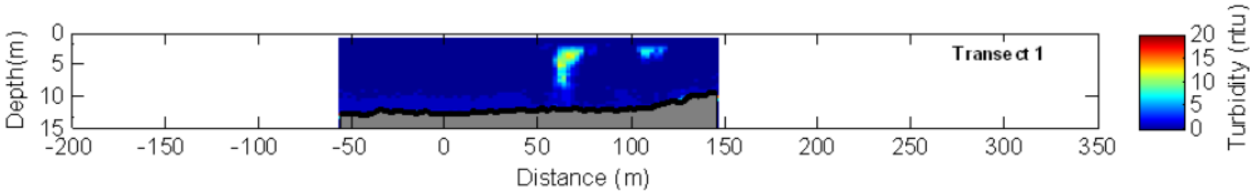
Panel 11

Figure 40 (continued). Observations during October 28, 2008 High Slack Disposal into the Mystic River CAD Cell. Shown are plan-view contours of calibrated turbidity (above background) measured with ADCP near-surface (panel 9), mid-depth (panel 10), and near-bottom (panel 11) during transects F – K.

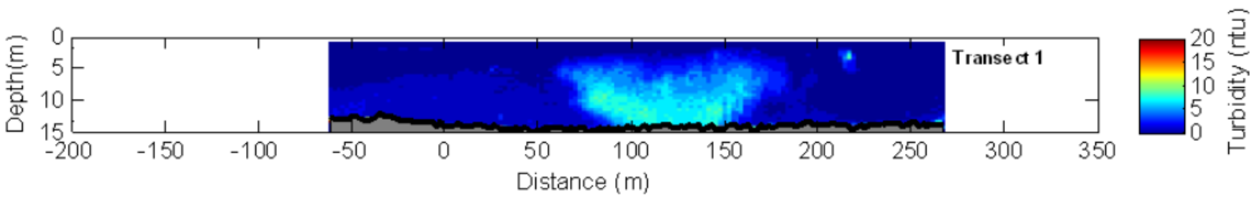
3.3 Plumes Caused by Ship Passage

ADCP transects and vertical profiles were opportunistically taken in the wake of large vessels that transited the area to observe the suspension of any bottom sediment caused by the prop wash of the vessel. Attempts were made to make ship passage observations beyond the extent of any dredge related plume. Figures 41 and 42 present vertical contours of turbidity and suspended sediment from ADCP transects in the wake of five vessels which transited during dredging operation monitoring. No large vessel passages occurred during disposal monitoring. All vessels were tug assisted but appeared to also be under their own power. In four of the five vessel observations, turbulent wakes of bubbles appear in the figures as ADCP hits which are predominately at the surface. The bubble signatures in the ADCP transects also exhibit a vertical streaking, not characteristic of suspended sediment plumes, caused by the rapid movement of the bubbles toward the surface. The vessel with the deepest known draft, the tanker ship *Nor-easter* (draft 10.5 m), created the most extensive plume of suspended sediment as it passed. A plume was created at low levels of ~12 NTU (~25 mg/L), approximately 325 ft (100 m) wide, and throughout most of the water column from just below the surface to the bottom. These turbidity and suspended sediment measurements could not be confirmed with vertical profiles as the plume appeared to be dissipating quickly in the strong wake turbulence and was difficult to reoccupy for profiling. The tanker ship *Acadian* also generated a low level suspended sediment wake as seen in Figures 41 and 42 with turbidity of ~12 NTU, a suspended sediment concentration of ~30 mg/L, and a width of at least 500 ft (150 m). The OBS sensors showed readings as high as 10 NTU above background. The last two vessels observed each generated very small (30-80 ft wide) localized near bottom plumes, seen as small features in the ADCP contours with OBS readings ranging from 7 to 16 NTU above background. No evidence of the plume was seen outside of the navigation channel.

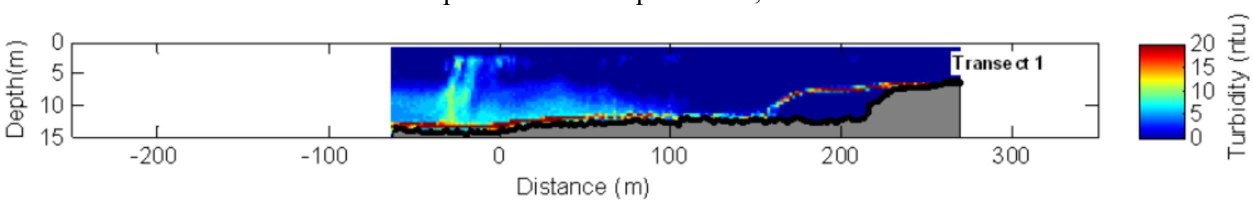
Container Ship *Raykjafoss* on June 30, 2008 draft na



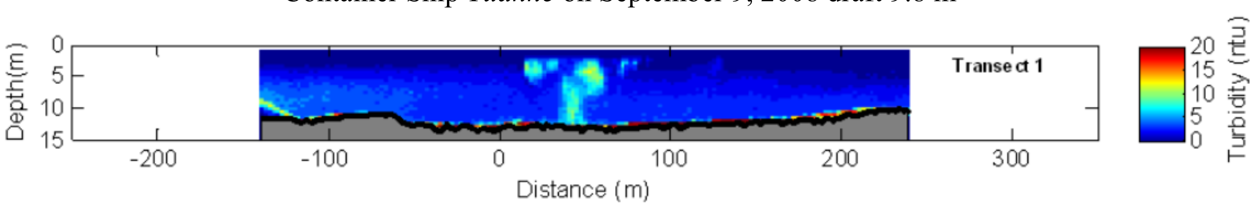
Tanker Ship *Nor-easter* on July 2, 2008 draft 10.5 m



Tanker Ship *Acadian* on September 9, 2008 draft na



Container Ship *Yuanhe* on September 9, 2008 draft 9.8 m



Cruise Ship *Grandeur of the Sea* on September 10, 2008 draft 8 m

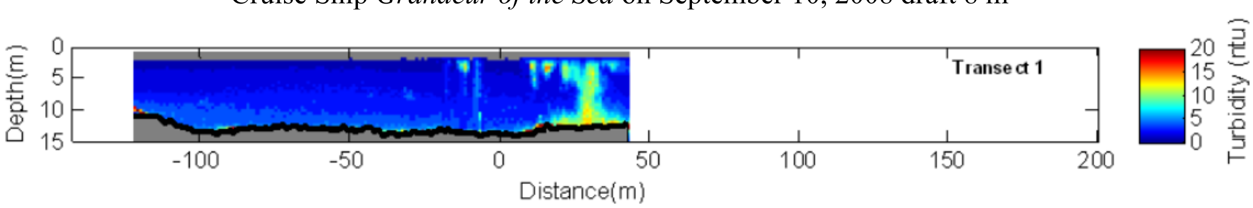


Figure 41. Vertical Contours of Turbidity Measured with ADCP along Cross Channel Transects behind Large Vessels Transiting the Area.

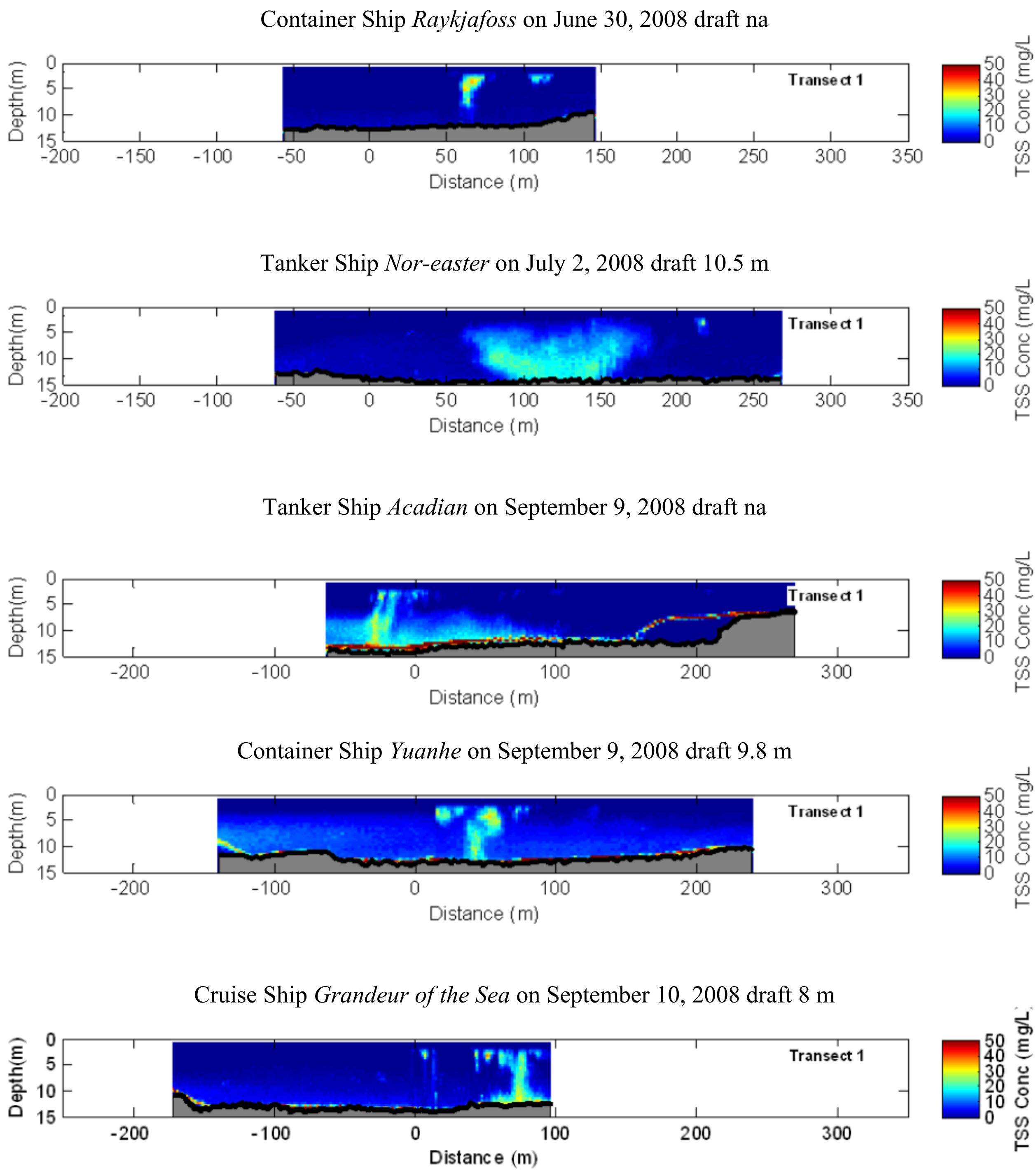


Figure 42. Vertical Contours of Suspended Sediment Concentration Measured with ADCP along Cross Channel Transects behind Large Vessels Transiting the Area.

4.0 CONCLUSIONS

A number of general observations can be made and conclusions drawn based on an overview of the results from the 16 tide phase dredging plume surveys and the five disposal plume surveys performed during this study, including:

Performance Goals -

- Turbidity values never exceeded the established threshold criteria (<25 NTU's above background in areas outside the navigation channel in water depths of less than 25 feet depth MLLW) during any of the dredging plume surveys. No monitoring exceedance protocols were initiated.
- Turbidity values never exceeded the established threshold criteria of the Water Quality Certification for this project (≤50 NTU above background levels 500 feet down current of the CAD cell) during any of the disposal plume surveys. No monitoring exceedance protocols were initiated.
- At no time were any plume remnants found to migrate on to sensitive resource areas (i.e. the identified winter flounder spawning habitat).

Dredge Plumes -

- The suspended sediment plumes produced by dredging operations were of relatively low concentration. The highest turbidity readings within 500 (150 m) of the dredge were less than 20 NTU above background and suspended sediment concentrations were less than 40 mg/L.
- The dredge plumes were typically confined to the channel, although low concentration plume filaments (<5 NTU; < 12 mg/L) were observed on two occasions (during max flood and high slack tides) as far as 650 ft (200 m) from the channel in the southern channel area.
- During times of strong tidal currents, a consistent pattern of dredge plume evolution was observed particularly in the northern MSC study area. The plumes were narrow and concentrated near the dredge (150-250 ft [50-75 m] wide and up to 20 NTU above background) and usually present from surface to bottom. They then widened, dissipated, and settled to the lower half to two-thirds of the water column as they were carried down the channel by the tide. Finally the plumes dissipated to background levels typically between 1000 and 1500 ft down-current.
- Frequently the plumes were observed across the full width of the channel in the lowest one-third (or less) of the water column at low concentrations (<5 NTU; <12 mg/L above background) as they approached background levels typically between 1000 and 1500 ft down-current.
- During slack tide conditions the dredge plumes largely pooled beneath the dredge. Typically the plumes were no wider than 100- 150 ft and dissipated to background levels in as little as 500 to 1000 ft (150 to 300 m) down-current from the dredge.
- Maximum dredge plume length varied with the tidal currents in the channel. Some dredge plumes detected during near slack conditions had maximum lengths of less than 500 ft (150 m). The max ebb and max flood plumes traveled further but dissipated to near background

levels (<5 NTU and < 12 mg/L) within 1500 ft (450 m) of the dredge often across the full width of the channel.

- It is estimated that fine sediments from dredge plumes remained in the water column for up to 1.5 to 2 hours based on the distance plumes traveled and the tidal current speed.
- Turbidity and suspended sediment measurements made up-current of the dredge were well within the background variability suggesting that no plume residuals remained in the water column beyond a few hours.

<u>Disposal Plumes -</u>

- With little current to transport and disperse the suspended sediment, the disposal plumes stayed close to the point of release transported in large part by their own momentum. The densest part of the plumes, 40-50 NTU (120-140 mg/L) above background, were never observed beyond 500 ft from the point of release usually well within CAD cell or on one occasion at the CAD cell boundary.
- Plume filaments were observed outside the CAD cell at or within 500 ft of the CAD cell boundary, but at low concentrations < 20 NTU (50 mg/L) above background.
- Vertical shear due to estuarine circulation and horizontal shear due to the lateral flows around the bend in the Mystic River near the CAD cell help to disperse the disposal plume after release.
- Within 15 minutes of release, all the observed disposal plumes were limited to the lower 2/3 of the water column where they were confined to the channel.

<u>Large Vessel Passage Plumes –</u>

- Two of the five observed large vessels passages generated turbidity plumes resulting from prop wash which resuspended sediment off the bottom.
- The vessel plumes where similar in intensity and extent to some of the weaker dredge plumes observed. Turbidity in the vessel plumes reached as high as ~12 NTU and TSS as high as ~25 mg/L above background and the plumes were up to 325 ft wide.
- Since it is reasonable to assume that vessel plumes extend along the length of the channel as the vessels move through it and that they occur frequently in the wake of harbor vessel traffic, it is likely that a significant amount of material is resuspended from the channel bottom and sides by large vessel traffic.

5.0 REFERENCES

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